A
TEXT BOOK
of
SANITARY ENGINEERING

[Including Plumbing]

BY

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BIBLIOGRAPHY

(1) *The Sanitary Inspector's Handbook* – Clay

(2) *Refuse Destruction and Separation* – Neal

(3) *Collection and Disposal of Refuse* – N. V. Modak
(Report to the Bombay Municipal Corporation)

(4) *Text Book of Public Health* – Frager and Stallybrass

(5) *How to Design and Instal Plumbing* – Matthias

(6) *Engineering in Public Health* – Babbit

(7) *Australian Sanitary Engineering Practice* – Randerson

(8) *Drainage Problems of the East* (1906) – James

(9) *Sewage Disposal in the Tropics* (1910) – Clemesha

(10) *Sewage Disposal in India and the East* (1924) – G. B. William

(11) *Sewage Works* (1935) – F. C. Temple

(12) *Surface Drainage* (1918) – Gubbay

(13) *Surface Drainage in the Plains of N. India*—F. C. Temple
(Paper Published by the British Inst. of C. E)

(14) *Sewage Disposal* – N V. Modak

(15) *Sanitation in India* – Turner and Goldsmith

(16) *Sewerage and Sewage Treatment* – Babbit

(17) *Sewage Treatment, Design and Specifications*—Escritt

(18) *The Work of the Sanitary Engineer* – Escritt and Rich

(19) *Sewage Treatment Works* – Keefer

(20) *Sewerage and Sewage Treatment* – Hardenberg

(21) *Water Supply and Sewerage* – E. W. Steel

(22) *American Sewerage Practice* – (3 Vols.)—Metcalf and Eddy

(23) *Sewers (Theory, Design, Specification, Construction)*—Beavan and Rees

(24) *Arithmetic of Sewage Treatment*—Imhoff

(25) *Sewage Treatment* – Imhoff and Fair

(26) *Principles of Sanitary Science and Public Health*—W. T. Sedgwick

(27) *Standard Methods of Water & Sewage Analysis* – American P. H.
Association

(28) *Public Health Engineer*—Phelps

(29) *Disposal of Sewage*—Veal

(30) *Bacteriology*—Fairbrother

(31) *Sewerage*—Folwell

(32) *Sewage Purification and Disposal*—Kershaw

(33) *Extension of Sewage Treatment Plant at Dadar*—(*Journal of the Institute of Engineers, India*) *Sept.* 50 – N. V. Modak and M. A. Lokhande

(34) *Sewage Treatment–Imhoff Tanks* (*Journal of the Institute of Engineers* (*India*) *June* 51)—M. V. Suryaprakasam

(35) *Bulletins issued by* Dorr-Oliver

(36) *Industrial Wastes Treatment*—Dr. Bhoota and Rao

(37) *Water & Sewage Work Magazine*

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CHAPTER I

INTRODUCTION AND SCOPE OF WORK

THE object of sanitation is the preservation and maintenance of health of the individual and the community, by preventing communicable diseases.

The **fundamental principles of sanitation** are enunciated below :—

(1) Provision should be made in every house of copious supply of pure and wholesome water.

(2) The house should be free from damp. For this purpose all materials used in its construction should be non-absorbent and impervious to water, and every external source of damp should be provided against.

(3) Every room of the house should be provided with adequate means of admitting fresh air and expelling used air, so that it is continually charged with a stready steam of fresh air.

(4) Every part inside the house including every nook and corner should be fully lighted, as far as possible, by direct light of the sun, the latter at least for some part or other of the day.

(5) All substances which are of such a nature as to catch, carry, hide, or retain particles of dust, whether employed in the structure of the building, or decoration, or furnishing, should be avoided. For particles of dust mean, in most cases, germs of diseases. Thus stone carvings, embossed plasterings and mouldings, ornamental railings, cotton or woollen fluffy carpets should be avoided.

(6) All refuse and waste matter, whether solid, liquid, or gaseous, which is of offensive nature, and injurious to health must be removed away from human habitation as fast

as it is produced, and disposed of in such a manner as to render it harmless.

Sanitary Engineering, in its wider sense, must cover all these aspects. The first has been dealt with in a separate volume, viz. *Water Supply Engineering*, and it is proposed to treat the remaining five aspects in this volume.

Though the fundamental principles are the same everywhere as above, considerable differences must occur in the standards applied, and the methods adopted, as they necessarily depend upon the climatic conditions, economic and sociological circumstances, religious concepts, and habits of people.

Thus in respect of the second principle mentioned above, viz. damp, unless a site is marshy or low-lying, a plinth 50 to 70 cm. (1½ to 2 ft.) high is generally sufficient in this country for preventing damp rising from the ground. Damp-proof courses and provision of hollow space below floor is required only in exceptional cases.

In respect of (3) viz. ventilation, as the difference between the in-door and out-door temperatures in this country is not so great as in Western countries, the rules governing our ventilation are quite different. The same is the case in respect of (4) viz. natural light in house. Though every nook and corner of every room should be adequately lighted, we, in this country, have to provide means to mitigate sun's heat and glare by providing shades or hoods over windows.

With regard to (5) viz. preventing dust, our tropical country is at a great disadvantage as the atmosphere is normally always dry and dusty, which makes it obligatory to keep milk and food-stuffs always covered for protection from dust and flies.

Even with regard to the last, viz. fast removal and early disposal of refuse and excremental matter, the prevailing high temperature tends to accelerate decomposition giving rise to the formation of excessive gases in sewers. The ventilation of sewers, therefore, demands special consideration. Again, the gradients of sewers which are generally deemed adequate in cold climates are found unsatisfactory in tropical climates. Further, the rainfall in this country, unlike that in the Western countries is restricted to one season, in which it is concentrated causing heavy torrential flow. If storm water is admitted into sewers, their size is increased which is found unsuitable for creating self-cleansing velocity in the hot weather season with its meagre discharge.

In respect of the habits and religious prejudices of people the difference is still more marked. A large proportion of the people in this country is in the habit of using loose coir or other fibrous material with ashes, sand, brick dust, road scrapings, etc. for burnishing household utensils, and these materials ultimately enter drains and cause them to be blocked. Similarly, leaves of certain trees are used as plates for taking food in this country and these also find their way to the drains, which, as a result, tend to be choked. As another instance, water is essentially used for ablution, instead of toilet paper. This makes the night soil still more wet and renders the problem of its treatment more difficult in rural districts where water carriage system is impracticable. As one more instance, the majority of people in this country are vegetarians. This fact is reflected in the chemical analysis of Indian sewage, which shows much less nitrogenous matter and particularly sulphur contents than the sewage of the countries in Europe.*

As an instance of religious prejudices may be mentioned the fact that even touching human fæces, not to talk of removing them, is supposed in India to defile the person who does it. They must either be removed by people of a particular scavenger class, or left for an indefinite period to decompose until they dry, after which, trodden under feet of men and cattle, they are crushed to powder and blown by wind. In contrast to this the dung of a cow, or as a matter of fact, that of even a buffalo is used to 'purify' the floor and walls even of the prayer room !

* "Sewage Disposal in India and the East" by G. Bransby Williams.

Thus climatic and other conditions considerably affect the methods of sanitation in this country.

For dealing with waste matter, particularly of excremental nature, produced in house premises, water-carriage system is the best. In it all the waste products are flushed by force of water into drains and sewers and rapidly carried away to a safe place for final disposal or treatment. But for this a plentiful supply of water is essential. In this country, however, excepting in about 20 large cities like Bombay, Calcutta, Madras, Kanpur, Banaras, etc. it has not been possible so far mostly for want of adequate funds, first for providing a public water supply and next for executing a sewerage scheme. The method, known as the "conservancy" or "dry" system, has therefore been employed. In the latter the night soil is collected into pails or baskets which are emptied by hand and carried on head by sweepers away from towns for final disposal. Conservancy must always be regarded as a potential danger to public health by contamination of underground water through contamination of soil and contamination of food by flies. For this reason it is necessary that the conservancy system, wherever it is prevailing, must ultimately be replaced by the water carriage system as early as possible. Still in sparsely populated districts and hill-stations where roads are long, and houses scattered, and in most villages it is bound to remain, as the cost of water carriage system would be prohibitive and the normal flow of sewage would be too insufficient to render sewers self-cleansing.

Where adequate supply of water is available from a river or a private well, a system, intermediate between the two mentioned above, which may be termed "semi-conservancy" may be adopted with more or less complete house drainage and outfall on site either in the form of a cesspool, or a small sewage disposal plant such as a septic tank with soakage pit or a filter.

A complete system of sewerage based on water carriage comprises house drains, properly trapped and ventilated with all sanitary appliances properly fitted to them, branch sewers, trunk sewers leading to a point of outfall with appurtenances such as manholes, lampholes, inlets, siphons, flush tanks, regulators, overflows, lifting devices, etc. and finally outfall works. For efficiency of working, the following basic principles must be observed :—

Materials—Hard, strong, durable, smooth, impervious and non-corrodible.

Bore—Smooth, circular, and true to centre.

Capacity—Smallest possible, consistent with peak load, so as to ensure maximum depth of flow for carrying the volume.

Alignment—Straight between points of access.

Gradients—Sufficient to ensure non-silting velocity, and to maintain maximum depth of flow.

Branches—Streamlined in the direction of flow; not even a right-angled junction allowed.

Access—Free to every part of the system for inspection, cleaning or repairs.

Trapping—All openings except those provided for ventilation to be sealed with sufficient depth of water against gases.

Ventilation—All main drains to be air-flushed.

The subject is treated in two parts. The first deals with all the aspects of Sanitary Engineering mentioned above, except sewerage and disposal of sewage. The latter are dealt with in the second part.

PART I

CHAPTER II

ENVIRONMENTS FOR HEALTHFUL LIVING

The Effect of Climate on Health:— Climate affects the health of people through various meteorological conditions, most important of which are the temperature, humidity, and atmospheric pressure.

As a general rule, most vigorous races are produced in places where the difference in temperatures of hot and cold seasons is great, while weak and languid races are to be seen in places of equable temperature.

In the tropics the external heat sometimes exceeds the blood heat, and thus there is little call on the heat-producing function of the body. As a result, less food is required, and therefore the metabolism is decreased. On the other hand, the skin is extremely active, secretion of sweat is enormously increased, which causes evaporation from the body surface, and tends to cool the blood. Great heat is enervating.

Just the opposite of this takes place in cold climates. To maintain the blood heat against the cooling effect of the surrounding air, tissue metamorphosis is rapid, in-take of food is larger, secretion of urine is increased, while the function of the skin is reduced to a minimum. Rapid tissue changes permit of greater physical and mental activity without causing a feeling of exhaustion.

Where the climate is humid, the evaporation from the lungs and skin surface is retarded. The temperature of the air, though not severe, becomes oppressive. Moist climate is less healthy as it favours the growth and development of bacterial life. Organic matter also putrefies rapidly in a moist, warm climate. Very rapid change in weather conditions affects the health.

Trade Winds :—The heated air from the tropical regions rises and cooler air from the poles flowing towards the equator replaces it. On account of the daily rotation of the earth, the air currents from the poles are diverted in the directions resultant to the two motions, i. e. towards N. E. on the north of the equator, and towards S. E. on the south of it. These are called Trade Winds.

How Monsoons are Caused in India :—The south-east trade winds from the south of the equator coming from the ocean are full of moisture. As soon as they reach the peninsula they are deflected by it into two currents. (1) The Bay of Bengal Current, and (2) The Arabian Sea Current.

(1) The Bay of Bengal current first bursts on the Malabar Coast early in June, and in its further course is deflected towards the north by the range of high Arakan hills on the east of the Bay. This range on the east and the Himalayas on the north together form, as it were, two vertical sides of a box on the east and north sides of India and force the monsoon currents—both the forward and the retreating, through the remaining two sides. Thus the Bay of Bengal current flowing northwards through the N. E. Bay of Bengal, Burma, Assam, and Bengal is deflected towards the west by the Himalayas, up the Gangetic Plain, through Bihar, U. P., and southern portion of the Punjab, pouring plenty of rain all over its way. This is called the South-East monsoon.

(2) The Arabian Sea current or the South-West monsoon bursts on the Western *Ghats* of the Bombay State called the *Konkan* and advances over the Deccan, Madras, and Madhya Pradesh, precipitating considerable rain, and proceeds through the Madhya Pradesh to meet the Bay of Bengal current along a line which extends from Orissa to North-West India. It is by this time the third week of September.

Retreating or North-East Monsoon :— The South-West monsoon then retreats from the Punjab and the adjacent region. Most of its moisture having been exhausted by this time, it is of continental origin, hence dry, except where it has blown over the sea. It is therefore characterised by lightly clouded skies, occasional rain and sultry weather. The much talked of October heat is due to this return monsoon.

As the Bay of Bengal current retreats down the Gangetic Plain, and the Arabian Sea current retreats from Rajputana, Gujerat and the Deccan by a series of intermittent actions, fine weather conditions slowly extend eastwards. By the end of October the depression over North India disappears and is transferred to the centre of the Bay, causing heavy rain on the east coast of Madras and the south of the peninsula, where the rainiest period of the year is the latter half of October and November.

The period of 2 to 2½ months following the retreat or monsoon i. e. November to January is the most pleasant particularly in North India. In the winter the sky is clear, but there is a great difference in the day and night temperatures, and there is a gentle cold breeze from the land.

Selection of a Site for Building

(1) A dry, bracing climate is preferable for buildings to a mild, humid one. A place where the death rate is low should be regarded as satisfactory.

(2) An elevated site is drier on account of low subsoil water level, and rain water from it drains away rapidly. It should be gently and uniformly sloping.

(3) A place where the Local Authority has enforced restricting byelaws to prevent random development should be preferred.

(4) There should be no traffic dangers of dust and noise. Select a place, where streets are wide, and there are no obstructions to free breeze.

(5) A place in the neighbourhood of *kilns, tanneries, chemical* works, cemetery, night soil, or refuse depots, and such other nuisances should be avoided.

(6) A site, which was previously a depression, subsequently filled with debris, called "made ground," is unhealthy and may have insecure foundations.

Orientation :—This means not only the facing of buildings in a particular direction, or directions, but also the placing of every room in the house, and arranging its doors and windows in such a manner, as to allow the inmates of the house to enjoy to the utmost, whatever is good and avoid whatever is bad in respect of health and comfort, in the elements of nature, such as the sun, wind or breeze, and rain.

Our vast country may be climatically divided into three regions, viz. (1) coastal, (2) plain, and (3) hill station, each requiring different treatment in respect of the general outline plan of houses or orientation.

The houses in coastal regions, where the humidity in the air, and not the temperature affects comfort and health, the plan should be open and extended, resembling the letters, "L", "E", "U", or "H" with the arms opening in the direction of the breeze. There should be large windows in the outer walls, and free cross ventilation. There should also be a large, unobstructed open space around buildings. The rooms should be large, no matter if their height is restricted.

The houses in the regions of the plains, where high temperature in summer, and the cold in the winter are the deciding factors, there should be one or two central lofty rooms lighted and ventilated by clerestory windows, and round these apartments should be grouped other rooms, and beyond these are placed verandahs especially on the West and South to shelter outside surfaces from the sun's rays. During hours of maximum heat or cold, the clerestory windows are closed. On hill stations a compact plan—square or approximately square, with inner central passages to serve the rooms, with no outside verandahs, except perhaps, one on the North are the arrangements required.

As regards the disposition of different rooms a verandah, which is a necessary feature in Indian homes, should be in the direction of the prevailing breeze, and the deeper it is, the better. A drawing room is better placed in North or N.-E. Bed rooms should be so placed that they will receive plenty of breeze during nights and will not be heated by the afternoon and evening sun. There should be plenty of cross ventilation for continual change of air, without a draft being felt. A dining room should be close to the kitchen, with plenty of light and cheerful atmosphere. The kitchen should be in the N.-E. corner, so that it will receive the morning sun, and will remain cool during the rest of the day. The store room should be near the kitchen, and the prayer room somewhere near the dining room in a secluded alcove. Staircase which is the main thoroughfare to the upper floor should be fire-proof, sufficiently wide for two persons to go abreast, well lighted and ventilated, easy to climb, and situated in a lobby, no matter how small.

A guest room should have all the conveniences of a bed room, and should be independent of other private rooms. An entrance to it from a small verandah, and an independent passage-way from it to the bath and w. c. would add to its convenience. A motor garage is best located inside a house for both economy and convenience. It should have cross ventilation as there will be inflammable petrol in it.

Damp and Its Prevention:—Apart from the annoyance caused by unpleasant odours, foul air, and mildew, damp is very dangerous to health. In the presence of warmth and darkness it breeds germs of tuberculosis and other diseases. It is no less dangerous to building structures also. When damp rises in brick masonry, certain salts dissolved in it also rise with it and cause the exposed surface to disintegrate and fall to powder. Damp causes dry rot in timber used where ventilation is lacking.

There are three sources of damp: (1) that rising from the ground upwards into walls and floors, (2) the damp descending from leaky roof into walls below, and (3) the damp penetrating the exposed surfaces of walls by rain during continued wet weather.

The first is the most difficult to be remedied, especially if the moisture is under hydrostatic pressure. The methods of damp-proofing are: (1) Surface Treatment, (2) Integral Treatment, and (3) Interposing a layer or membrane of water-repellent material.

In surface treatment the pores in the exposed surface are blinded by a coat or thin film of a water-repellent material, such as solution of silicates of soda or potash, barium hydroxide and magnesium sulphate applied in alternate application, alum and soft soap also similarly alternately applied, coal tar, bitumen, resins and gums.

In the integral treatment, an inert material like chalk, fuller's earth, talc, etc. is mixed with concrete or mortar, just to fill the pores, or a chemically active material like silicate of Na or K, chloride of aluminium or ammonia, iron filings, etc. is mixed to make the mortar dense and water-resistant.

In the third, a layer from 5 to 50 mm. (¼" to 2") thick of a water-repellent material such as sheets of slate, lead, asphaltic felt etc. or a layer of mastic asphalt or hollow tiles of stoneware or terra cotta are interposed in walls below the plinth level and in floors between two layers of concrete. But when the water is under considerable hydrostatic pressure as in basements, in addition to the above, an R. C. C. slab designed to withstand the pressure is placed below one of the above layers under the floor and against the walls 50 to 100 cm. (2 to 4 ft.) high above floor.

If a building is on a hill slope, the land above the house can be drained *around* the building rather than *through* it by excavating a trench upto the foundation round the building on the higher side, and laying in it porous pipes called "hollow tiles" to a gentle fall with butt joints, embed them in gravel and carry the discharge to a lower level on the slope. The rest of the trench may be filled with rubble, and the top one foot with soil.

The other two sources are easy to remedy by first investigating and then removing the cause, which in the case of a roof may be a broken tile, or a crack in terrace and treating the surface with one of the materials mentioned above.

Hollow walls of bricks in two skins with a cavity of 55 mm. (2¼") between and bonded together by metal ties is a method extensively practised in Western countries for preventing penetration of rain water but is rarely used in India.

CHAPTER II

VENTILATION*, AIR CONDITIONING AND LIGHTING

Objects of Ventilation:—These are (1) to supply deficiency of oxygen, (2) to remove toxic poisons, (3) to remove odours, and (4) to remove body heat, and excess moisture from the air, and to cool the surrounding objects.

Composition of Air:—The air is a mechanical mixture of several gases as shown in the following table.

TABLE No. 1

Constituent Gas	Percentage by Volume	Remarks
1. Nitrogen	78·10	
2. Oxygen	20·95	
3. Carbonic acid gas	0·04	Slightly variable
4. Argon	0·91	
5. Neon, Krypton, Helium, Ozone	Traces	
	100·00	

Besides the above, the air contains water vapour varying from 1 to 5 per cent, and impurities in the form of (a) Dust comprising very fine particles of soot, pollen, skin, human and

* Ventilation in the tropics is fundamentally different from that in the temperate countries, e. g. their climate being very cold, rooms have to be heated inside. This causes a great difference in temperature and pressure of air inside and outside. They therefore get a lot of "accidental" or unauthorised ventilation, not only through holes and crevices in doors and windows in outside walls but also through pores in the material of walls. Their chimneys, further help ventilation by inducing an upward draught. They depend upon convection current for ventilation. Thus a window area of only 150 sq. cm. (24 sq. in.) per head is deemed sufficient for them. Theirs is essentially a problem of heating air inside rooms. In contrast we keep windows open for breeze, which makes the difference in temperature and pressure inside and outside our rooms very small. Our ventilation essentially depends upon the air movements, and we require a minimum of 0·2 sq. m. (2 sq. ft.) or 12 to 15 times as much window area as they, and that too with cross ventilation. Ours is essentially a problem of cooling, rather than of heating, except on a few hill stations.

animal excreta, hair, cotton fibres, etc., and mineral matter, such as iron rust, volcanic dust, sand or stone dust, dried mud etc. (b) Microbes attached to organic dust, which are microscopically fine living organisms. (c) Chemical impurities such as ammonia, nitrous and nitric acid, sulphuretted hydrogen, sulphurous and sulphuric acid, sulphur dioxide, chlorine, methane and carbon monoxide.

(1) **Nitrogen** :—This is an inert gas and serves the purpose of diluting oxygen.

(2) **Oxygen** :—This is the most important gas upon which life and combustion depend. It is a very strong and active constituent and hence requires to be diluted.

(3) **Carbonic Acid Gas** :—Though it is present in such small quantities in the air, as 0·04 parts in 100, it is most vital to the growth of the vegetable life. In the presence of sunlight, the green colouring matter of plants called *chlorophyll*, absorbs carbon from CO_2 from air and gives out oxygen, so necessary to the animal life. During night also the same process goes on, but at a very slow rate. It was once supposed that plants give off CO_2 during night, but it has been proved to be incorrect. The sources of CO_2 are : (1) Respiration, (2) Fermentation, or putrefaction of organic matter, (3) Combustion and (4) Emanations from certain soils and volcanoes.

(4) & (5) **Argon and Traces of Other Gases** :—Though the proportion of argon is 23 times that of carbonic acid gas, this and the other gases which are found in traces are all inert, and therefore, unimportant.

(6) **Water Vapour** :—This is perhaps more important than even temperature in causing comfort or otherwise. It increases with temperature of the air and a slight fall in the latter causes saturation and consequent sultriness and physical discomfort.

(7) Particles of dust of mineral origin are not so harmful. At the worst they may cause some irritation to the lungs, throat, or the eyes. But those of organic origin are likely to be dangerous as they carry micro-organisms.

All the micro-organisms carried by dust may not be harmful, but many of them are disease-carrying. Hence a general conclusion may be drawn that the greater the number of these microbes, be they of any kind, in a sample of air, the more susceptible is the air to hold pathogenic germs.

Respiration :—In a closed room the effect of animal, respiration is doubly adverse, on the air enclosed. For, when we inhale, we consume a part of oxygen from the air, and when we exhale again, we render the air impure by filling it each time with carbon dioxide, organic matter and water vapour. A typical analysis of exhaled air which was originally fresh is shown in the following table :—

TABLE NO. 2

Constituent Gas	Volumes per 10,000	
	Fresh Air	Respired Air
Oxygen	2094	1642
Nitrogen	7810	7824
Carbon dioxide	4	442
Argon and other gases ...	92	92
	10000	10000
Water vapour	150	560
Organic matter and bacteria ...	Very little	Considerable increase

Besides, each breath tends to heat the air progressively.

Effect of Air Stagnation :—In a closed occupied room with no provision for ventilation the air first gets progressively heated and loaded with moisture. The heat comes from the radiation from the body, and the moisture comes from the respiration and from the pores in the skin. It is estimated that ·3 to ·35 kg. (10 to 12 oz.) of water are given out from lungs, and ·7 to 1·15 kg. (25 to 40 oz.) from the skin surface by an adult person in health in 24 hours. The latter is evaporated then and there when the air is not saturated and is in slight motion, and therefore, is not felt. The water vapour given off by the skin hangs about under the clothes, in a saturated layer as a blanket, preventing evaporation from the skin surface. The walls, furniture and other objects in the room absorb heat from the air and get heated to a temperature approaching that of the body and radiate it back, so that the loss of heat by radiation is very small. The body has therefore to depend entirely upon the evaporation from lungs to get rid of the heat. The nervous system calls forth the action of the sweat glands, and sweat pours freely. But as there is no air motion, the condition becomes worse, respiration is accelerated, heart beats rapidly, and one feels exhausted. With a further rise in the wet bulb temperature, fainting may occur. The body temperature may rise to even 105° F. Ultimately death may occur by heat stroke.

From the above discussion it will be clear that the ill effects, or even the discomfort has nothing to do with the increase of carbon dioxide, but to the toxic poisonous gases, accumulation of heat and increase in humidity. But all these are very difficult to estimate. However, in a crowded room they increase in more or less the same proportion as the carbon dioxide increases. In other words, the amount of carbon dioxide bears a constant ratio to them. Therefore, the percentage of carbon dioxide in the air is taken *to serve as an indicator of the stagnation* or otherwise.

Standard of Ventilation :—The average air contains 0·04 per cent or 4 volumes of carbon dioxide per 1000 volumes of air. The maximum impurity allowed in occupied rooms is equivalent to 0·06 per cent or 6 parts by volume per 10000 parts of air.

From the above standard the amount of impurity added by respiration, etc. should not exceed 0·02 per cent or 2 cu. m. per 10000 cu. m. (2 c ft. per 10000 c. ft.) of air.

An average adult at rest gives off 1700 c. c. (0·06 c. ft.) of carbon dioxide per hour. He would therefore raise 285 cu. m. (10000 c. ft.) of the originally fresh air which contained 1150 cu. m. (0·04 c. ft.) of carbon dioxide to the maximum limit of impurity allowed in one-third of an hour. Or, if the net capacity of the room were 85 cu.m. (3000 c.ft.) he would vitiate it to the maximum permissible extent at the end of one hour. Or, if the room were only of 28 cu. m. (1000 c. ft.) capacity, the air in it will have to be changed three times per hour.

This standard is found to be impracticable. The usual standard allowed is given in the following table :—

TABLE NO. 3*

Nature of Room	Capacity Allowed per Head	
	Cu. m.	Cu. ft.
Residential quarters	8·5	300
Dormitories and rooms which are occupied both by day and night	11 5	400
Factories	7 0	250
Schools	4·0	144
Hospital wards	28·5	1000
Army barracks	17·0	600
Stables	20·0 to 22·5	700 to 800
Dog kennels	·18 to 5·5	65 to 200
Fowl houses	115 to 170 litres	4 to 6

However, mere provision of so many cub. m. of air space is of no use unless efficient means are provided to introduce fresh air and allow the used up air to escape. For this purpose adequate sizes of inlet and exit openings must be provided at proper places and the air must travel continually at a certain minimum speed.

(1) **Natural Ventilation** :—This is very simple and least expensive. It consists of providing sufficient area of inlet openings in the outside walls on one side for admitting fresh air, and outlet openings in other exposed walls for the escape of used air. However as it depends upon breeze, it does not prove efficient when the air is still.

Positions of outlets and inlets are very important in natural ventilation. As the used air gets warm and becomes lighter, it rises. Theoretically, therefore, the outlets should

* Bombay P. W. D. Handbook.

be just below the ceiling or main ridge, and the inlets, near the floor. But this may cause draught to persons sleeping on the floor. Again as windows supply also light, they need to be above floor level. A practical arrangement is to place windows both on the windward and leeward sides with their sills at 50 to 75 cm. (2 to 3 ft.) above floor and extend them almost to the ceiling as shown in Fig. 1. This will incidentally provide against the contingency when the wind blows in the opposite direction in winter, in which case the inlets would become outlets.

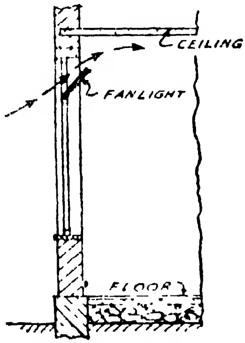

Fig. 1 – Windows both on windward and leeward sides and carried almost to ceiling.

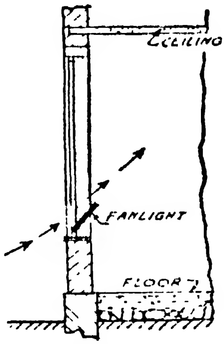

Fig. 2— Fanlight of window at bottom opening inwards.

A further improvement is to provide fanlights which would prove real ventilators when the windows are closed. A fanlight on the windward side should be hinged either at the bottom or the centre and should open inwards as in Fig. 3 so that the current of cold air should be deflected upwards to avoid a draught. A few alternative arrangements are shown in the above figures.

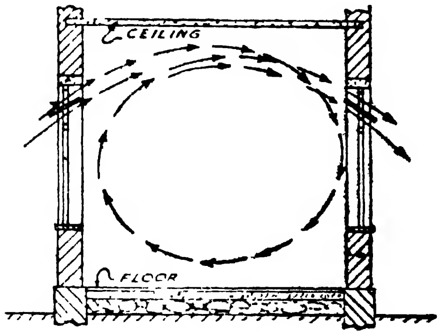

Fig. 3—Fanlights hinged at centre opening inward to deflect current upwards.

Ridge ventilators as shown in Fig. 4 or a turret or staircase room rising above the rest of a flat or pitched roof with openings in the side walls are very efficient in keeping the house cool during nights, when the outside cool air entering the rooms through the windows on lower floor would carry away heat from the warm surfaces of walls and furniture inside the house, become warm and light and escape through these openings.

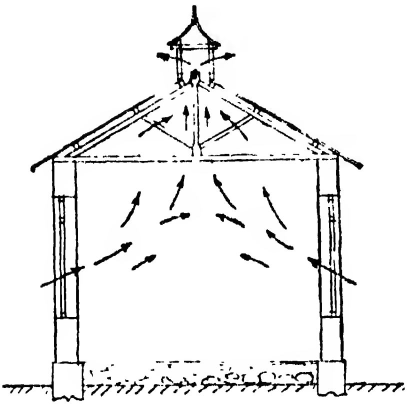

Fig. 4—Ridge ventilator.

Artificial or Mechanical Ventilation:—In congregational halls, theatres, and temples during fairs there is often such a large gathering of people that any provision for ventilation is sure to prove unsatisfactory. Mechanical means have to be provided, either for pumping cold air through openings at the bottom, or extracting used air from openings at the top, or both. There are four systems of doing this viz. (1) *Plenum* or propulsion system, (2) *Extraction* or vacuum system, (3) *Balanced* system and (4) *Air-conditioning*.

In the Plenum system air is forced or pumped through openings near the bottom. As it is used up, it gets warm and lighter and passes out through openings near ceiling or ridge. In the extraction system exhaust fans are placed in the openings near ceiling which extract the used warm air, and as the pressure is reduced, its place is taken by cold air through the openings at the bottom. In the balanced system, pumps at bottom and exhaust fans at the top are both employed. This system is of course more efficient but costly. Air conditioning is treated later in greater detail.

While providing efficient ventilation a number of other factors also must be considered and due allowance made for them. The important amongst them are:

(1) All illumination except electric, involves a process of combustion, and therefore, adds to the carbon dioxide and water vapour in the air for which the following allowance is made :—

An ordinary gas burner consuming 140 litres (5 c. ft.) of gas per hour requires 255 cu. m. (9000 c.ft.) of air and is equivalent to 3 adults. An oil lamp requires as much air as one man. A lighted candle requires as much air as one half man.

(2) Heights of ceiling of rooms above 4 m. (12 ft.) should be neglected in calculating the cubic contents of rooms unless the outlets are placed just below the ceilings. For, the air warmed by respiration rises to the ceiling and hangs there.

(3) The cubic capacity of heavy furniture such as beds, sofas, movable wardrobes, etc. should be deducted from the capacity of the room as they displace that much air.

(4) Although carbon dioxide diffuses in the fresh air more or less freely, the organic emanations do not. They hang about the corners and near ceiling and round about furniture where obstruction to free circulation of air is met with. Hence, instead of one large window in the centre of a room, 2 or 3 smaller ones of total equivalent area distributed over the wall surface are preferable.

External Ventilation :—We have so far considered ventition inside buildings, but unless there is sufficient unobstructed space surrounding buildings, particularly on the windward side to warrant free circulation of air, no amount of internal ventilation is of any use. There are certain minimum standards to be applied to (1) existing town areas, which are crowded and where land values are high and so not very fast and rigid rules could be enforced, and (2) extensions and future developments.

(1) **Standard for Existing Town Areas** :—(*i*) A minimum space equal to half the height of the higher of the two buildings on any face, permanently unobstructed, open to

sky to be left between two buildings e. g. if the gully between two houses is only 4 metres (10 ft.) wide, the height of each house must be limited to 8 metres (20 ft.). As another example, for allowing a house to be built or raised to a height of 20 metres (50 ft.), the space between the two must be a minimum of 10 metres (25 ft.). This is called $63\frac{1}{2}°$ standard of air plane, i. e. 2 vertical to 1 horizontal.

(ii) The height H in ft. of a building should be governed by the formula :

$$H = 1{\cdot}1 \times W + 1$$

where H = height of building in metres, W = width in metres of the street on which the building abuts.

The procedure in the case of buildings with tall houses and narrow streets is to mark on the town plan set-back lines keeping the necessary road width as per above formula between houses and acquiring the necessary strip of land from every owner of the houses under the Land Acquisition Act.

(2) **For New Towns and Extension of Existing Ones :—**

Area of Building Plot :—$\frac{1}{20}$ to $\frac{1}{10}$ ha. ($\frac{1}{8}$ to $\frac{1}{4}$ acre) minimum.

Built-up area :—$\frac{1}{3}$ area of the plot maximum. If the minimum area of the plot is $\frac{1}{10}$ ha. ($\frac{1}{4}$ acre), the built-up area may be restricted to $\frac{1}{4}$ that of the plot.

Minimum Open Air Space Round Building :—6 m. (20 ft.) in the front and rear and 3 to 5 m. (10 to 15 ft.) on the sides.

Height of Buildings :—12 m. (40 ft.). Not more than three storeys (ground and two) to be allowed.

Number of Tenements :—Each floor to contain not more than two tenements. Each to have an independent bathroom and w. c. attached to it.

Width of Road :—Minimum 12 m. (40 ft.).

The following specifications are applicable to buildings both in the old parts of a city as well as in extension areas:—

Minimum Area of Kitchen :—6·75 sq. m. (72 sq. ft.).

Minimum Area of Living Rooms :—11·25 sq.m. (120 sq.ft.).

Minimum Height of Floors :—3 m. (10 ft.) between top surfaces of successive floors.

Maximum Window Area :—$\frac{1}{7}$ of floor area.

Air Conditioning

Air conditioning implies controlling simultaneously, the temperature, humidity and air motion and also eliminating or at least reducing the toxic poisons and bacteria in the form of dust in the air. The object of air conditioning is to render the air comfortable and healthful, and incidentally conducive to efficiency.

The Meaning of Comfort:—Comfort depends on the physiological good combination of the temperature, relative humidity, and air movement.

Again, air conditioning may be either partial or complete. Using *khas tatties* with water spray and creating air motion by *punkhas* is a sort of partial air conditioning. Further, air conditioning may be for the summer or winter or the whole year.

Though exact experiments have not been made so far in this country to determine the limits of the above combination, experience has shown that the comfort zone for the average conditions in this country extends from 25°C (77° F) with 60% of relative humidity to 28°C (82·4° F)* with 45% relative humidity, and almost still air (velocity not exceeding

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* However, this upper limit of comfort zone, viz. 28°C (82·4°F.) temperature and 45% relative humidity cannot also be maintained at all places in a tropical country like ours for two reasons : (1) that at several places the temperature in summer rises to as high as 45°C (115° F.). To bring down the temperature to 28°C (82°F) and raise the humidity from probably, 15 or 20% in the dry, parching air to 45% is uneconomical, and (2) there would occur a 'temperature shock' to a person entering an air-conditioned room with 28°C (82° F.) from outside air temperature of 43°C (110° F.) and above, causing him to feel chill suddenly which is detrimental to health. The difference should not normally exceed 8°.

To meet this difficulty there are two ways :—(1) To persons accustomed to temperatures above 43°C (110° F.), a room with 38°C (100° F.) would give good comfort, and if the correct relative humidity is introduced in the dry, parching heat, and further, the air is kept slightly in motion he will feel quite comfortable even without a low temperature.

(2) To prevent temperature shock, a lobby is provided at the entrance such as of theatres, the temperature of which is mid-way between the inside and outside temperatures, so that a person from outside goes through two stages of temperature, and does not feel the difference so much as to feel suddenly chill.

9 m. (30 ft.) per minute). The cycle of operations in air conditioning is as follows:—

(1) Air cleaning in filters, or washers.

(2) Cooling in summer, or heating in winter.

(3) Humidifying or adding moisture to air in summer, or dehumidifying or extracting moisture from the air in winter as the case may be.

(4) Pumping or forcing the air for distribution through ducts in different rooms.

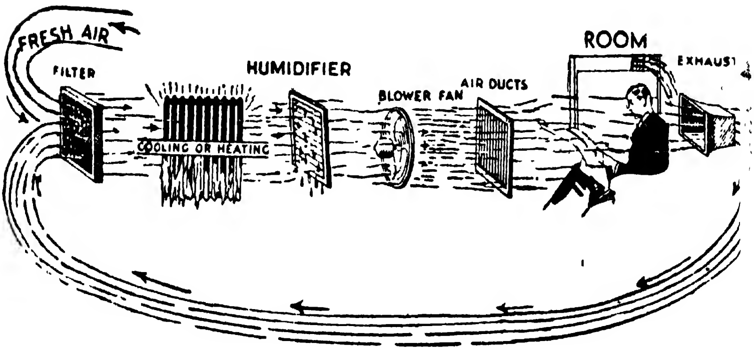


Fig. 5.

All these operations are shown diagrammatically in Fig. 5. It will be seen from the figure that part of the used air is recirculated after washing and filtering it for economy.

(1) For cleaning, air is sucked through cellulose or fibrous material, either dry, or moistened with an oil just like air cleaners in automobile engines, or it is washed of all dust particles by either impinging the air on wet surfaces, or by atomised spray of water.

(2) **Cooling** or **refrigerating** is done either directly by passing the air over ice, or indirectly by passing the air to be cooled over the surface of a metal coil through which a volatile refrigerant of either a non-inflammable type such as

CO_2, SO_2, etc. or of an inflammable type such as NH_3, CS_2 and several others is circulated. The principle of refrigeration is illustrated in Fig. 6.

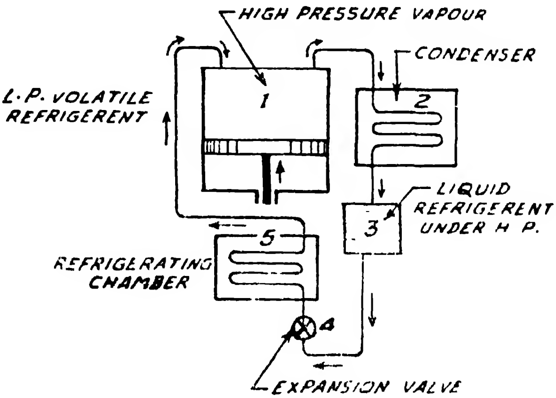


Fig. 6—Diagram showing the principle of refrigeration.

The vapour of the volatile refrigerant enters the cylinder of a compressor, *1*, in which it is compressed. This results in increasing its pressure as well as temperature. It then passes through a condenser, *2*, consisting of pipes or tubes or coils. The condenser is supplied with cooling water at a suitable temperature, so that the high pressure vapour is converted into liquid which is still under high pressure, but with its temperature reduced to almost that of the cooling medium in the condenser. The liquid refrigerant, which is collected in the vessel, *3*, now enters through an expansion valve, *4*, into an evaporator, *5*, consisting of a chamber with large diameter tubes or coils, in which its pressure is suddenly reduced, and therefore it changes again into a vapour, and while doing so, it absorbs a large amount of heat from the material to be refrigerated surrounding the evaporator tubes. After the vapour has absorbed heat in the process of refrigeration, it is used again in the cycle through the compressor, condenser, expansion valve and evaporator. It should be noted that on one side of the expansion valve the refrigerant is under high pressure and temperature, and on the other side it is under a low pressure and temperature. The above cycle of operations is shown by means of arrows in Fig. 6.

(3) **Humidification** :—In winter, because of the low temperature of air, the latter contains less moisture. When it is heated, the humidity is still further reduced. Humidifying is done either by evaporation of water-spray, as in the air-washer, or by application of steam jet designed to discharge into air, flowing through an air-washer, or by atomising water by means of compressed air.

Dehumidification on the other hand, is done either by (a) condensation or (b) desiccation. Condensation is done by surface cooling or spray cooling, both of which have been already described. The extra water of condensation goes to a drain. (b) Desiccation is done either by absorption or adsorption. The absorbents used are solutions of ammonia, calcium chloride, etc. known as brines. Adsorption is the adhesion of molecules of water vapour from the air to the surfaces of the solid bodies called absorbents. The latter in common use are silica gel, calcium chloride and activated alumina. Silica gel is a synthetic product, chemically pure silica in the form of hard, crystalline, pea-sized granules and is very porous. It can be reactivated by heating. Broadly speaking, absorbents are liquids and adsorbents are solids.

(4) **Air-circulation** is effected by (a) suction or blower type air pumps, (b) air ducts, main as well as branch ducts, with outlets and inlets with grilles and dampers. The ducts are of metal designed to carry the proper volume of air with just sufficient velocity. Dampers control the direction, volume, and velocity of the circulated air. Grille is a latticed outlet or inlet.

The methods of systematic air-conditioning may be classified into (1) the central system and (2) the unit system. The only difference between the two is that whereas in the central system the different operations are performed at different places, and only the conditioned air is supplied to rooms

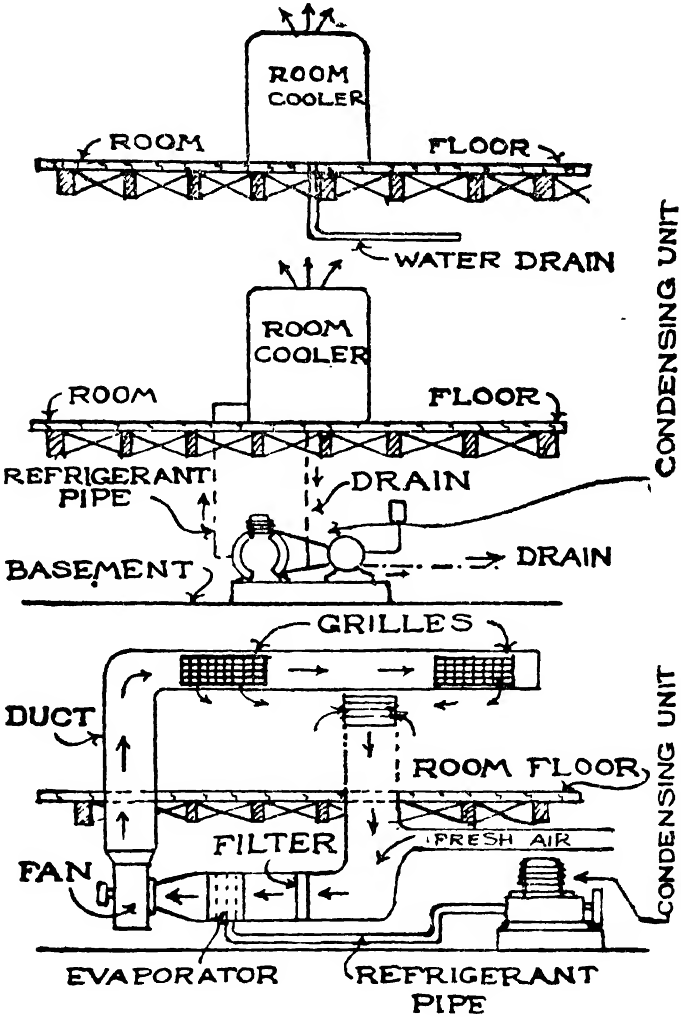


Fig. 7—A self-contained cabinet unit.

Fig. 8—A cabinet in room, with condensing unit in basement.

Fig. 9—Air conditioning on central system.

through concealed ducts near ceiling level, in the unit system portable, attractive cabinets placed inside rooms are self-contained in every respect. In both cases the temperature is controlled automatically by a thermostat, and humidity by a humidistat. Figs. 7 and 8 show diagrammatically the two systems. In Fig. 7, a self-contained cabinet unit is shown, in Fig. 8, a unit in a room with its condensing part in a basement is shown, and in Fig. 9 air-conditioning on central system is illustrated.

Natural Light

The importance of sunlight cannot be stressed too much. Its restorative and recuperative value is almost equal to that of fresh air. Even plants become pale, and ultimately die, if they are deprived of light,—instinctively they turn to light. Similar is the case with human beings. Those who are doomed to spend most of their time in darkness, grow pale and anæmic, lose their vitality, and the power of resistance to disease.

The sun's rays especially on clear days in an atmosphere free from smoke and dust are the best disinfectant. Even the diffused light of the sun has this power, though to a less degree. It has been proved that even the deadly bacilli of typhoid will be killed, if exposed to sun's direct light, within ½ to 2 hours, and to diffused light within 5 hours. Tuberculosis bacterium which is highly resistant to drying in dark places, is quickly killed with direct sunlight.

The visible light rays of the sun are composed of seven colours. Beyond the red are the long-wave infra-red heat rays, and beyond the violet are the ultra-violet short-wave rays, both of which are invisible. The ultra-violet rays are very powerful in destroying bacteria, and possess therapeutic values to a remarkable extent. The cells of the skin and the corpuscles of the blood circulating in the veins and arteries close to the skin surface, absorb these rays, and as a result the blood is purified, and its circulation accelerated. This causes a feeling of health and vigour. They aid in depositing calcium in the bones of growing persons. Failure to deposit calcium results in rickets.

A house should, therefore, be so built that every room will receive the sun's rays directly in some part of it some time or other during the course of the day, and that there should be at least one open verandah on the sunny side, or a terraced roof. Besides, there should be no corner in the entire house which is not sufficiently lighted. Darkness is synonymous with dirt. If a room is generally dark, it is sure to be dirty. Even in a room lighted moderately well, the darkness in corners and recesses is sure to conceal dirt and dust. The average house-maid's broom is bound to fail, in its circular sweep, to penetrate into the depth of the recesses and corners to clear it. All sorts of visible vermin and invisible microscopic bacteria, are sure to grow with unchecked activity as the darkness envelops them. On the other hand, if there is light in such corners and recesses, to make the dirt visible, none but the most slovenly person will knowingly allow it to accumulate there.

However, strong sunlight which causes a glare is harmful to the sight. It strains the eye. The strain can result from close work like reading, sewing, etc. both in glare as well as in dim light. The light should not also flicker. The light coming from the North direction is more effective and steady: that is why continuous windows are provided for lighting factories, workshops, etc. on the top of the wall on the North side, and they are, therefore, called "North lights". Class rooms in schools also should derive their main light from the North. The windows for this should be placed at regular distances so as to insure uniformity of light. Government regulations for design of school buildings require the following :

"The edge of the last window in the North wall should be behind the last row of pupils, and not more than three feet from the west wall.

The light from the North should not be masked by bonnets or even verandahs on the North, except where the sun glare is excessive.

The total window area should be one-fifth of the floor area and at least half of this should have a North aspect.

Sky-lights should never be provided in class rooms. If there is deficiency of light, North light should be provided as is done in factories and machine shops with light coming in from the North."

Sometimes in spite of a room having large windows there is deficiency of light on account of defective outlook such as a narrow facing street and a tall building on the opposite side. In such a case, considerable improvement can be made by white-washing the walls frequently to reflect light.

For lighting cellars whether used for business or domestic purposes, pressed glass blocks should be fixed into the pavements. A variety of these blocks have lenses or prisms formed on the underside. They collect light and project it in the desired direction. They produce conditions almost of broad daylight in the basement rooms below street level.

Questions

1. What is the composition of air? What changes take place in the originally fresh air which is breathed in and respired?

2. Describe step by step what would happen to persons who are crowded into a small room without any means of changing the air.

3. What laws govern natural ventilation? How does natural ventilation as practised in this country differ from that as practised in the cold countries of the West?

4. Why are heights of ceiling above 3·75 m. (12 ft.) of rooms, a disadvantage in natural ventilation? How could they be made effective?

5. What is the object of air-conditioning? What is its special advantage over the best form of ventilation?

6. What is a 'comfort zone'?

7. Show diagrammatically the different operations involved in all year round air-conditioning.

8. How is cooling effected? Show by a refrigeration flow diagram.

9. How is dehumidification accomplished? What is an absorbent and how does it work?

10. How are the sun's rays beneficial to human well being?

11. What are "North lights" and why are they provided in factories?

12. How should a school class-room be lighted?

CHAPTER IV

PIPES, FITTINGS AND OTHER MATERIALS

ALTHOUGH various materials are used for the manufacture of pipes for drainage work, such as vitrified clay (stoneware), cast iron, lead and its alloys, concrete (both plain and reinforced), galvanised iron, steel, copper and brass, the first four, viz. stoneware, c. i., lead and concrete are those principally used.

The requirements of an ideal pipe are that,

(*a*) It should be strong enough to withstand the internal pressure and external load, and sometimes vibrations to which it may be subjected in certain positions.

(*b*) It should be durable, i. e. should not deteriorate by the atmospheric influences, or by chemical reactions in the sewage.

(*c*) It should be smooth on the inside, i. e. not only free from blisters, air-blows, sand-holes, etc. but should present a polished and glazed surface, so as to be impervious to water and air.

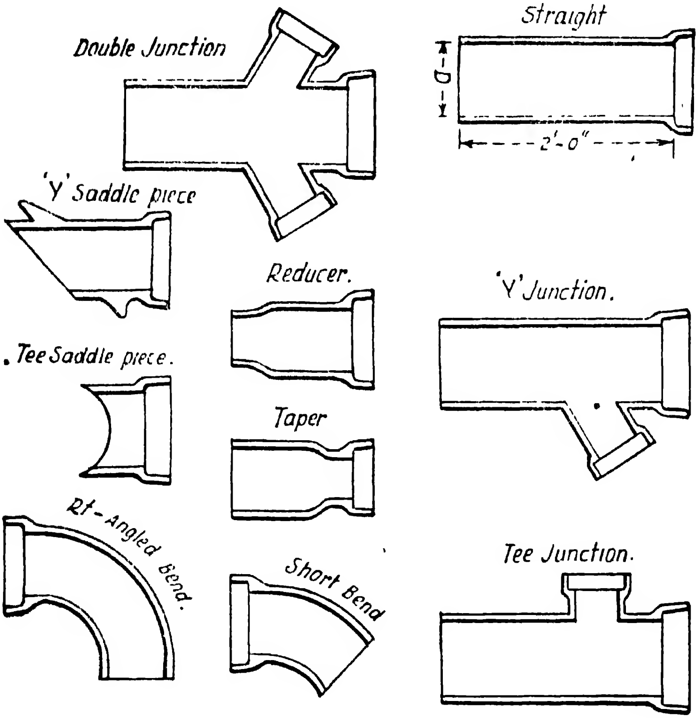
(*d*) It should be uniform in section, straight, and true to centre throughout.

(*e*) It should be cheap both in initial cost and maintenance, and easily and cheaply jointable.

The choice of pipes of a particular material is governed first by the consideration whether the drain is to be constructed below or above ground. If it is to be below ground, then its position, depth, nature of the ground, whether made-up, water-logged, or subject to movement, are further factors to be considered.

Stoneware pipes satisfy most of the above requirements, but are brittle. Besides, they are available in this country in 60 cm. (two feet) lengths only, and in diameters not exceeding 60 cm. (two feet). At present, they are manufactured in this country at Raneeganj in Bengal, and Jabalpur in M. P.

The exterior of the spigot ends and the interior of the sockets are provided with grooves not less than 1·5 mm. ($\frac{1}{16}$ in.) deep and are left unglazed in these portions so that an efficient joint should be formed by cement sticking to the surfaces properly.



Figs. 10-19—Stoneware pipes and their usual fittings.

British Standard Specification No. 65 (1937) stipulates the following tests :—

(1) **Absorption Test :—**

For thickness upto 2·50 cm. (1 in.) 7% increase in weight
,, ,, ,, 3·20 cm. ($1\frac{1}{4}$ in.) 8% ,, ,, ,,
,, ,, ,, 3·80 cm. ($1\frac{1}{2}$ in.) 9% ,, ,, ,,

(2) **Hydraulic Test**:—Pipes must withstand an internal pressure of 1·5 kg./$cm.^2$ (20 lbs. per sq. in.) for at least 5 seconds without showing signs of injury or leakage.

Figs. 10 to 19 show the usual fittings of stoneware pipes. Besides these, there are traps of different kinds which are illustrated later under that caption.

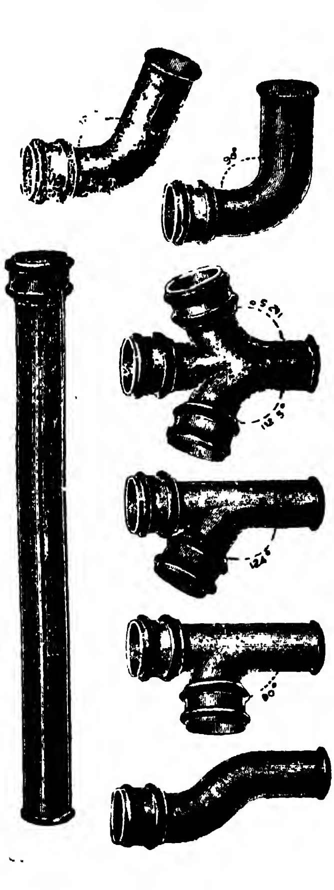
Cast Iron Pipes:—These shall be made from a suitable grade of pig iron and good, clean scrap. The cast iron shall be dark grey on fracture and should not be brittle. It shall be such as can be easily cut, drilled, chipped and filed. The pipes shall be free from flaws such as cracks, sand and air holes, and when struck with a light hammer shall give a clear, ringing, bell-like sound.

Cast iron pipes suitable for drainage work are of various grades: (1) Cast iron drain and sewer pipes 75 to 600 mm. (3 in. to 24 in.) diam. suitable for underground work, (2) Soil pipes 100 to 150 mm. (4 in. to 6 in.) diam. (3) Waste, ventilating and heavy rain-water pipes, and(4) Light rain water pipes.

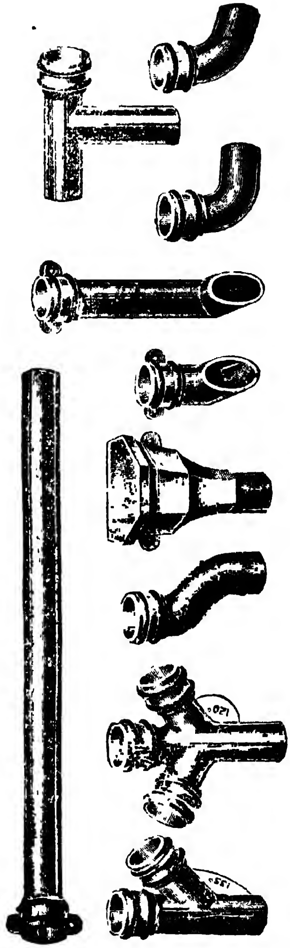
(1) · **Cast Iron Drain Pipes**—These are much costlier than stoneware pipes; but being of 2·75 m. to 3 75 m. (9 or 12 ft.) length, the joints are fewer. They are more suitable to withstand considerable internal pressure to which they may be subjected, for instance, in inverted siphons, or to external loads under heavy road or railway embankment. The joints can be made perfectly water-tight. They can be laid with safety upon piers, or as cantilevers, or suspended in hangers. They offer greater resistance to flowing water, ice, etc., and are more expeditiously laid, and may be subjected to stress immediately.

For protection against corrosion they are dipped, while hot, into a bituminous solution, called Dr. Angus Smith's solution.

(2) **Soil Pipes**:—Soil·pipes are pipes for receiving and conveying discharges from soil fittings, viz. water closets, urinals, and slop sinks. They are 75 to 150 mm. (3 to 6 in.) in diam. and are mostly laid vertically on the external side of walls.· Soil pipes are always carried up without diminution



Figs. 20 to 26—C.I. Soil pipe and standard fittings



Figs. 27 to 36—C.I. Rain water pipe and usual fittings.

of their diameter to points above the roof at which level they may safely act as ventilators to the drain. Soil pipes are thicker and stronger than waste pipes.

The standard length is 2 m. (6 ft.) including socket. The usual soil pipe and its fittings are shown in Figs. 20 to 26.

(3) **Waste Pipes**:—These are suitable for all fittings other than soil fittings, i. e. they are used with lavatory basins, baths, rain water pipes, etc. There are two grades : Heavy and medium, both being 2 m. (6 ft.) long. These pipes are provided with ears for fixing them against walls.

(4) **Light Rainwater Pipes**:—The standard length is 2 m. (6 ft.). The pipes have spigots and sockets and ears for fixing them against walls.

Figs. 27 to 36 show the usual rain water pipe fittings.

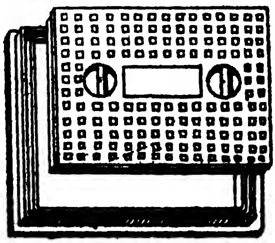
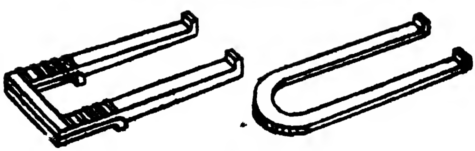


Fig. 37—C. I. frame and cover for inspection chambers.



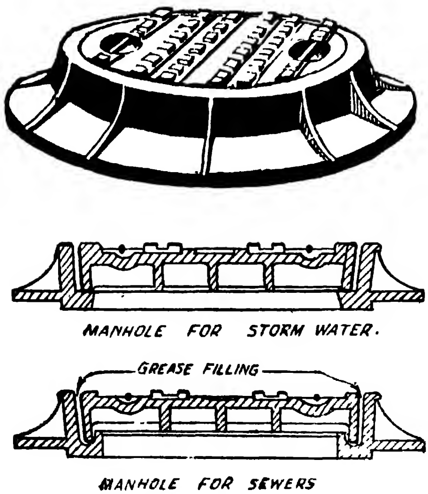
Figs. 38, 39– C. I. steps for use when manholes are deep.

Manhole Covers of Cast Iron with Frames:—These are covered by B. S. No. 497 (1933). The covers and frames should be cleanly cast, free from air and sand holes and cold shuts, neatly dressed and carefully fettled. The castings must be sound and easily drilled, tapped and filed and shall ring clearly when struck all over with a light hammer.

Weldless and Welded Steel Sewers :—These pipes are covered by B. S. S. No. 534 (1934) for steel Spigot and Socket Pipes and Specials for water, gas and sewage. Class "D" pipes should be used unless otherwise specified. All steel pipes should have received Dr. Angus Smith's protective process. As a further protection all pipes which are not to be embedded into concrete should be wrapped with hessian cloth thoroughly soaked into hot bituminous composition.

Steel pipes are supplied at a rate per lineal metre and not by weight.

Chequer Plates :—These are used in covering openings on the floors of manhole chambers, pumping stations, and similar works. They should comply with B. S. S. No. 15 (Revised 1930).



Figs. 40-42 – Heavy C. I. covers suitable for manholes in streets. The covers for sewer manholes are made air-tight by filling grease.

Concrete Pipes :—Concrete is a very suitable material for drainage pipes which can either be pre-cast, if of small size, in moulds, or *in situ* for large sewers. The only drawback of concrete pipes is that sulphuretted hydrogen (H_2S), given out when sewage decomposes, has an adverse effect on it, causing corrosion. But if the concrete is well made and also the sewage is fast removed to out-fall work before it reaches that stage of decomposition which causes H_2S to escape, experience has proved that concrete is the most suitable material in respect of cheapness and durability and has come recently into universal use. The smallest concrete pipe is 10 cm. (4 in.) in diameter, and is usually 1 m. (3 ft.) long excluding socket. Pipes above 15 cm. (6 in.) diameter are manufactured by the centrifugal process. A hollow mould is made into which concrete of the proper consistency is poured and the mould is rotated or spun round its horizontal longitudinal axis very rapidly, so that by the centrifugal force exerted in the process, the finer material is brought towards the centre and the coarser material carried to the outer surface, thus making the inner surface smooth, dense, and non-absorbent ; Indian Hume Pipes are manufactured after this process. Pipes of 15 cm. (6 in.) and above, up to 2 m. (6 ft.) in diam. are manufactured in 2 m. (6 ft.) lengths. All pipes above 60 cm. (24 in.) and those less than that, which are likely to be subjected to considerable internal pressure or external superincumbent load, are provided with steel reinforcement.

Asbestos-Cement Pipes :—The material for these consists of an intimate mixture of hydrated inorganic cement and clean asbestos fibre. No organic material, except carbon black for pigment is allowed.

The effective lengths inclusive of sockets are 2 and 3 m. (6 ft. and 10 ft.) for 5 to 10 cm. (2 to 4 in.) diam. pipes, and 2 m. (6 ft.) for 12·5 and 15 cm. (5 and 6 in.) size.

All the standard fittings shown on page 32 for c. i. pipes are available also for asbestos cement pipes.

Lead Pipes :—These are used in connection with flushing system of house drainage only in this country.

The lead used for pipes should contain 99·75 per cent. metallic lead, total impurities not exceeding 0·25 per cent. Pipes must be sound, free from laminations and flaws, and cylindrical, smooth and uniform in section with uniform wall thickness.

Modern lead pipes are produced in extrusion presses, the metal being forced out while in a semi-molten condition by hydraulic pressure. Thus seamless pipes of any length can be produced. These are called "drawn lead pipes". Lead pipes can be easily bent, bored, expanded and jointed. They do not thus require the usual fittings such as bends, elbows, etc. like pipes of other materials, except plastic.

Lead pipes upto 2·5 cm. (1 in.) diam. are usually marketed in coils of 20 m. (60 ft.) or lengths of 4 m. (12 ft.) and those above this size in straight lengths of 3 or 4 m. (10 or 12 ft.).

Among other materials required in connection with house drainage and plumbing work are the following :

Brick, stone, lime, cement, sand, concrete, timber, etc. are very common materials and therefore need not be described. If necessary, the reader is referred to the author's *Materials of Construction* for them.

A few other special materials are described below.

Lead used for pouring in joints must conform to the following composition :

Metallic lead not less than	99·84 p. c.
Antimony not more than	0·05 ,,
Zinc ,, ,, ,,	0·01 ,,
Other impurities ,,	0·10 ,,
Total	100·00

Solders :—These are extensively used in plumbing work. Their composition, melting points and the fluxes used are given in Table No. 4 below.

Gasket Material : —For this, yarn of either spun hemp or jute (hessian) woven into a loose form of rope 20 mm. (¾ in.) in diameter is used. It should be strong, clean and perfectly dry. Before using, it is impregnated with either paste of neat cement, or some tar product, such as bitumen or hot asphalt. The latter makes it less liable to rot, and makes the joint a little more flexible to withstand slight settlement or vibrations.

TABLE NO. 4

Name of Solder	Constituent Parts per cent			Melting Point °C (°F)	Flux used
	Lead	Tin	Antimony		
Plumber's	67·3	31·0	1·7	225°C (440°F)	Tallow
Tinsmith's	49·0	48·0	3·0	190°C (370°F)	Resin, resin and tallow or fluxite
Blow pipe	35·0	62·0	3·0	170°C (340°F)	Tallow, resin or fluxite

Rust Cement:—This is a compound of one part by weight of flowers of sulphur, two parts of powdered salammoniac, NH_4Cl, (*Nowsagar*), and 200 parts of fine cast iron filings, free from hard skin and any impurities. The sulphur and iron filings are first mixed dry and then the solution of salammoniac is added to it. The mixture soon begins to rust and gets warm in the process. It should then be covered with water until ready for use. If a quick-setting composition is required, the proportion should be 2 of sulphur flowers, 1 of salammoniac and 100 parts of iron chippings.

This material is used for making joints of pipes in which hot water is likely to be discharged.

Soil or the Plumber's Black:—This is also often called 'tarnish' or the 'plumber's smudge,' and consists of a wet paint made by mixing glue size, lamp black and powdered chalk in water. It is used for covering up the bare metal surface outside the area to be covered by the joint. It prevents the solder from sticking to and tinning that part on which it is applied.

Questions

1. What are the requirements of an ideal pipe ? What is the standard length of stoneware pipes in this country ? What are the advantages of C. I. pipes over stoneware pipes ?
2. Distinguish between soil and waste pipes.
3. What are 'drawn lead pipes' and why are they so called ? What are the advantages of lead over other pipes ?
4. What is the possible risk in using concrete pipes and how can it be avoided ? How are spun pipes manufactured ?
5. What is the function of a gasket in joints ?
6. What is rust cement and where is it used ?

CHAPTER V

TRAPS AND THEIR FUNCTION

FOR THE proper understanding of the subject it would be well to give a few definitions of the technical terms at this stage.

Sewage consists of any one, or the combination of, liquid wastes of the following three different classes:—(1) Water-borne excremental matter and all other waste water from human residences called domestic sewage; (2) Industrial or Trade wastes from manufacturing processes, and (3) Such surface water including rain water (the latter is called storm water) as may be admitted into the underground conduits. The first two generally go together.

Sullage or *slop water* contains waste water from kitchens, waste from baths, wash water from privies, and also a considerable quantity of urine. It differs from sewage in that that night soil is excluded from it.

A *drain* generally implies a conduit or an open channel, conveying waste water of any sort. But, when applied to the underground system of sewerage it has a restricted meaning, and represents the pipe used for the drainage of a single private property consisting of one or more houses in the same compound. A drain is laid, maintained, and repaired *at the owner's cost*.

A *sewer* is a conduit conveying sewage, to which house drains are connected. It is laid, maintained, and repaired *at public expense*.

Branch or *lateral* sewers collect and convey the sewage to the main or trunk sewer. All these are called *collecting sewers*. The sewer from the lower end of the collecting sewer to the point where sewage is finally disposed is called *outfall* *sewer*, and the place where the sewage is finally disposed, or treated is called the *outfall*.

The bottom surface of a drain or sewer along which sewage flows is called the *invert*.

An *inspection chamber* is a chamber in the form of a vertical shaft built on the top of a drain to the ground surface with a removable cover at the top, at every change of gradient, or change of direction, or, at intervals of 35 m. (100 ft.) or part, for inspection, or cleaning. It is called a *manhole*, when built on the top of a sewer. The latter is usually larger and deeper.

A *soil pipe* is a thick, heavy pipe, usually of c. i., asbestos cement or lead, receiving discharges from soil fittings, such as water closets, urinals, and slop sinks, *directly connected* to the drain.

A *waste pipe* is similar, but lighter and thinner, for receiving waste water from baths, lavatory (wash hand) basins, kitchen sinks, etc. A waste pipe discharges its contents on to the *top of a gully trap* outside a house. The trap is connected to a drain pipe.

A *cesspool* is an underground water-tight tank into which excreta and household waste water are collected and stored, until they are periodically removed away and suitably disposed of.

A *house connection* is the connection of the drain of a house with a public sewer, laid underground.

A *catchpit* is a chamber built below the level of the invert of a drain, in which, on account of the reduced velocity of flow, heavier particles such as of sand, silt, etc. precipitate.

Conservancy system is the system of collecting fæcal or excremental matter on the premises into pails, by manual labour, and treating it suitably either with chemicals, or in most cases with earth, so as to render it harmless.

Self-cleansing velocity is the velocity, which causes all solid matter, both heavy and floating, to be easily carried by the flow.

Trap:—The function of a trap is to provide a barrier in the way of foul gases in a drain, soil pipe, or a waste pipe, so that they cannot escape to the atmosphere either inside or outside a house. This it does by providing a water seal. The deeper the seal, the more efficient is the trap. This function makes traps very essential fittings in a drainage system, the efficiency of which depends upon their proper functioning.

Fig. 43 shows 25 mm. (1-inch) drawn lead pipe trap with a 5 cm. (2-inch) water-seal, a screw plug for cleaning at the bottom, and its three developments known as *P*, *Q*, (half *S*), and *S*. The names are given according to the resemblance of their shapes to the letters *P*, *Q*, and *S*.

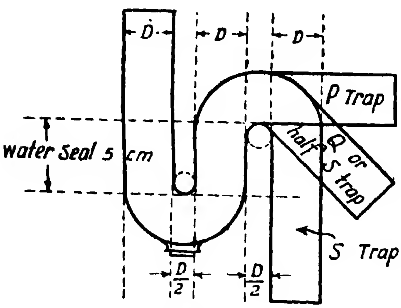


Fig 43 — Development of *P*, *Q*, and *S* traps
The water seal and access plug for cleaning are shown.

All drain openings (except those provided for ventilation), and every sanitary fitting must be provided with a suitable trap.

The requirements of a good trap are that,

(1) It must be made of a non-absorbent material.

(2) It must provide an adequate seal of water *at all times*.

(3) It must not restrict, obstruct, or retard the flow of water, by presenting any rough surface, projection, angles, contractions inside it.

(4) It must be self-cleansing.

(5) It should retain a minimum quantity of water consistent with providing a deep seal and a large surface.

(6) It should provide means of access for cleansing and the access cap or plug, provided for this purpose, should conform to the internal curved surface of the trap so that neither a protrusion nor a recess is formed inside, causing the slightest obstruction to the flow.

The factors which may break the seal of a trap are :—

(1) Collection of gases under pressure in a drain, waste or soil pipe due to its blockage, which may force their way through the water seal.

(2) Evaporation of water if the sanitary fitting is not flushed for a long time especially in the summer.

(3) Leakage of water through a faulty joint.

(4) Siphonage due to one of the following common causes :—

(*a*) A piece of paper or a rag caught part way in, or dirt of absorbent nature accumulated near the bend, sucking the water by capillary attraction.

(*b*) Momentum caused by a sudden discharge of a flush.

(*c*) Partial vacuum produced in a fitting at a lower level when another fitting on the upper floor connected to the same soil or waste pipe is suddenly flushed. The latter is illustrated in Fig. 44 in which water closets *A*, *B*, and *C* on three different floors are connected to and discharge into the same soil pipe. When the w. c. *A* is suddenly flushed, there will be a fall of water down the soil pipe which would entrap and carry air with it in its descent. This would draw some air also from the branches *P* and *Q* of the closets on the lower floors, creating a partial vacuum in them. As a result of this, water from the traps *B* and *C*, would be sucked up as shown by the arrows and would flow down the soil pipe thus destroying the seals.

The preventive measures for the above are as follows :—

(1) Collection of gases under pressure could be prevented by providing a ventilating pipe in the portion between

the trap and the soil pipe as is shown in dotted lines in the figure. This vent pipe should be carried above the eaves, so that no sooner gases are collected they would escape to the atmosphere at that height without causing any nuisance.

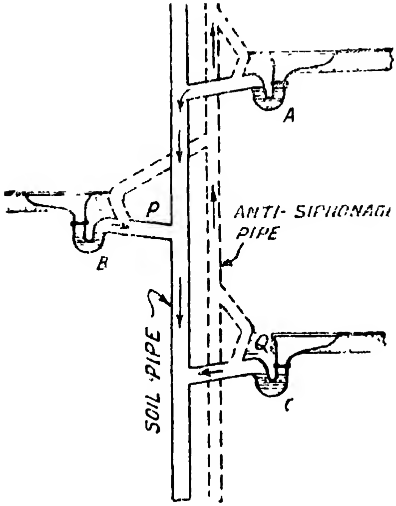


Fig. 44—When the closet *A* is suddenly flushed, the water falling down the soil pipe extracts air from the branch, *P*, causing a partial vacuum, which starts siphonic action and empties the trap of w. c. *B*. The same might happen to the trap *C*.

(2) Remedies for unsealing of the trap by evaporation are—(*a*) providing a deep seal, and (*b*) putting a few drops of glycerine into the trap. This would form a film on the surface of water and check evaporation during the period the fitting is not flushed with water.

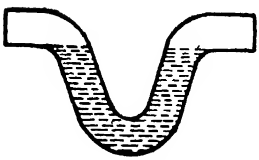
(3) The remedy for prevention of siphonage due to any cause is also to provide a vent pipe as shown in dotted lines in the above figure. This would establish a direct communication with the atmosphere and provide means of relief when the gases are under pressure and supply the deficiency when there is a partial vacuum. This pipe is called an *anti-siphonage pipe**

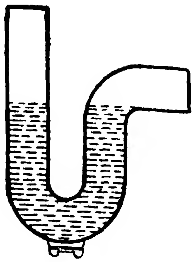
* London County Council Bye-laws require that in order to ventilate the branch effectively, the anti-siphonage pipe should be connected between 8 and 30 cm. (3 in. and 12 in.) from the crown of the trap bend, and to guard against the possibility of its being fouled where it joins the soil or waste pipe and eventually be choked by the waste water, the branch must always be made with the anti-siphon pipe bending in the direction of the flow of water in the manner illustrated in Fig. 44.

and should be at least two inches in diameter and either carried independently as a separate vent pipe a few feet above the eaves of the house, or connected to the ventilating part of the soil pipe above the highest fitting.

Traps may be made of either glazed stoneware, c. i., glass, enamelled iron, drawn or cast lead, copper, brass, glazed fire-clay, or vitreous china. Traps of small bore are usually fitted with cleaning caps screwed to the bottom. Some traps are in two parts, the bottom half could be unscrewed for cleaning purposes.

There are a number of different forms of traps, each suited to a specific purpose. A few important ones amongst them are illustrated below :—





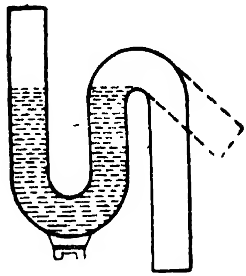
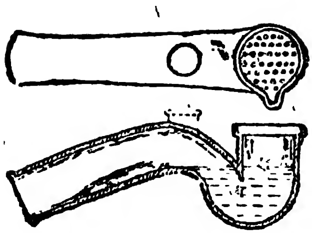


Fig. 45—Running trap. Fig. 46—'P' trap Fig. 47—'Q' and 'S' traps.

The simplest is what is known as a *running trap* shown in Fig. 45. Figs. 46, 47 show *P* and *S* traps respectively. A *Q*, or *half S* trap is like an *S* trap with one of its legs bent at an angle as shown in dotted lines in Fig. 47. *P*, *Q* and *S* traps are those in most common use. Figs. 48, 49 show a *nhani trap* in plan and section. It is provided with a perforated hinged cover to arrest coarse, solid matter. There are two types : one with a very shallow seal to suit the small thickness of upper floors and is used where the waste water is not very foul such as in rooms for draining water used for washing floors. The other type of *nhani trap* called *D trap* shown in Figs. 48, 49 has a deeper seal, and is provided with a branch for connecting anti-siphon pipe. It is used in bath rooms where very foul water such as urine is sometimes likely to be discharged.

Fig. 50 shows a *bottle trap* which is very satisfactory as far as its deep seal is concerned. But the central portion which projects sharply is objectionable. However, it can be opened for cleaning by unscrewing the bottom half.



Figs. 48, 49—Plan and section of a *D*-trap—another form of 'nhani' trap

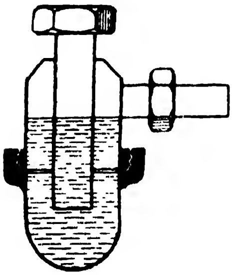


Fig 50—Bottle trap.

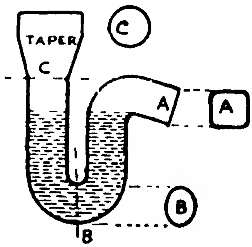


Fig. 51—Anti-*D* trap.

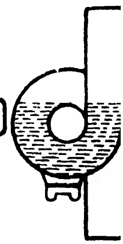


Fig. 52—Knot trap.

Fig. 51 shows an important trap called the *anti-D trap.* Its special features are that in addition to having a deep seal, it has a tapered inlet, and further the cross sections at A, B, and C are square with rounded corners, oval and circular respectively, as shown in the figure. This makes it proof against siphonage by momentum, which is mainly due to the square out-go. Its odd cross sections, however, make it difficult to be jointed with pipes of circular bore.

Fig. 52 shows a *knot trap* which is satisfactory both as regards the deep seal and facilities for cleansing.

Fig. 53 shows an *intercepting trap* of stoneware. It is fixed generally in an inspection chamber built at the lowermost end of the house drain to prevent the foul gases from the street sewer from entering a house drain. The trap is provided at top with a cleaning eye, or rodding arm with a close-fitting plug (See Figs. 148, 149) to allow a cleaning rod being easily manipulated to remove obstruction in the drain between the trap and the street sewer without disturbing the road surface. As this trap serves the purpose of disconnecting or intercepting a house drain from the street sewer it has received that name.

There are a number of patent traps belonging to the class of anti-siphon traps which are called *resealing traps* as they work on the principle of holding a larger quantity of water so that enough would be retained after discharge to fall back into, and reseal the trap. The use of such traps is permissible where there are only one or two ablution fittings connected to the same waste pipe. When there are more fittings, an anti-siphonage pipe must be provided. The trap illustrated in Figs. 54, 55 called *Grevak trap* belongs to this class. When siphonic action takes place, the level of water falls down to *A* as shown in Fig. 56 but at the same time, the bye-pass is opened, through which, air passes as shown by arrows and as a result the atmospheric pressures are

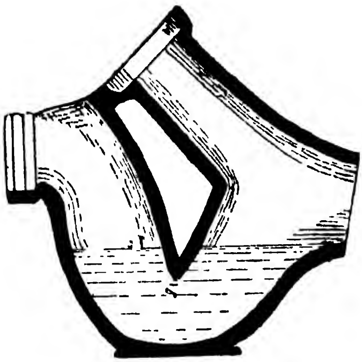
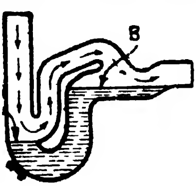
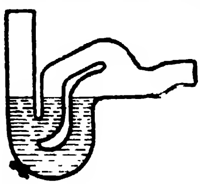


Fig. 53—An intercepting trap of stoneware.





Grevak trap:
Fig. 54 – Level falls to *A* under pressure and bye-pass opens.
Fig. 55 – Trap resealed.

equalised and the siphonic action is stopped. Immediately afterwards the water contained in the "storage chamber," *B*, falls back and reseals the trap as shown in Fig. 55. There is a screw-plug on one side at the bottom which makes the trap accessible for cleaning.

Another interesting example of an ingenious design of a resealing trap is the *Sureseal trap* shown in Fig. 56. Normally, the water level in the trap is at *AB*, but when siphonic action takes place, it falls to *BC*, when air passes through the middle vent and equalises the pressures.

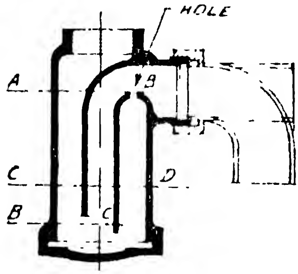
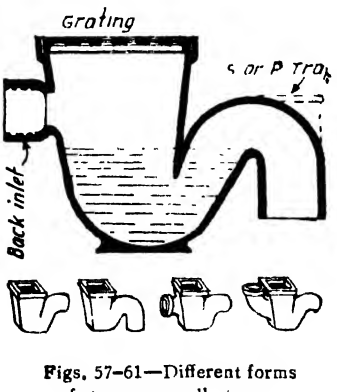


Fig. 56—Sureseal trap.

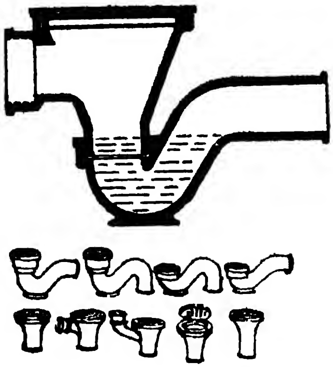
In the meanwhile, as the hole *B* at the top of the dome-shaped "reservoir" is very small, the latter remains still full, and as soon as the pressures are equalised, this column of water falls and the water level in all the three legs reaches the line *CD*, thus sealing the trap once more, though with a less depth of water. The screw-cap at the bottom makes the entire trap accessible for cleaning.

Fig. 57 shows a vertical section of a stoneware *S gully trap* often called simply a "gully." It may be even a *P* trap as shown in dotted lines. Such traps are employed for the reception of waste water from sinks, bath and rain water down-take pipes at their entry to branch drain. They are also used for admitting surface water from yards and paved walks into the drain. For the latter purpose they are provided with a c.i. grating at top to exclude coarse solid matter which is likely to block the drain.



Figs. 57–61—Different forms of stoneware gully traps.

The primary object of a gully trap is to cut off or disconnect a house from direct communication with drain by means of a water seal about 5 cm. (2 in.) deep so as to serve a barrier to gases from the drain or a sewer. The traps shown in smaller sizes in Figs.58 to 61 at the bottom are the different variations of the type for use in different positions.



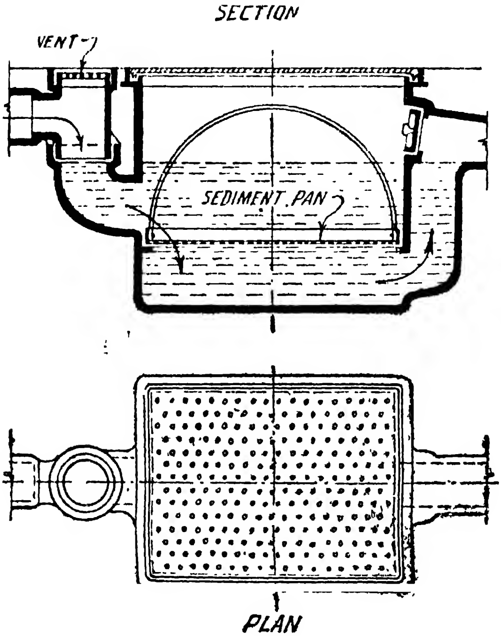
Figs. 62-71—Different forms of cast iron gully traps.

Fig. 62 shows a section of a gully trap made of cast iron. Unlike the one mentioned above of stoneware, it is in two pieces and has a separate top piece which is reversible. The lower joint is made as usual with a gasket of hemp and cement. The four small sketches below it, in the upper row, are different variations of it, and the five figures in the lower row are several other designs of the upper piece of the trap to suit different purposes.

Grease Trap is not so important in this country as, in the first place, the greasy and oily plates and other utensils are scrubbed with ashes and earth and then washed; secondly the warm air inside sewers in this country generally does not favour solidification of oils and grease. Still in the cold weather season on hill stations and during temporary spells of cold they may be required, particularly on waste pipes from kitchens and baths of hotels, restaurants and large residential institutions. If the grease is not removed before it enters drains and sewers, it sticks to the interior surface of the conduits, becomes hard and causes great nuisance by obstructing the flow.

The trap shown in Figs. 72, 73 has a large surface area, deep seal and holds a large volume of cool water. There is a perforated g. i. bucket or a pan with a long curved handle, loosely placed inside it. The greasy water on entering the trap mixes with the large body of cool water, so that the grease is solidified and being lighter, rises to the surface, while the liquid, free of grease, passes below it.

There is a detachable cover at the top. The accumulated grease must be removed from time to time (twice or thrice a week) by opening the cover and lifting the bucket by means of the curved handle. If this is not done, not only will the trap cease to function by the blockage, but it would act as a small cesspool giving out foul stink. On this account some sanitary authorities consider a grease trap a nuisance rather than a convenience and recommend another type, which is in



Figs. 72-73—Plan and section of a Grease trap.

fact, a large gully trap provided with a flushing rim, and an automatic flushing tank above the ground level. The flush breaks the congealed grease into pieces which flow away with the waste water.

Questions

1. What are the requirements of an efficient trap ?

2. What is an anti-D trap and how does it work ? Illustrate by means of a sketch.

3. What are the specific uses of (i) a resealing trap, (ii) a gully trap, (iii) an intercepting trap ?

CHAPTER VI

SANITARY FITTINGS

THESE may be divided into two categories: (1) *Soil Fittings* and (2) *Ablution Fittings*. Soil fittings comprise water closets, urinals, and slop sinks with their accessories. These are connected directly to drains. Ablution or waste water fittings consist of baths, lavatory basins, sinks and drinking fountains, and discharge on top of a gully.

As a general rule, all sanitary fittings should be fitted against external walls so that the room in which they are placed may be capable of through ventilation. The floor should be of a non-absorbent material like glazed tiles, polished flagstones, terrazzo, etc., with coved angles at the junction of floor with wall, and at least 30 cm. (one foot) wide tiled dado. Every water closet room should be disconnected from the house by a ventilating lobby, however small.

Water Closet:—This essentially consists of a pan or a basin and a trap. The basin should be of impervious and smooth material—preferably white glazed and should retain sufficient depth of water to hold excreta floating. The shape of the basin should be such as would present least space to be fouled. The trap should have a minimum water seal of 5 cm. (2 in.). Fire-clay is a porous material, dependent for imperviousness on the superficial glaze. When a crack occurs, water is absorbed by the material and the surface is discoloured, and the material soon deteriorates. Vitreous china is the most suitable material. It is not merely glazed but is vitrified throughout. It is strong, acid-resisting and light.

Fig. 74 shows the basin of an Indian type water closet (w. c.) suitable for use in a squatting position. The trap is in a separate piece, which is shown attached, both in elevation and section in Figs. 75, 76. The branch opening on the top of the bend of the trap is for connecting a vent or anti-siphon pipe. The minimum depth of such a closet including the trap, is 45 cm. (18 in.). A depression of about 55 cm. (21 in.) has therefore to be provided below paving to accommodate such a closet. An Indian type closet basin is not so efficient as the European type commode. In the first place it exposes greater surface to be fouled. Secondly the excreta do not drop into the water in it as in a commode. They therefore foul the

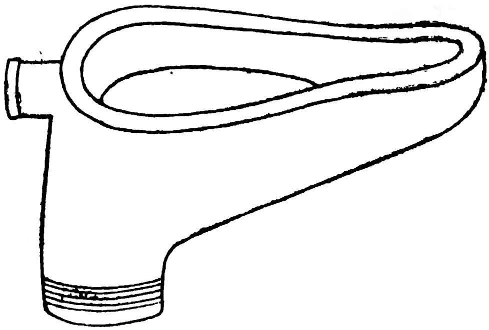
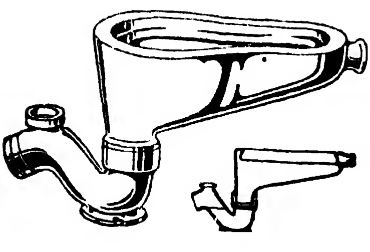


Fig. 74 – Elevation of an Indian type w. c. (Upper part without trap).

surface, for scouring which, greater quantity of water (at least 10 litres or two gallons each time) is required for flushing. If provision for water inside the basin, where the excreta drop, is made, the shallow depth of the latter would cause splashing of water, which is objectionable.



Figs. 75, 76 – Elevation and vertical section of an Indian type basin and trap.

The European or commode type of closets are of two main varieties : (1) the Wash-down type, and (2) the Siphonic type. Each again, may have either a *P*-trap or an *S*-trap and may further be of a pedestal type or corbel type. The latter being supported on a bracket, fixed into wall, the space below it is accessible for cleaning.

Wash-down Type:—Fig. 77 shows a pedestal type wash-down closet with a *P*-trap. It is straight-backed so that fouling of the surface would be reduced to the minimum. It has a wide flushing rim and a trap with 5 cm. (2 in.) water seal. It holds a small quantity of water and yet presents a large water surface. Fig. 78 shows another design of a wash-down type

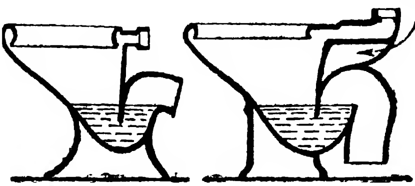


Fig. 77—A vertical section of wash down water closet of commode type.
Fig. 78—A vertical section of another variety of a wash-down closet with an after-flush chamber at the back.

water closet with an *S*-trap. It is also of the pedestal variety. The special feature of this closet is the small chamber on the back side, called *after flush* chamber, below the flushing rim. When the flush is operated, this chamber is filled, and as it has a small outlet hole, it holds a quantity of water sufficient to seal the trap later, if the latter is unsealed by siphonic action. Both the above closets are satisfactorily flushed with 10 litres (2 gallons) of water in one operation.

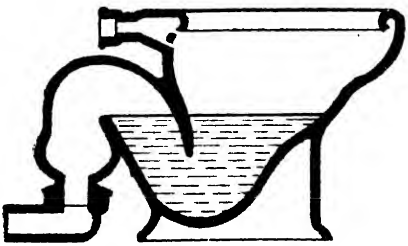


Fig. 79—A vertical section of a siphonic water-closet with outlet pipe first widened and then suddenly contracted.

The siphonic water closet is a step forward in design, in which the pressure of the atmosphere is utilised to assist the flush. The latter thereby becomes more efficient. A siphonic closet need not necessarily have the overhead flushing cistern high above the seat to exert pressure as in the case of the Indian type or the wash-down type. It may be behind the seat just a little above it as shown in Fig. 80. The user can operate it very easily while in a sitting position. There are two popular varieties. The one shown in Fig. 79 has its 75 mm. (3 in.) outlet pipe from the trap first widened and then suddenly contracted to 40 mm. (2½ in.) diam. at the end. This causes the discharge in the basin to be mixed with air inside the outlet and to carry away some air with the flow. This reduces the pressure in the outlet, while the pressure at the inlet end is atmospheric. Thus the contents of the basin are pushed down with a great force or rather sucked out.

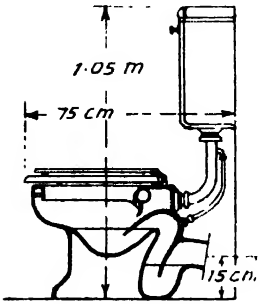


Fig. 80—Another variety of siphonic water closet Note the flushing cistern at a low level on the back side.

The second type is illustrated in Fig. 80. It has two traps. In the top of the bend between them is introduced a small pipe, which is joined to the flush pipe a little below the cistern. When the handle is operated to cause a sudden flush, water passing at a high speed down the flush pipe withdraws air from this narrow pipe. This means that air is exhausted from the space between the two traps causing a partial vacuum in it. The atmospheric pressure on the surface of water in the pan far exceeds this reduced pressure in the part between the two traps and this sets up siphonic action.

The advantages of a siphonic closet are that the flush does not depend on the head of the flushing cistern, but on the siphonic action, and is therefore certain, more forceful and automatic. It admits, therefore, in the first type of a deeper seal. It requires less water for flushing. Thirdly, as the diameter of the outlet pipe is restricted, a soil pipe of 75 mm.

(3 in.) diam. is sufficient instead of the usual 10 cm. (4 in.) which is an economical advantage.

Valve closets, which were once very common, are now obsolete and need not be described.

The important dimensions of closets are :—

Indian type :—Length at top 60 to 70 cm. (23 to 27 in.)
Overall height 40 to 50 cm. (16 to 21 in.) (inclusive of trap)
Width at top . 25 to 30 cm. (9 to 11 in)

Commode type :—Overall height · 40 cm. (16 in.)
Overall length : 50 to 65 cm. (20½ to 25 in.)
Distance of trap to floor 2 cm. (¾ in)
Angle of outlet . for *S* trap 180°, for *P* trap 104°.

Standard Equipment of a closet on water carriage system consists of (*a*) a waste water preventer or flushing cistern, (*b*) a flushing pipe, and a vent pipe or anti-siphonage pipe if there is more than one closet on different floors connected to the same soil pipe.

Flushing Cistern :—Flushing cisterns are made of either c. i. plain or galvanised, porcelain-enamelled, pressed steel, or pressed steel porcelain-enamelled. Of late, cisterns of plastics also are in the market. The flushing capacity of a cistern is 10 to 14 litres (2 to 3 gallons) of water. The requirements of a good cistern are that,

(i) It should be filled rapidly and automatically and without making a noise. For quick filling the minimum diameter of the feed pipe should be 1·2 cm. (½ in.) and larger if the pressure head is small. For automatic filling a ball valve is fitted. For preventing noise the delivery pipe from the ball valve is carried to discharge near the bottom of the cistern. This pipe is known as the silencing tube and must have a small hole near the top to prevent back siphonage into the supply pipe.

(ii) There should be an overflow connection of at least 1·2 cm. (½ in.) diameter at the proper level.

(iii) The cistern should be mosquito-proof. This is achieved by covering it with a close-fitting lid.

There are two general types : (*a*) Bell type, and (*b*) Flat-bottomed type.

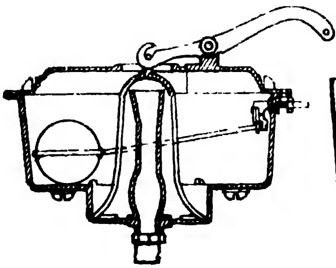


Fig. 81 – Waste water preventer or flushing cistern of the bell type.

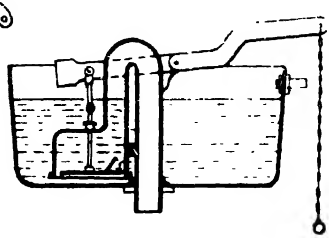


Fig 82 – Flat bottom type.

(*a*) The *bell type* is illustrated in Fig. 81. There is a sump or a well formed at the bottom in the centre through which the flush pipe passes and ends with its open mouth a little above the water level. Resting at the bottom of the well, over the flush pipe, is a bell to the top of which, a lever arm with a chain at its end is attached. On pulling the chain, the bell is lifted and on releasing it, it falls down suddenly to its former position. As a result of this movement, the water enclosed within it spills over the top of the flushing tube and causes siphonic action to commence, which gradually attains full speed. This type of cistern is very popular as it is cheap, has very few moving parts and can be serviced by a layman But it is very noisy in action and erratic in performance.

(*b*) The *flat-bottomed type* illustrated in Fig. 82 has a flat bottom through which the flush pipe rises. The latter is bent a little above the water level to form an inverted U-tube, the shorter or inlet leg of which is enlarged to form a small cylinder open at the bottom. Inside the cylinder at its bottom is a copper disc, which when lifted by the handle upon pulling a chain, suddenly lifts also the water above it, which spills over the crown of the U-tube, starting siphonic action. There is a hinged valve in the disc which opens up and allows the remainder of the water in the cistern to pass freely up the siphon bend.

The waste-preventing cistern in the case of Indian type and wash-down commode type should be at a height of 2 m. (6½ feet) and the flushing pipe 30 mm. (1¼ in.) diam. But if the height is less, 40 mm. (1½ in.) diam. discharge pipe should be used. In the case of siphonic closets pressure head is not important. The service pipe may be either of lead or g. i. 15 mm. (½ in.) in diameter with a copper float, and the overflow pipe also of lead or g. i. 20 mm (¾ in.) diam.

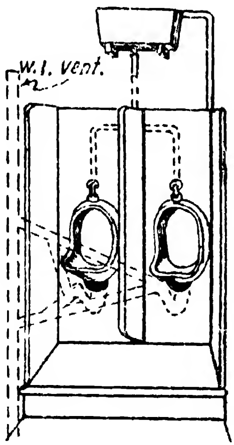


Fig. 83—Bowl type urinal. The traps and anti-siphon pipe are shown in dotted lines.

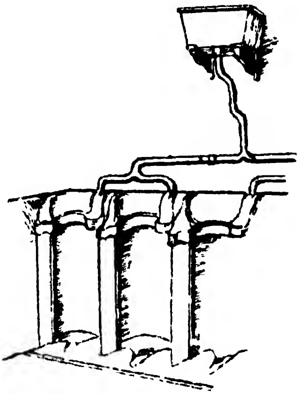
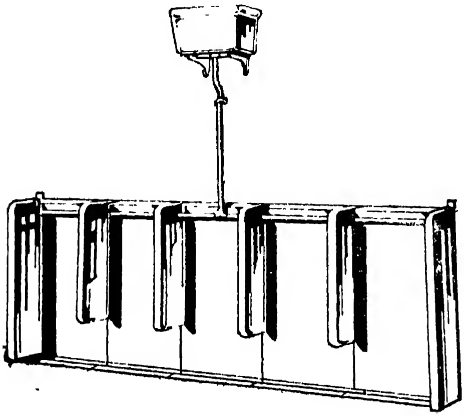
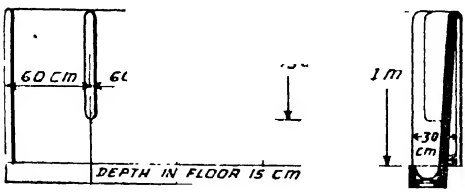


Fig. 84—Channel type range of urinals.

Urinals :—Urinals are usually made of white glazed fire-clay though the future trend is of stainless steel, which would be more useful for rough use. Fire-clay urinals are made in three types : (*a*) The *bowl type*, (Fig. 83) with lipped basin and flushing rim, fixed to wall. These are provided with a hand-operated flush either by a flushing tap or 5 litre (one-gallon) cistern. The bowl urinals have 40 mm. (1½ in.) diam.

rebated outlet in the ware. (*b*) *Slab type*, comprising a flat wall slab with screens or partitions on sides and a floor channel, as shown in Figs. 85, 86 and 87. These are suitable for factories, schools, and public buildings. (*c*) *Channel or*





Figs. 85, 86 & 87—Slab type range of urinals.

Concave Back type with sides in one piece (Fig 84) suitable for hotels, restaurants and offices. When in ranges the average spacing is 60 cm. (2 ft.) per stall, depth 35 cm. (1 ft. 2 in.) and the height of screen above floor level 1 m. (3 ft. 6 in.) The floor should be of impervious material with treads slightly sloping towards the channel. The latter should be covered with a grating of brass or white metal. The outlet of a range of urinals should be 75 mm. (3 in.) c. i. or lead pipe.

Urinals are soil fitments and should be connected to drains and soil pipes *directly.*

Single stall and range urinals built for public use are better flushed by automatic discharging siphons of 4 to 14 litres (one to three gallons) capacity discharging once in 10 to 25 minutes.

Slop Sinks:—As these are likely to be used also for the disposal of urine, they are more allied to water closets and must be treated as soil fittings. It is essential that they should be connected directly to a soil pipe, and not discharge into the open. Slop sinks are usually made of white glazed fire-clay and are provided with a trap and a flushing cistern and are fitted exactly like a water closet with anti-siphonage pipe, etc. Sometimes a grating is provided at the top to intercept all solid matter which is likely to choke the trap. Slop sinks are not in very common use in India.

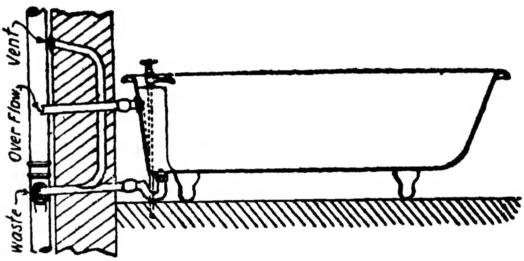
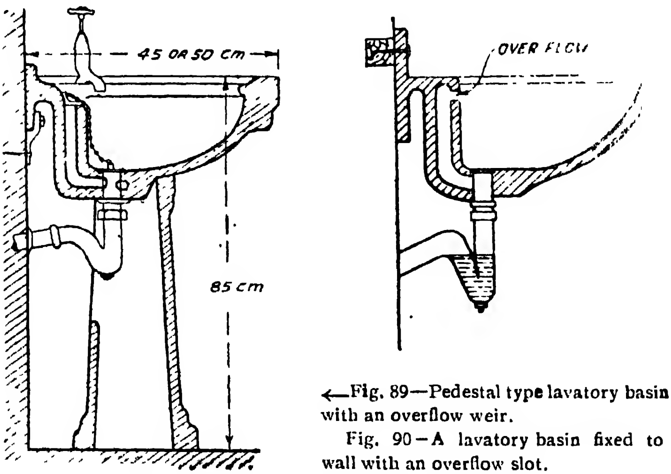


Fig. 88 – Porcelain-enamelled bath fitted with waste, overflow and anti-siphonage pipes.

(2) **Ablution or Waste Water Fittings.—Baths**:—These are made of various materials, such as marble for very high class work, glazed fire-clay for rough usage, as in public baths, and cast iron porcelain enamelled on the inside and white painted on the outside, for domestic use. Vitreous enamelled pressed steel baths are recently available in the market. They are light and still strong. Copper bath is light and strong, and it absorbs less heat from hot water and is thus economical, but is subject to lose its shape by indentations where rough use is involved.

Baths may be either parallel or taper. The latter type is more economical for hot water supply. In the parallel type there are two varieties again viz. rectangular (magna) and tub pattern. The usual dimensions are : length 1·70 or 1·85 m. (5 ft. 6 in. or 6 ft.); overall width : 70 to 75 cm. (28 to 29 in.); depth inside at waste : 43 to 45 cm. (17 to 17½ in.); height overall with feet · for 4 cm. (1½ in.) seal trap : 58 cm. (23 in.) and for 8 cm. (3 in.) seal trap : 60 cm. (24 in.).

The main requirements of a good bath are that it should be quickly filled and emptied and the overflow should be easily accessible for cleaning. For quick filling and emptying the supply pipe should have a minimum diameter of 20 mm. (¾ in.) and the waste pipe 4 to 8 cm. (1½ to 3 in.) Fig. 88 shows a typical bath of porcelain enamelled c. i. standing on 1·2 m. (four feet) fitted with 40 mm. (1½ in.) lead waste with 4 cm. (1½ in.) seal trap, an anti-siphonage pipe and an overflow pipe. Sometimes the overflow and waste are combined in a vertical tube of chromium or nickel-plated metal or vulca-



←Fig. 89—Pedestal type lavatory basin with an overflow weir.

Fig. 90—A lavatory basin fixed to wall with an overflow slot.

nite. The overflow is through the top of the tube which, when raised, opens a valve and allows the water to flow to the waste pipe through a siphon.

Lavatory Basins.—These may be made of either earthenware, fire-clay, stoneware, or vitreous China. The latter are most popular at present, but the latest trends are of designs in plastic and stainless steel. Lavatory basins are available in various shapes and sizes : round, square, oblong, rectangular or circular quadrant—the latter to suit a corner between two walls. They may be of pedestal type, or supported on cantilever brackets fixed to or into walls. The outlet should be a minimum of 30 mm. (1¼ in) pipe with 4 to 8 cm. (1½ to 3 in.) seal trap. For holding water into the basin a rubber or vulcanite round tapering plug, to fit the outlet, secured by a chain and stay, is provided.

The most important part of a lavatory basin is the overflow, which should be easily accessible for cleaning. Some basins are provided with a slot with or without nickel-plated grating inside it, to exclude solid matter, others with a weir overflow. Fig 90 shows a design with a slot, and Fig. 89 a section of a pedestal lavatory basin with a weir overflow with a 8 cm. (3- in) deep seal trap of 30 mm. (1¼ in) waste pipe.

Where space is restricted, as for instance, in a train, or an aeroplane, a tip-up basin is provided. Its one advantage is that it allows emptying the basin very quickly with a good flush.

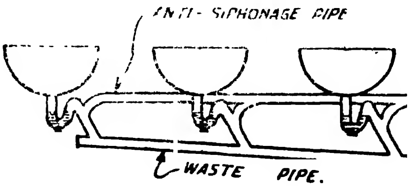
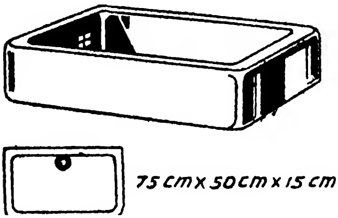


Fig. 91—A range of three lavatory basins. There is a common waste pipe, and also a common anti-siphonage vent pipe.

When several basins are installed in a range, especially on different floors, it is necessary that the waste from each should be taken into a main waste pipe, which should be carried up and ventilated. This waste pipe should discharge into an open gully at the bottom. Each trap is provided (vide Fig. 91) with an anti-siphonage pipe connected to a main ventilating pipe, which should either be carried separately up to 1 m. (3 ft.) above the highest sanitary fitting, or joined to the main waste pipe at that level.

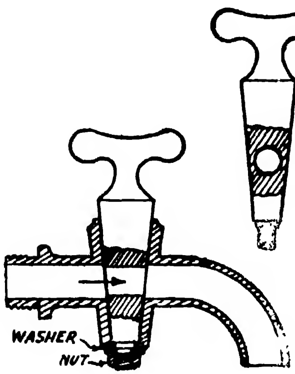
Sinks :—These are rectangular shallow receptacles having a flat bottom with a slight fall towards the waste outlet, with all internal angles rounded for easy cleaning. Those in use at present are mostly of fire-clay white-glazed inside and outside, but recently sinks of monel or stainless steel are available in the market. The latter are being increasingly popular as they are rustless, seamless and without projections and cavities in which dirt might lodge. With such metal sinks, the draining board forms a part made in one piece. The sizes of sinks vary according to the purpose for which they are used. Thus hotel sinks are very large (maximum size 160 cm. × 55 cm. (63 in. × 21 in.), vegetable sinks and butler's sinks are deep 40 cm. (15 in.), washing-up sinks and often kitchen sinks are in two compartments, one deeper than the other, one for washing and the other for rinsing.



Figs. 92, 93 – A perspective view and plan of a fire-clay sink.

The outlet should be provided with a "cob-web" grating of nickel to arrest solids. The waste should be at least 4 cm. (1½ in.) with an anti-D trap fitted with a screw plug for cleaning and should discharge into an open pipe connected at its lower end with a trapped gully so as to be disconnected from the drain. Kitchen sinks are provided with a draining board of wood, asbestos cement, pressed steel, plastics, or stainless steel supported on stirrups cast on the inside. When not required, it can be slipped into flanged runners underneath. The best height of a sink is 85 cm. (2 ft. 10 in.) and that of the draining board top, 90 cm. to 1 m. (3 ft.) above the floor.

Taps and Valves :—The simplest is the plug tap (Fig. 94). It consists of a spindle or plug tapering slightly towards the bottom, passing right through the pipe at right angles to the direction of the flow. It is secured to the pipe at the lower end by means of a washer and a nut. It has a hole or port inside the pipe, so that when the handle is given a quarter turn and made parallel to the pipe, the hole registers with the bore of the pipe and water flows through it, and when the handle assumes a position at right angles to the pipe, the solid part comes across the bore and the flow is stopped. The main disadvantage of this tap is that it closes very suddenly, causing concussion or "water hammer"; which may result often in the bursting of the pipe, if the pressure is high, and further, once it starts leaking, it cannot be repaired.



Figs. 94, 95 – A plug type water tap.

Fig. 96 shows a screw-down bib tap. The sketch is self-explanatory. The disc valve is of a non-corrodible metal alloy with a fibre washer below it, and is pressed down by the

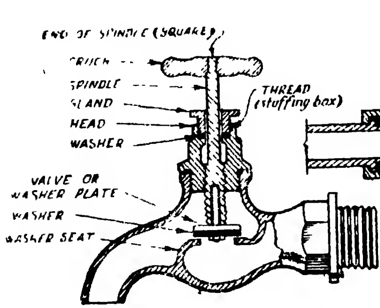


Fig. 96 – A screw-down bib tap.

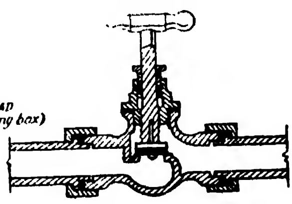


Fig. 97 – A screw-down stop-valve.

screwing motion of the spindle on the seat. Fig. 97 shows a similar device, but it is not a draw-off tap. It functions as a stop valve. Screw-down taps release pressure very slowly and also regulate the flow. If they leak, they can be easily rewashered.

Drinking Fountains:—These are installed in schools, factories and like places to avoid infection from lips of the consumer, a jet of water being projected to the mouth. They are made of white glazed fire-clay and mounted on brackets fixed to a wall. The fountain comprises a small bowl with an upstanding jet and a waste outlet with grating. Beneath the fountain and connected to the jet by a 10 mm. ($\frac{3}{8}$ in.) pipe is a non-concussive, self-closing valve fitted with a regulating screw for adjustment for varying pressures of water. The outlet is trapped and discharges into a gully, or is connected to a waste pipe. The fountain may be operated either by a wheel valve or press-action valve. All jets, valves, unions, etc. should be chromium plated.

The requirements of an efficient fountain are: (1) The orifice from which the jet starts should be so shielded that it should be impossible for the user to touch it with his lips. (2) The jet should be inclined and not vertical. (3) The orifice should project 1·5 cm. ($\frac{1}{2}$ in.) above the top of the bowl, so that contaminated water will not run back into it in case the waste pipe is blocked, and (4) The valve should be capable of adjusting the jet.

Questions

(1) What are the requirements of an efficient w. c. and how far does the standard Indian type basin satisfy them?

(2) Explain with the help of a sketch the working of a bell type flushing tank.

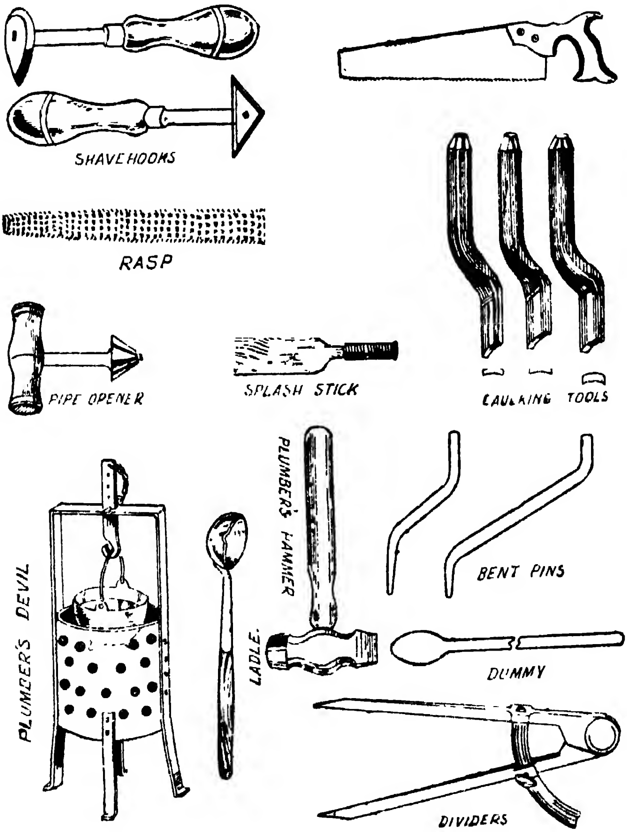
(3) Under what circumstances is an anti-siphonage pipe necessary to a water fitting?

(4) Draw a sketch of a range of two lavatory basins with the necessary fittings.

CHAPTER VII

PLUMBING & JOINTING

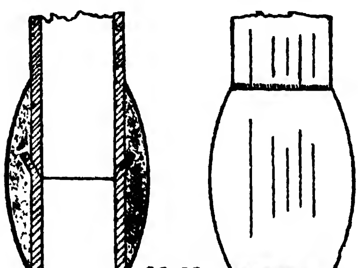
THE word *plumbing*, though it literally means lead-working, is generally interpreted to include also the work such as sheet metal working and jointing of pipes of vitreous clay and all metals and everything in connection with the installation of the various appliances that are employed in the collection and disposal of waste products from building premises.



Figs. 98 to 113 — Plumber's tools.

Plumber's Tools :—Figs. 98 to 113 show important plumber's tools. In addition to these, some of the tools commonly used by a mason, carpenter, and pipe-fitter, such as, a steel square, a plumb bob, auger, screw driver, spirit level, chisels, pliers, trowels, pipe wrench, taps and dies, etc. are required.

Lead pipes are jointed by what is called a *wiped joint*, so called because it is finally finished by wiping the molten lead with a cloth. When the ends of the pipe to be jointed are in a horizontal position, it is called an *underhand* wiped joint and, when they are in a vertical position, it is called an *upright* wiped joint. The process of making a wiped joint is this: The pipes are first straightened, the ends rasped with a file to make them square, and then a socket is formed at one end by opening it out with a turn-pin and a mallet and a spigot on the other end of the other pipe tapered for 5 mm. (¼ in.) by rasping it off to a feather edge so as to fit it about 3 mm. (⅛ in.) into the bell-mouth of the socket. The next operation consists of covering both the ends for a distance of 10 to 25 cm. (4 to 9 in.) with *soil*, or the plumber's black, consisting of a mixture of size, lamp black and powdered chalk. This prevents the solder from adhering to the pipe where it is not required. When the soil has dried, the lengths which are to be occupied by the joint, about an inch or two on each side, are then shaved or scraped clean of the soil with a shave-hook, and tallow applied to the surface so scraped, for a flux. The spigot end is then firmly fixed into the socket, and substantially supported and if it is an underhand joint, a stout brown paper is placed below the joint to pick up the solder, and molten solder is poured with a ladle using a splash stick to fix the solder in place and to prevent splashing.



Figs. 114, 115—Upright wiped solder joint of lead pipes.

The joint is then wiped off by manipulating a wiping cloth or a pad treated with wax or tallow to prevent solder sticking to it, with quick movements of hand till a neat bulbous joint is formed. See Figs. 114, 115.

An upright joint is made in a similar way; only, instead of a brown paper placed below the underhand joint to catch the falling solder, a collar of lead sheet cut to shape to form a sort of a funnel is tied round the pipe a little below the joint, and painted with soil on both sides. It is removed after the joint is made by wiping.

For making a branch joint, a hole of the size of a small coin is first pierced by a pipe-opener on the main pipe, which is then widened by a bent bolt and hammer, forming at the same time a lip on the main pipe. The end of the branch pipe is tapered by a rasp to form a good fit into the lip. The soil is applied and the part going into the joint shaved. The taper is rigidly fixed into the lip and after applying tallow for flux, solder is poured to make a wiped joint. A branch joint is shown in Fig. 115.

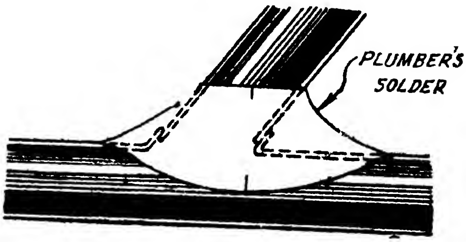
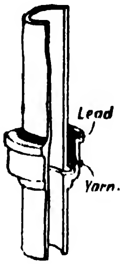
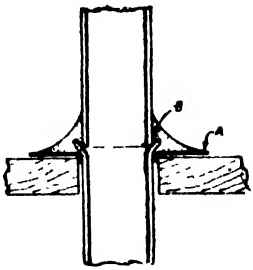


Fig. 116—Wiped branch joint of lead pipes.

Fig. 116 shows another variety of a wiped joint in a lead pipe called a *flange joint* for running lead pipes in a chase or groove inside a wall. The pipe is supported by wooden or stone blocks fixed into the projecting corner of wall at 3 m. (10 ft.) vertical distances. A similar joint made without the block and lead collar, just for lengthening a pipe is called a *taft joint* (Fig. 119). It is not, however, so strong as the upright joint.





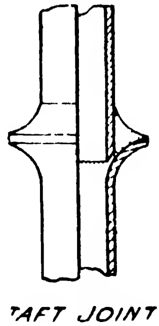


Fig 117 – A joint of c. i. soil pipe with spun yarn and molten lead caulked all round.

Fig. 118 – A flange joint for running a lead pipe in a corner between two walls or a groove, supported on a horizontal piece of wood. *A* – lead washer; *B* – solder.

Fig. 119 – A taft joint, simple, but not strong.

Expansion Joints:—When hot water is discharged through a fitting such as a kitchen sink or a bath, flexible, air- and water-tight joints are required to be made in the pipe at short lengths. Otherwise, distortion is sure to take place. For making such joints the pipe, if long, is first cut into pieces, each not exceeding 1·5 m. (5 ft.) in length, and a socket, 12 cm. (5 in.) long and 2·5 cm. (one in.) larger in

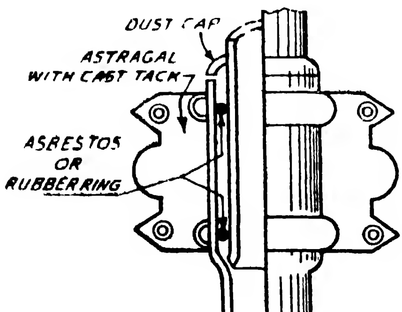


Fig 120 – An expansion joint in lead pipes.

diameter is formed at one of their ends. Then two compression rings made of either asbestos or composite rubber are mounted on the spigot, one at the bottom and the other at about 5 cm. (2 in.) above it. The spigot end is then forced into the socket, when the rings will roll and take up the proper positions as shown in Fig. 120. A dust cap is fitted on the top to exclude dust.

The pipe is then fixed against the wall by means of an astragal with tacks of non-corrodible metal driven into the holes of the latter. An astragal is a round moulding to fit on the socket, with ornamental flat wings on either side with holes, for receiving tacks as shown in the figure.

(2) **Jointing Underground C. I. Drain or Sewer Pipes** :—If molten lead is to be used for making the joint, the pipes must be absolutely dry, or else, the lead may splutter and blow out, and it would be very difficult to set the joint right, once it is spoiled.

The first thing is to cut a length of yarn sufficient to go round the spigot end plus 2·5 cm. (one inch) for overlap, from the bundle of the gasket. It should be wound round the end close to the edge of the socket, and pushed into its bottom by means of a caulking tool with a thin blade end. This should be evenly forced into the annular space of the pipe, and should be repeated several times, so as to fill the joint up to 5 cm. (2 in.) of the pipe.

After this, lead should be kept in a molten state nearby· To enable the lead to run into the space without spilling outside, and to fill the annular space completely, various methods are used : (1) A ring of wet clay is formed on the spigot end and pressed to the edge of the socket end to serve as a stop, with a fairly large hole formed at the top through which the poured lead is to run to the bottom and the sides· After the pouring is completed, the clay is recovered and reused for the next joint.

(2) A patent steel ring with a clamp as shown in Fig. 121 is tightened close to the edge of the socket and molten ead poured from the top.

(3) An asbestos rope with a steel clamp and chain, as shown in Figs. 122, 123 is tightened close to the edge of the socket to guide and prevent molten lead from spilling.

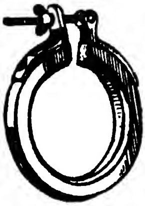


Fig. 121 – Ring type joint runner of metal.

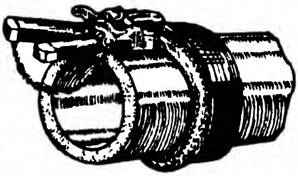


Fig. 122 – Asbestos rope runner in position.

Fig 123 – Asbestos rope runner.

The molten lead must be at a good heat (yet not red hot); otherwise, as soon as it comes in contact with the cold surface of the pipe, it would solidify and block the passage. Sometimes a little powdered resin is sprinkled on the molten lead and the latter shaken. The resin acts as a flux and keeps the lead in a liquid form.

The pouring must be completed in one operation.

After the lead is slightly cooled and hardened, the guiding ring is removed.

Caulking:—Lead shrinks considerably on solidifying. It must therefore be expanded to make a tight joint. Besides, it is likely that some air bubbles might have been left making the joint hollow at places. To prevent air being entrapped in the molten lead, it is necessary for large pipes to leave one or two small holes in the bottom half portion to serve as air vents.

The expansion of the lead and tightening of the joint is effected by means of caulking instruments. A slightly thicker tool is used for this purpose than that for the yarning. Its octagonal end is hammered evenly by holding the flat end on the poured lead all round the pipe. This process of caulking must be skilfully done.

The joint should be finally finished off neatly as shown in Fig. 124. It is simpler to make a vertical joint such as for soil pipes. (See Fig. 132).

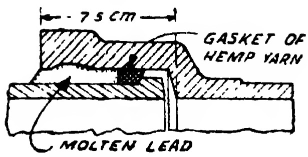


Fig. 124 – Lead joint of C. I. pipes.

A joint with the use of lead wool or lead rope is made in a similar manner, using a gasket of yarn in the first place, and inserting strands of lead wool 6 mm. (quarter inch) thick all round, one at a time and caulking it hard. Lead wool has the advantage that it makes an efficient joint in wet situations or under water where molten lead is out of the question.

For facility of caulking at the bottom, a hollow is made in the bed below each joint sufficiently wide and deep to manipulate the caulking tools with ease.

When a drain passes through a wall, every precaution must be taken so that the drain pipe is quite clear of the superincumbent weight of the wall. The precaution consists of building either a relieving arch or a lintel over the drain, or passing the drain through a larger and stronger piece of c. i. pipe.

On account of difficulties in the manufacture of pipes of large diameter, the annular space between the spigots and sockets is not always concentric. It is therefore necessary to make it as concentric as possible by driving three steel wedges 120° apart round the circumference after inserting the yarn first. If molten lead is to be used, extra yarn must be packed hard before the wedges are removed. If lead wool is to be used, it is easy to take out these wedges safely.

Instead of lead, a mixture of very fine stone dust and hot sulphur in equal proportions, is very commonly used in England. It makes a very satisfactory water-tight joint and has the further advantages that it is light, and does not require caulking.

Asphalt and tar, with or without a filler material like cement or stone dust, mixed hot to make a plastic material, are often used with success. There are also some patent materials like Leadite, Jointite and others which are melted on the job and poured into the joint just like molten lead.

C. i. pipes used for house drainage as soil and waste pipes, are jointed in the same way with a gasket of hemp yarn and molten lead. (See Fig. 117). C. i. rain water pipes are jointed with red lead as they do not carry foul water.

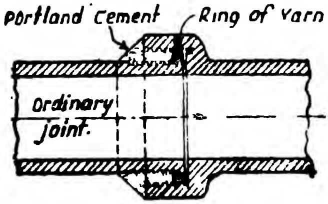
Frequently c. i. pipes require to be cut To do this a line around the pipe where it is to be cut is first marked by means of a piece of chalk or charcoal. Then with a chisel held radially on the line, strokes of moderate strength are given by means of a hammer in quick succession, moving the chisel each time a little all round the pipe. This should be continued until the pieces are separated. A stoneware pipe also can be cut in a similar manner.

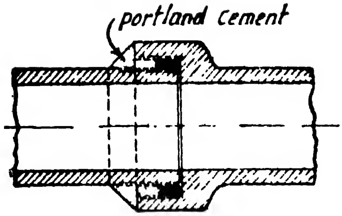
When a pipe is cut to form a shorter length, its spigot end has no bead on it. It cannot, therefore, retain the gasket. To solve the difficulty, a wrought iron ring is heated to expand sufficiently to be driven on to the pipe end. It is then cooled with water and the contraction causes the ring to fit tightly to form a bead.

(3) **Jointing Stoneware Pipes:**—For this a line of stoneware pipes, previously thoroughly cleaned on the inside, is first laid dry with the spigot ends pointing in the direction of the downstream The jointing is started from the lowermost end of the line. The spigot is held centrally in the socket, and a gasket of untwisted yarn of hemp, jute or oakum* thoroughly soaked in a paste of neat cement or bitumen as specified, is thrust or "caulked" all round the spigot with a special caulking tool. Then neat cement, wetted with water to form a plastic ball, is forced into the annular space so as to fill it thoroughly. The joint is then finished off by wiping at an angle of 45° to form a neat fillet. A longitudinal section of

* Oakum is the long, loose fibrous material obtained by untwisting and pulling old ropes.

such a joint is shown in Fig. 125. It is necessary to clean out the inside of the pipe after each joint is made to remove cement, which might have been forced through on the inside. The simple but important matter is very often neglected.





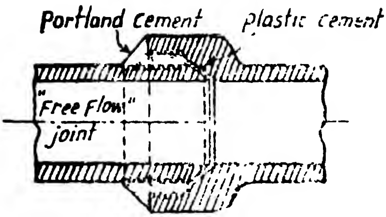


Fig. 125 – Ordinary joint.
Fig. 126 – Stanford joint.
Fig 127 – Knowles free flow joint.

The object of inserting a gasket is threefold :—(*a*) to ensure that the spigot remains concentric in the socket (*b*) to preserve the alignment, and (*c*) to prevent the cement from being forced on the inside, which would cause an obstruction.

The *ordinary joint* described above is very satisfactory and almost universally adopted. However, there are a number of patent joints for stoneware pipes. Amongst them the *Stanford joint*, shown in Fig. 126 with curve-shaped bitumen rings both on the spigot end and in the socket is claimed to give a little flexibility, and is suitable under conditions which would prevent the use of cement. Fig. 127 shows another joint known as the *Knowles free-flow joint*, in which the jointing material is cement, but it requires specially manufactured pipes in which a cup is moulded in the socket, and the spigot end is correspondingly shaped to fit the latter. A patent plastic material is used to paint them before they are put together. The remaining joint in both the above cases is made in the usual way with neat cement.

(4) **Asbestos Cement Pipe** :—The variety of these, commonly used in this country, consists of small diameter pipe with spigot and socket, used in a vertical position for house drainage work. The jointing is done by caulking hemp yarn soaked in cement paste as in stoneware pipes. A typical joint, in half elevation and half vertical section is shown in Fig. 128 It is worth noting that unlike c. i. soil or waste pipes, asbestos cement pipes are not provided with ears. They are therefore fixed to walls by means of some sort of holder-bats pinned or nailed to walls. Figs. 129-134 show a few forms of holder-bats and clips.

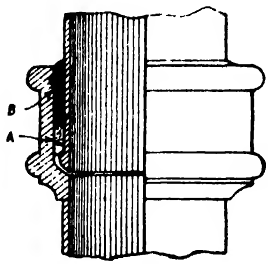
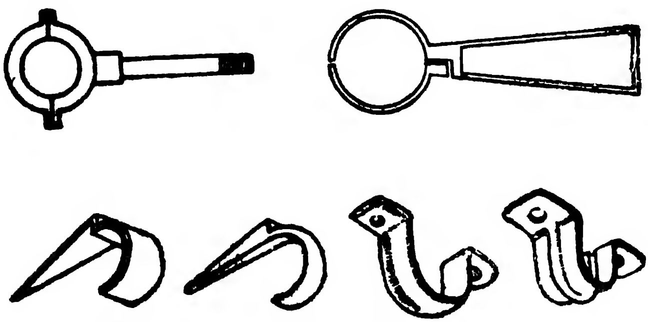


Fig. 128 — Asbestos cement pipe joint. *A*—Hemp of yarn; *B*—Cement.



Figs. 129 to 134 — C I. clips for fixing pipes to walls.

JOINTS BETWEEN PIPES OF DIFFERENT MATERIALS

(5) **Stoneware or Earthenware and Cast Iron** :—Such a joint is required, for instance, between the out-go of an earthenware w. c. trap and a lead or c. i. soil pipe. If it is a c. i. soil pipe the joint is usually made with yarn soaked in cement or bitumen, and cement caulked into the joint. But they often

become too rigid to stand, especially when the floor is resilient like that of timber, or the building is situated near a railway line so that it is subject to vibrations. Provision of a piece of

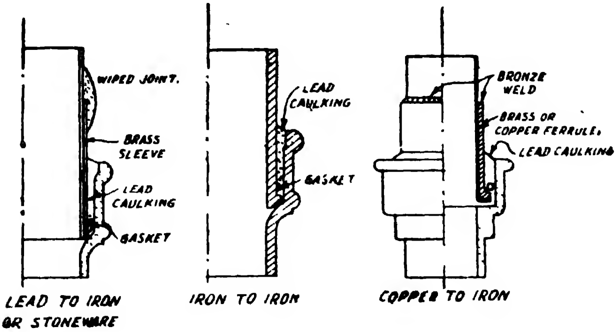


Fig. 135. Fig. 136. Fig. 137.

lead pipe or a lead bend between earthenware spigot and the c. i. pipe makes a very good job. In that case either a socket may be formed on one end of the lead pipe to suit the earthen-

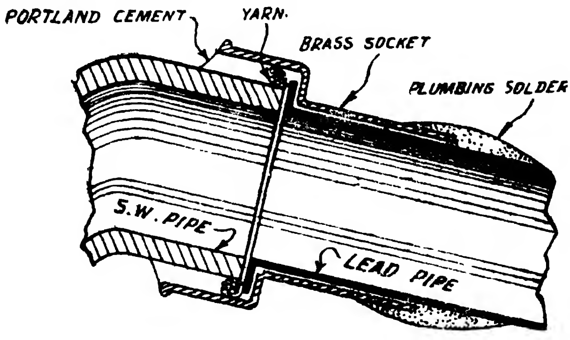


Fig. 138 – A joint between a lead pipe and the out-go of earthenware water closet. A brass ferrule having a socket is introduced to make the joint.

ware spigot and the joint filled with red lead, or better still a brass or copper ferrule having a socket should be fixed as shown in Fig. 138. It will be seen from the figure that the joint between the brass ferrule and the earthenware is made with yarn and cement caulked into it, and that between the ferrule and lead pipe is made with molten lead wiped in the usual manner.

(6) **Joint between C. I. Soil Pipe and Lead Pipe**:—Such a joint occurs at the other end of the lead pipe shown in Fig. 138, which is to be jointed to a c. i. branch of a soil pipe. For this joint also a brass or copper ferrule is required between the lead pipe and c. i. socket and the joint with the latter is made with yarn and caulked lead, as shown in Fig, 139. The joint between the ferrule and the pipe is made as usual with wiped molten solder.

(7) **Joint for Pipes Carrying Hot Water**:—Caulked lead joints of c. i. waste pipes connected to baths, sinks, and lavatory basins through which hot and cold water passes alternately are not successful. For, the coefficients of expansion of lead and c. i. are different. A good plan is to make such joints with cement or red lead. A much better alternative is to use rust cement.*

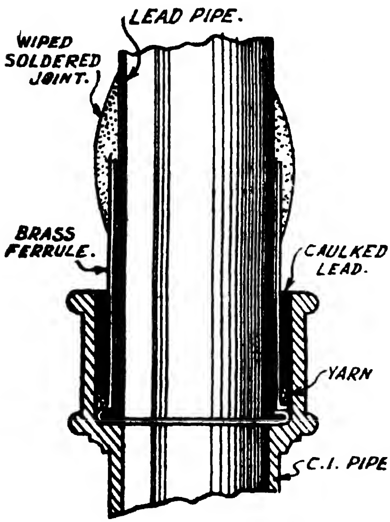


Fig. 139—A joint between a lead pipe and a c. i. soil pipe. A brass ferrule is used to make the joint.

(8) **Copper to Iron Joint**:-Oftentimes nickel-plated light gauge copper pipes are used for wastes from baths, basins and sinks. They are strong, rigid, and light, and generally require no provision for expansion. They are jointed to c. i. pipes with a brass or copper ferrule which is inserted between the copper spigot and c. i. socket. The joint with c. i. is made with yarn and lead caulking, and that between the ferrule and copper pipe is made with bronze weld.

* See page 37.

For easy reference the methods of making different joints are shown below in a tabular form.

TABLE NO. 5

Joint between	Purpose	How made
(1) Lead and Lead	House connection	Plumber's wiped soldered joint.
(2) Stoneware and stoneware	Drain or sewer	Gasket and cement or Sulphur-sand composition.
(3) C. I. and C. I.	– Do –	Gasket and lead (molten or wool) caulking, or sulphur-sand composition.
(4) C. I. and C. I.	Rain water	Red lead or cement.
(5) Asbestos cement and asbestos cement	Soil or waste pipe	Yarn and cement.
(6) Copper and copper	Soil or waste pipe	Bronze weld.
(7) Lead and socketed end of c. i. pipe	House connection	Bronze or brass ferrule caulked with lead into iron socket, and plumber's soldered wiped joint with lead pipe.
(8) Lead pipe and spigot end of c. i. pipe	– Do –	Brass socket and spigot thimble with caulked joint with iron, and plumber's wiped joint with lead pipe.
(9) Copper or iron and stoneware	– Do –	Gasket and cement caulking.
(10) Lead and stoneware pipe	– Do –	Brass socket and spigot thimble with yarn and cement caulked between stoneware spigot and brass socket and plumber's wiped lead joint between brass spigot and lead pipe.

Questions

(1) Describe in detail the process of making an underhand wiped solder joint.

(2) What is the object of using a gasket of yarn in a joint ?

(3) How is a stoneware or c. i. pipe cut ? If a short length of a c. i. pipe is used in making a joint, how is a bead formed on its spigot end ?

(4) Draw a section of a joint of the spigot end of a lead pipe with a socketed end of stoneware pipe.

(5) What is the object of using a brass or copper ferrule ?

(6) Why is an expansion joint in a lead pipe carrying hot water at intervals necessary and how is it made ? Describe by means of a sketch.

(7) What precautions are taken to make large diameter c. i. sewer pipes concentric at joints ?

(8) Why is caulking of poured lead necessary ?

(9) What materials other than paste of neat cement are used in jointing c. i. or lead pipes ?

CHAPTER VIII

HOUSE DRAINAGE

THE AIM of house drainage is to remove all putrescible waste products away from residential premises as fast as possible to a public sewer for final disposal without causing the least nuisance. This is best accomplished by water carriage system. As most of the work connected with this system is underground and expected to function properly with the least attention, nothing must be left undone, in the first instance, while designing and laying the system of drains, to ensure the best results for the preservation of the health of the family and eventually of the community.

General Principles :—For efficient drainage certain fundamental general principles must be observed. These are mentioned below :

(1) **Water-tightness** :—The pipes used must be hard, strong, durable, non-corrodible, impervious and smooth on the inside. All other materials must be smooth and non-absorbent and all joints must be perfectly water-tight.

(2) **Alignment** :—All drains must be laid straight between points of access, both in plan and in section. Because, if there are bends or angles, not only there would be obstruction to the flow, but inspection and cleansing would become very difficult and sometimes impossible.

(3) **Inspection Chamber** :—There should be an inspection chamber of adequate size for facility of inspection and cleaning at every change of either direction or gradient, or at intervals of 100 ft. if the drain is straight and long.

(4) **Size** or **Bore** : – The diameter of the drains should be minimum possible, consistent with maintaining maximum depth of flow to convey the volume. If the diameter is large as compared with the volume, the depth of the flow would be too small to carry floating solids away by momentum. In other words, the velocity would not be self-cleansing. The minimum diameter prescribed for house drains is 100 mm. (4 in.). If it is a large house, the main drain should be 150 mm. (6 in.) and branch drains 100 mm. (4 in.).

(5) **Branches Streamlined in Direction** :—All branches should be so connected that their discharge will help the flow of the main drain. Even a right-angled junction causes obstruction to the flow.

(6) **Branch Drains Short** :—Branch drains should be short, say, not exceeding 7·5 m. (25 ft.) in length. If they are longer, an intercepting trap (vide Fig. 53) which intercepts or disconnects gases and provides an arm for cleaning should be installed at their junction. A long branch necessarily requires a ventilating pipe, because, the surface in contact with sewage inside a long drain pipe is large and the adhesions of foul matter must be continually giving out objectionable gases. If these are not allowed to escape to air at a level high above eaves, there is possibility of their finding an entrance into the house.

(7) **Gradients** :—The fall to be given to the drain should be adequate to ensure self-cleansing velocity, which is obtained in the case of a 10 cm. (4 in.) house drain by giving it a fall of 1 in 40, and for a 15 cm. (6 in.) drain, of 1 in 60. If this is not available, an automatic flushing tank of adequate capacity must be provided at the head of the drain as explained later in this chapter. A gradient very much in excess of the limit given above is also harmful, since an excessive fall would cause a high velocity with the depth of flow reduced to such an extent that floating matter which would touch the bottom would be prevented from being carried away on account of friction, apart from the danger of scouring the inner surface by the sand and gravel in the sewage.

(8) **Trapping** :—All inlets to drain except those provided for ventilation must be trapped with a water seal of sufficient depth.

(9) **Drains to Terminate outside House**:—There should be no entrance to drain inside a building. If a gully is inside, and if it does not receive sufficient water frequently as originally intended, it will lose its seal by evaporation and the foul gases from the drain may escape inside the house.

(10) **Drains under Houses** :—As far as possible a drain should not pass under buildings. Where this cannot be

avoided, special precautions, such as use of a c. i. pipe instead of stoneware, a good fall, and easy means of access for inspection should be provided.

(11) **Waste Pipes to Discharge in the Open Air**:—All waste pipes such as those from baths, basins, and sinks and all rain water pipes must deliver over gullies placed in accessible positions outside, and must on no account, be connected directly to drains.

(12) **Ventilation**:—The entire drainage system should be thoroughly ventilated. This is dealt with further in greater detail in this chapter.

(13) **Disconnection** :—The main drain should be disconnected from the street sewer, and long branches from the main drain. However, there are two contrary opinions on this point. This is discussed in detail later.

(14) **Separate Drain for Rain Water** :—As far as possible there should be a separate drain for rain water.

(15) **Avoiding Roots of Trees** :—A drain should not go near a tree, and any roots of trees met with while excavating a trench for laying drains, should be removed. This is necessary because, trees are always in search of underground water, and if they come across a drain they are likely to thrust their roots into the joints.

Information to be Collected :—For designing a proper drainage system for a house the following information is necessary:–

(1) The diameter and kind of the street sewer. It may be of stoneware, c. i., concrete or brickwork.

(2) Depth of the invert of the sewer below ground surface.

(3) Direction of the flow.

(4) Whether the public drainage system is separate, i. e. it takes care of sewage only, or combined, i. e. admits also the storm and surface water in addition, or partially separate, i. e. carries sewage, plus roof water and surface water from paved yards only, and

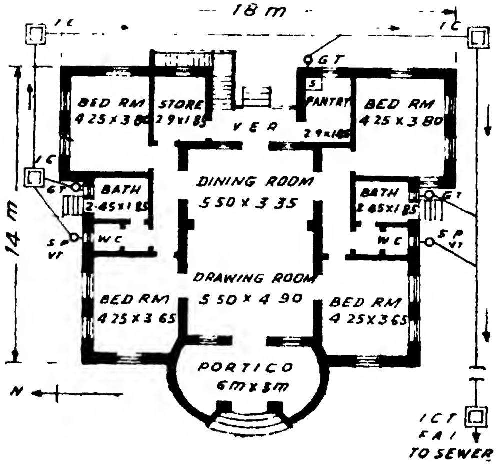
(5) The ground levels from the head of the proposed drainage line to the boundary line where the drain is to join the street sewer and the invert level of the latter. These will

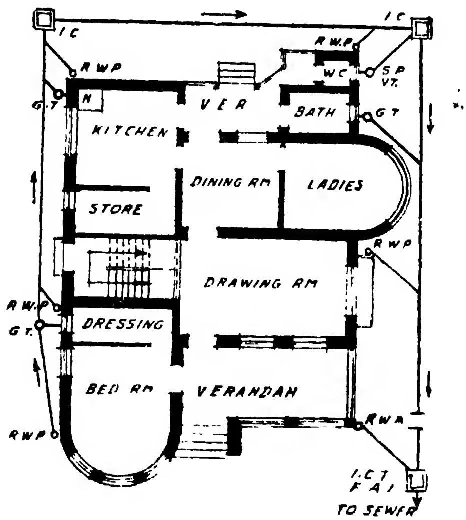
give an idea as to whether the gradient necessary for self-cleansing velocity viz. 1 in 40 for a 10 cm. (4 in.) drain, and 1 in 60 for 15 cm. (6 in.) drain, is available. If not, some other means, such as an automatic flushing tank, must be provided. The ideal conditions, in this respect, are that the main drain, starting from the first inspection chamber at the head, should lie at 45 cm. (1 ft. 6 in.) to 75 cm. (2 ft. 6 in.) below the ground with the fall as above to create self-cleansing velocity. The main requirements are that there should be sufficient bedfall and that the drain should be covered by at least one foot of soil below the ground.

Economical Planning of Drainage System:—After this the plan of the building, on which all the sanitary fittings and rain water pipes are shown, should be studied carefully with a view to designing a scheme on economical lines. Though the drainage system must depend on the nature of the building, and the number and different positions of the sanitary appliances, still it is possible to evolve a number of different drainage plans, from amongst which, the most economical one could be selected. Long surplus lines of pipes, unnecessary gullies and inspection chambers can be avoided by conveniently grouping the sanitary fittings. Bad planning not only increases the cost, but also the cost of maintenance, and provides a number of unsightly pipes about the building.

Figs. 140 and 141 show drainage plans of two buildings based on the principles mentioned above.

Inspection Chamber:—As already mentioned, an inspection chamber is required at every change of direction or gradient. It is also required at 30 m. (100 ft.) intervals, if the drain line is very long and straight, for facility of cleaning. The inspection chamber consists of an underground chamber with 25 cm. (9 in.) brick walls in mortar, plastered with cement on the inside. The floor should be of concrete with a channel of half-round glazed stoneware pipes at bottom and cement plaster above. The channel may be curved in the direction of the flow if there is a change in direction. The floor on the top of the channel is "benched up" or given a steep slope with concrete and finished smooth at surface. The

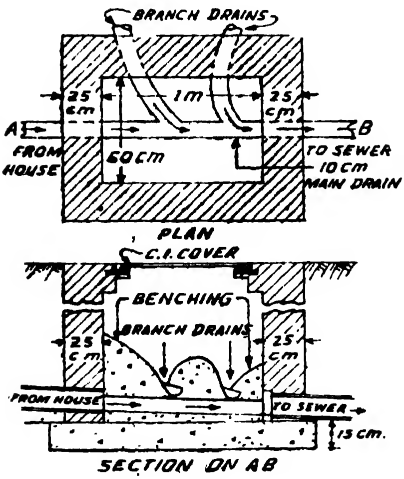




Figs. 140, 141—Plans showing drainage lines. S. P. VT.—Soil pipe ventilated. I. C.—Inspection chamber. G. T.—Gully trap. I. C. T.—Intercepting trap. R. W. P.—Rain water pipe. F. A. I.—Fresh air inlet.

benching is done to prevent solid matter splashed up by the force of the flow depositing on the top. The benching will help in sliding it down into the channel again. The size of the chamber depends upon (1) the depth underground, and (2) the number of branch connections. It should be such as would allow a man to bend at ease and cleanse the main drain or any of the branches which may join at the chamber. For shallow chambers up to 75 cm. (2 ft. 6 in.) deep, a size 60 × 75 cm. (2 ft. by 2 ft. 6 in.) will suffice. In this length one branch could be conveniently accommodated. The length should be increased by 25 cm. (9 in.) for each additional branch. The longer dimension should be in the direction of the main drain line.

A c. i. frame with an air-tight cover should be provided at the top. For air-tightness sometimes the grooves in the frame are filled with grease. Figs. 142, 143 show a plan and a vertical section of a typical inspection chamber with two branches joining the drain. The sketch will show how the open channels at the ends of the branches are curved in order that the discharge from the branches should help the flow of the main drain. The masonry at top is corbelled out to suit the size of the manhole frame and cover.



Figs. 142, 143 – Plan and section of a typical inspection chamber.

At every junction of a branch drain and at every curve there is always some loss of head due to friction. To allow for this an extra fall of 15 to 25 mm. (½ to 1 in.) is given, in the channel at the bottom of every inspection chamber.

Gully Traps :—These are essential parts of a house drainage. They are employed for the reception of waste water from sinks, baths, and lavatory basins. They are also used for receiving water from rain water down-take pipes and also surface water from paved yards and walks. The primary object of a gully trap is to cut off the house from direct communication with the drain, this being effected by a water seal at least 6·5 cm. (2½ in.) deep. There should be a grating of good design on the top to deliver the water rapidly into the gully and at the same time to exclude all solid coarse matter. The gully trap may be of either stoneware or c. i. There are many forms to suit different purposes as shown in Figs. 57 to 71. Some of them provide a back inlet to admit water below the level of the grating, but above the surface of water inside. Gullies should have a flat base and should be firmly bedded in concrete with the top in a perfect level plane. A grease trap (vide Figs. 72. 73) is a variety of a gully. A *nhani trap* (see Figs. 48, 49) is also a form of gully trap specially made shallow to suit the thickness of upper floors, which is usually 10 to 15 cm. (4 to 6 in.) thick. It is usually fixed inside a house, in sinks (*moris*) and Indian type bathrooms.

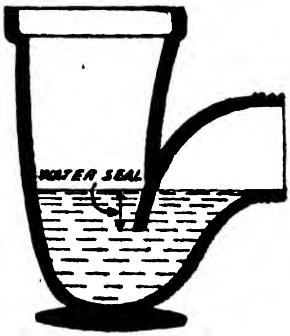


Fig. 144 – A stoneware gully trap.

Ventilation of Drains :—The entire drainage system of a house must be ventilated, or rather flushed with fresh air. The objects of ventilation are (1) To relieve the pressure of foul gases mixed with air accumulating in the drain which otherwise, might force their way into the house by breaking seals of the shallowest trap or traps. (2) To dilute the foul air in the drain to mitigate the evil if it enters the house on account of some defect in the drainage system, and (3) to prevent siphonage as has been already explained.

Ventilation of house drains is best achieved by providing a fresh air inlet at the lower end of drain preferably in the lowermost inspection chamber so that the cold air from the low level which is heavier would enter the drain and push up the air in main drain, soil and waste pipes, which having been made warm by the hot water discharges from baths, etc. becomes lighter and tends to rise. Fig. 145 shows diagrammatically the ventilating system of house drainage. The fresh air inlet is installed in the chamber at the tail end of the drain in

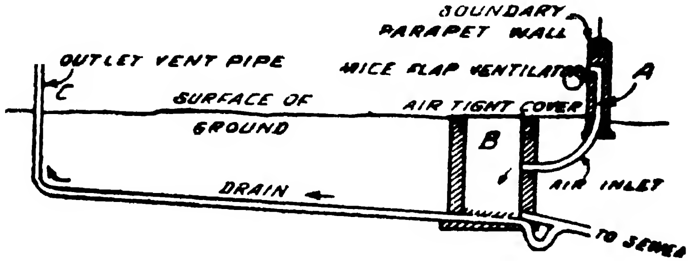
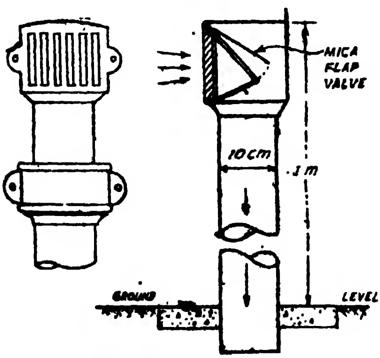


Fig. 145 – Ventilating system of a house drain.

which an intercepting trap also is fixed. The fresh air enters the drain as shown by the arrows and as it becomes warm, rises and finally goes out through the wire domes provided on the top of ventilating pipes above the house top. As shown in enlarged details in Figs. 146, 147 the fresh air inlet pipe should be 10 cm. (4 in.) in diameter and 1 to 1·25 m. (3 to 4 ft.) high above ground fixed vertically in concrete and finished with an enlarged square head at top. On one side of the head there are slits for admitting fresh air through a mica



Figs. 146, 147 – Enlarged elevation and section of a fresh air inlet pipe.

flap valve, so hinged at top that it easily opens inside, but closes with the slightest back pressure of gases from the drain.

Intercepting Trap:—It is also called a disconnecting trap. It has a deeper seal than an ordinary trap, and its special feature is that there is at its top an opening, called "a cleaning eye" or "a rodding arm," for facility of cleaning. Normally this opening is closed with a plug to which a chain is attached so that the plug should not be displaced.

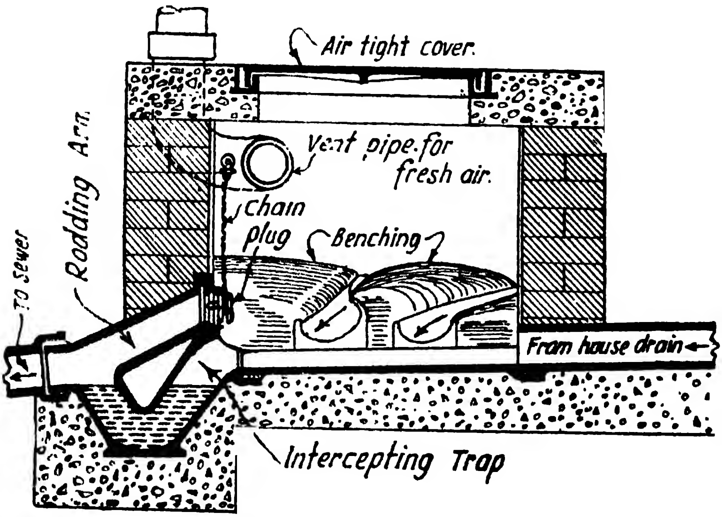


Fig. 148—An inspection chamber of stoneware at the tail end of a house drain, with two branches connected to the drain, an intercepting trap, and a fresh air inlet.

The purpose of an intercepting trap is, as its name suggests, to intercept or disconnect a house drain from the street sewer, and for this purpose it is fixed between the lowest end of the drain and the street sewer.

Sanitary authorities are divided on the utility of this trap. The arguments advanced in its favour are:

(1) If an epidemic like cholera or typhoid breaks out in a part of a district, the main sewer carries the sewage containing the bacteria of the diseases. Unless an intercepting

trap is employed between this sewer and the drain, there is every possibility of the sewer gases finding direct entrance to the house drain and spreading infection.

(2) Normally the street sewer to which all the rubbish from a district is admitted, is likely to be not so self-cleansing as house drains, if the latter are well designed and executed. There is, therefore, greater danger in public sewers of foul matter accumulating and decomposing than in house drains. An interceptor protects a house drain from these gases.

(3) If no interceptor were provided, i. e., if sewer gases were allowed to find a direct entrance to house drains, the vent pipe of the private drainage systems would act as ventilators of public sewers.

The arguments against an interceptor are :

(1) An intercepting trap is never properly flushed out, and that, therefore, foul matter may be deposited in it and become offensive.

(2) It is an unnatural impediment to the unobstructed normal flow.

(3) If the trap is blocked, which is not unusual, the sewage accumulates in the chamber, and this is noticed only when it overflows the top of the chamber causing the entire drain, and perhaps all the gullies on the ground surface to be flooded. There is, no doubt, the cleaning eye provided, but it is submerged under sewage and not easily accessible.

(4) It unnecessarily adds to the cost of drainage of houses.

(5) It is not unusual that the stopper may be fitting loose, or may be altogether missing. In that case, the sewer gases will find direct access to the house drain.

(6) In places where no intercepting traps were used, experience shows that no danger to health has arisen.

(7) The omission of the intercepting trap saves the cost not only to every house-owner, but also to the local authority since sewer ventilators, which have otherwise to be provided at intervals of 1000 ft. or so, at great cost are made unnecessary, as all the house ventilators which are hundreds in num-

ber serve the purpose even better, and all the sewers are literally air-flushed.

If an intercepting trap is to be employed, it should be done at the extreme end of the house drain adjoining the boundary of the premises near the sewer, in a chamber in which branch

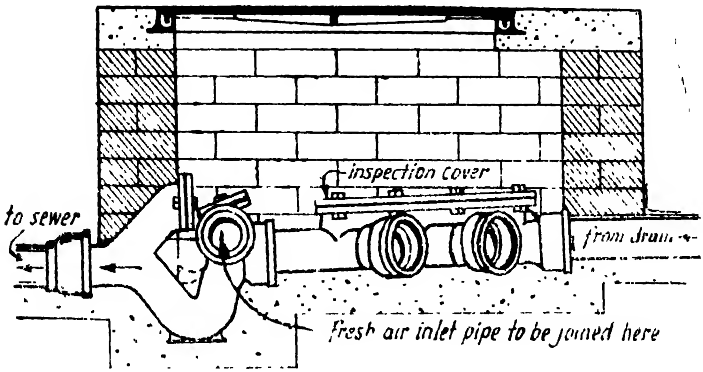
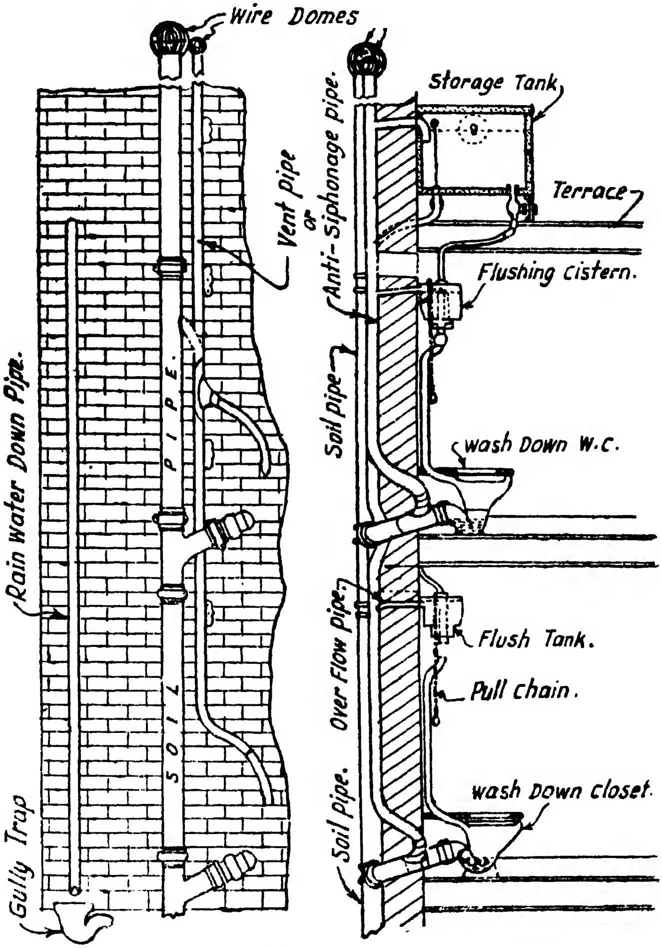


Fig. 149—Longitudinal section of an inspection chamber with all c i fittings including the intercepting trap. Note that everything is closed, including the junctions of the two branches. For inspection and cleaning, the inspection cover must be opened by removing bolts.

drains, if any, may also be joined. The fresh air inlet pipe should also be provided nearby with its mouth left open in one of the walls of this chamber. Fig. 148 shows an intercepting chamber in which an intercepting trap of stoneware is fixed. Advantage is taken of the chamber in connecting two branch drains also in it. The stopper in the rodding arm is held by a chain. The fresh air inlet pipe is also shown. Fig. 149 shows another intercepting chamber in which all the fittings viz. the drain pipe, branch pipes and the intercepting trap are all of c. i. This is why the junctions of the branch drains also are closed, and for facility of cleansing, inspection covers are provided. These are normally fixed to the pipes by bolts. The fresh air inlet pipe is also jointed to the c. i. drain instead of keeping it open in a side wall.

Figs. 150, 151 show an elevation and section of a two-storeyed house in which a soil pipe with water closets, one



Figs. 150, 151.

on each floor, with flushing cisterns and anti-siphonage pipes, and a rain water pipe are shown. The soil pipe is connected to the drain pipe directly, and rain water pipe discharges over a gully connected to the drain.

Fig. 152 shows an elevation of a building in which the w. c. s are arranged in a separate block attached to the main building by a bridged passage. The figure clearly shows the drain underground and the various vent pipes, and waste water pipes. The latter are connected to the drain, each through a gully trap. Only the soil pipe is connected directly to it, in the chamber on the right hand side. An intercepting trap is fixed in the last chamber at the extreme downstream end of the drain on the left hand side. Beyond this the drain joins a street sewer.

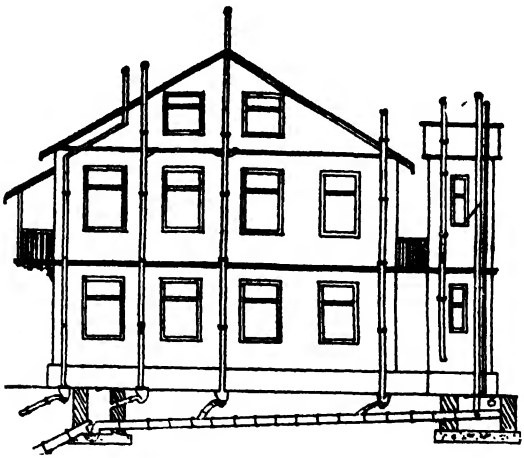


Fig. 152 – Complete house drainage system.

When the bedfall available for a drain is less than the minimum viz. 1 in 40 for a 100 mm. (4 in.) drain and 1 in 60 for a 150 mm. (6 in.) drain, it is necessary that an automatic flushing tank of the necessary capacity as stated later, must be installed to flush the drain every few hours. A simple automatic flushing tank is shown in Fig. 153.

The main tank may be either of brick work if built on the ground, or of steel if supported on wall brackets at a high level. The long vertical pipe is the siphon pipe, the lower end of which dips about 5 to 12 mm. ($\frac{1}{4}$ to $\frac{1}{2}$ in.) into the water in the lower shallow trough called the trapping trough. The water level in the latter is maintained by means of either a hole in the side, or a weir. There is a dome, or a bell, placed on the top of the siphon pipe, the lower end of which is supported by feet on the bottom of the upper tank. When the water fed by the tap at the top rises, that inside the dome also rises, but to a less extent as the air trapped inside the dome is compressed and therefore exerts pressure progressively more and more as the level rises. As soon as the level of water in the dome reaches the lip at the top of the siphon pipe, water falls over it through the highly compressed air, first by a succession of drops, which drive out sufficient quantity of air, causing the level in the dome to rise. This rise increases the overflow and expels a further quantity of air, gradually forming a vacuum and bringing the siphon in full action. The tank is then quickly emptied by atmospheric pressure.

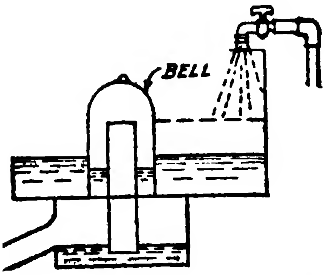


Fig. 153—Automatic flushing tank.

The capacity of the tank depends upon the diameter of the drain and the length of the drain to be flushed. Roughly for a 100 mm. (4 in.) drain 15 m. (50 ft.) long, approximately 140 litres (30 gallons) flush, and for a 150 mm. (6 in.) drain of the same length 275 litres (60 gallons) flush is sufficient. If the length increases, the capacity should be increased in the same proportion. The diameter of the flush pipe should be slightly smaller than that of the drain pipe.

On the other hand, if the bedfall of a drain is excessive, as for instance, when the sewer is at a very low level, if the drain pipe is laid along a straight incline to make the connection with the sewer, the excessive velocity created might scour the material of the pipe, and further the depth of flow would become very small. Under such circumstances a vertical drop is given to the drain pipe inside a manhole before it is connected to the sewer as shown in Fig. 154. Such a manhole is called a *drop manhole*. The vertical pipe in such a manhole is of c. i. with an inspection cap provided at top of the upper bend.

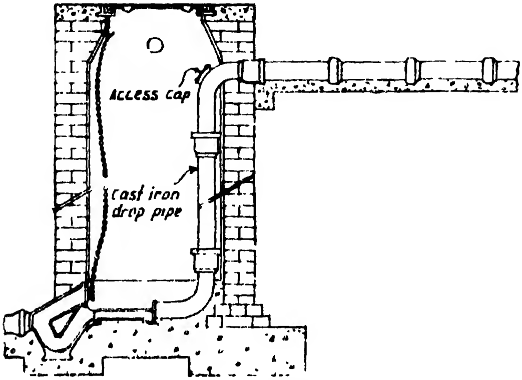


Fig. 154 – A drop manhole. Note the c. i. drop pipe and access cap on the top of the bend. An intercepting trap and fresh air pipe are also installed.

Connecting a House Drain to a Street Sewer:—This is usually done by the Local Authority at the owner's expense. The actual method depends upon several factors, such as the relative levels of the drain and the sewer, the material of which the sewer is made such as stoneware, c. i., brick work, etc. the size and shape of the sewer such as circular, or ovoid, etc. In any case as the sewer is designed to run more than half full, the connection should be made at least at two-thirds of its depth above the invert. If it is connected to a side

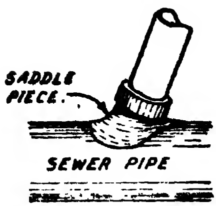


Fig. 155—10 cm. (4 in.) drain connected on the top of a sewer by means of a stoneware Y-saddle.

near the bottom, it is likely that when the sewer runs to its full capacity the sewage may back up and flood the drain, causing heavy deposit of silt which might block the drain. Fig. 155 shows a connection of a 10 cm. (4 in.) stoneware

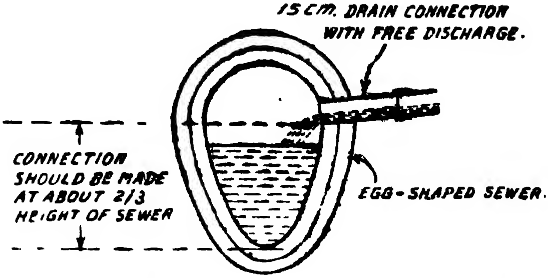


Fig. 156—Connection of a 6 in. drain with an ovoid sewer.

drain pipe on the top of a circular s. w. pipe sewer. First a hole is very carefully made of the requisite size on the top of the sewer, then a stoneware saddle piece is mounted in cement on it obliquely in the direction of the flow, making a water-tight joint, and in the socket of the latter is inserted the spigot end of the drain pipe making the joint as usual by caulking a gasket of hemp in cement. However, this sort of connection is possible only when the sewer is at a considerably low level with respect to the drain.

Fig. 156 shows another connection, in which a 15 cm. (6-in.) s. w. drain is connected to a brick-in-cement egg-shaped sewer. The junction is made at ⅔ depth of the sewer above its invert.

Example 1 :—The data available for the drainage of a certain house are as follows :—

Level of the invert of the 45 cm. (18 in.) public sewer ...	R. L. 20·50 m. (67·50 ft.)
Distance from the head of the drain to the sewer ..	120·00 m. (400·00 ft.)
Diameter of the stoneware drain pipe	100·00 mm. (4·00 in.)
No. of inspection chambers in the length ...	6

(*a*) What should be the minimum R. L. of the invert of the house drain at its head ?

(*b*) If the reduced level of the ground surface at the head of the drain is 25·90 m. (85·00 ft.) what bed-fall would you allow ?

Solution :—(*a*) As the drain is of 100 mm. (4 in.) diam. a minimum bedfall of 1 in 40 is required. In the distance of 120 m. (400 ft.) it would be $\frac{120}{40}$ = 3·0 m. ($\frac{400}{40}$ = 10 ft.) ...(1)

There are six inspection chambers. An extra fall* of 2·5 cm. (1 in.) should be allowed in each to overcome frictional loss due to bends, etc. i. e. 15 cm. (0·50 ft.) ...(2)

The connection of the house drain to the sewer must be made at the top of the latter, i. e. at 45 cm. (18 in.) plus 4 cm. (1½ in.) thickness of pipe i. e. at 49 cm. (1·62 ft.) above invert level ... ...(3)

There should be a cover of minimum 30 cm. (1 ft.) of earth over the drain for its protection. Earth cover = 30 cm. (1·0 ft.) ... ...(4)

(1) + (2) + (3) + (4) = 3·00 + 0·15 + 0·49 + 0·30 = 3·94 m. (10·00 + 0·50 + 1·62 + 1·00 = 13·12 ft.). The ground surface at the head of the drain must be at least 3·94 m. (13·12 ft.) above the sewer invert level i. e. at R. L. 20·50 + 3·94 = 24·44 m. (67·50 + 13·12 = 80·62 ft.)

(*b*) If this level is R. L. 25·90 m. (85·00 ft.) we have 1·46 m. (4·38 ft.) of extra head which can be best utilised thus : about 30 cm. (1 ft.) in increasing the earth cover, and the remaining 1·16 m. (3·38 ft.) in increasing the bedfall, which would then be 4·16 m. (13·38 ft.) in 120 m. (400 ft.) or 1 in 30.

Example 2 :—A 150 mm. (6 in.) house drain is 90 m. (300 ft.) long with 5 inspection chambers on its way. It is to be connected to an ovoid brick sewer at 75 cm. (2·5 ft.) above its invert level, which is R. L. 30·00 m. (100·00 ft.). What will you do if (1) the surface of the ground at the head of the drain is at R. L. 32·50 m. (107·00 ft.) and (2) if it is 35·00 m. (120·00 ft.).

---

* At least 15 mm. (½ in.) per bend is required,

Solution :—We need the following minimum heads :

(1) Head for drain connection above sewer invert ... ...0·75 m. (2·50 ft.)

(2) For frictional losses at 5 chambers...0·13 m. (0·42 ft.)

(3) For earth cover on top of drain ...0·30 m. (1·00 ft.)

Total ...1·18 m. (3·92 ft.)

This leaves only 1·32 m. (3·08 ft.) of head out of the total of 2·5 m. (7 ft.). For 150 mm. (6-in.) drain, the minimum fall prescribed is 1 in 60, or 1·5 m. (5 ft.) in 90 m. (300 ft.) distance. As the fall available is inadequate, an automatic flushing tank of adequate capacity as shown in Fig. 153 must be installed at the head of the drain.

(2) From the above calculations we want a minimum head of 1·18+1·50=2·68 m. (3·92+5·00=say, 9 ft.). But the head available is 5 m. (20 ft.). At the most we can utilise 30 to 50 cm. (1 or 2 ft.) more by excavating a deeper trench and about 40 to 50 cm. (1·5 or 2 ft.) in increasing the bedfall. A greater bedfall would increase the velocity and reduce the depth of flow, which is not desirable. We must therefore adopt some such device as shown in Fig. 154 to utilise the extra head.

Indian Standards for Public Sanitary Conveniences :—The following are the standards adopted which are collected from the Indian Factories Act and various other Government Resolutions .—

Factory : –

Number of Operatives	Privy Seats	Urinals
Up to 20	1	One for every
20 to 35	2	100 or fraction
35 to 50	3	of 100.
50 to 150	4	

For every additional 50 or a fraction of 50, one more.

Those for females should be quite separate from those for males, and marked distinctly in vernacular "For Women Only."

Schools :—

Number of Pupils	Privy Seats Boys	Privy Seats Girls
Up to 30	1	2
30 to 50	2	3
50 to 70	2	4
70 to 100	3	5

Above this provide one seat for every 50 boys and two seats for every 50 girls In addition, urinals, at 4 per cent should be provided for boys only.

Residential Houses :—There is no hard and fast rule, but calculations are made at one seat for every 10 members or less including children.

Cinema Theatres :—One privy for every 400 seats and one urinal for every 200 seats.

Theatres :—One privy and one urinal for every 200 seats.

These should be separate for males and females, distinctly marked to that effect either by a picture or letters in vernacular.

Amongst poorer classes, particularly in mill districts, docks and in localities where daily labourers reside, the number of latrines in private houses is insufficient to cope with the rush in early morning hours. It is therefore necessary to provide a few public latrines. On an average 20 seats per 1000 population should be provided. Otherwise fouling of road sides in the neighbourhood of latrines and urinals is sure to take place.

Besides, at certain public places, such as markets, tram termini, railway and public bus stations, etc., public latrines and urinals must be provided.

Questions

(1) Why is it necessary that drains should terminate outside a house and not inside? Why should soil fittings be directly connected to drains and why should waste water fittings discharge on top of gully traps?

(2) Why should branch drains be short?

(3) Discuss the arguments in favour and against the provision of an intercepting trap.

(4) Draw a neat sketch of a typical ventilating system of a house drainage showing fresh air inlet.

(5) The R. L. of the invert of an ovoid brick sewer 1500 mm. (5 ft.) diam. is 25·00 m. (75·00 ft). The R. L. of ground surface near the head of the drain is 30·00 m. (90·00). The length of the 100 mm. (4-in.) drain is 120 m. (375 ft.) on which there are six inspection chambers. Design the gradient.

(6) When is a flushing tank required? Draw its section so illustrate the working principles.

CHAPTER IX

INSPECTION OF HOUSE DRAINAGE

THE inspection of drainage system of a house may be either of a new house by local sanitary authorities for a certificate prior to occupation, or of old established system for improvement, or checking for removal of existing defects. In either case the following hints will be found useful :—

(1) First inspect the premises by going round the house, and verify from the drainage plan of the house, the positions of all drains, their branches, and soil and waste sanitary fittings. If, in the case of an old house a plan is not available, go round and also inside the house if necessary, and draw a rough sketch plan, showing soil and waste fittings, with the gullies of the latter and also of rain water pipes. The inspection chambers on the drain and branch pipes and the gullies should be numbered in serial order.

(2) After this check the following :—

(*a*) Do all the waste and rain water pipes discharge on tops of gully traps outside the house ?

(*b*) Is there any waste pipe directly connected to the drain ?

(*c*) Is there any gully trap inside the house ?

(*d*) Is there any inspection chamber inside the house? If so, is it provided with a double seal air-tight cover ?

In the case of old established drainage system the following additional checks should be made :—

(*e*) Is the intercepting trap clear of any obstruction ? Is there a stopper firmly fixed in the eye for cleaning of the drain ?

(*f*) Open the covers of all the inspection chambers and gullies, then open the taps in the house and see that the waste pipes are clear and discharge an unobstructed flow into the gullies. After this pour water into the chamber at the head of the drain or a branch and verify section by section between two successive chambers that the drain flows with full force.

(*g*) Is there any evidence of damp? The places where to check it are the following:—(*i*) In walls in front and sides of sinks and *moris*, (masonry sinks at floor level). (*ii*) In the surface of ground floor due to ground water rising by capillary action. (*iii*) In ceilings due to leaks in joints in bath rooms, w. c. s., *moris*, etc. on the upper floors, (*iv*) Top of walls as evidenced by stained patches due to leaky terrace or valley gutters in roofs, or leaks in tiled roof.

(3) After this examine carefully every sanitary fitting and check the questions listed below against each:—

(i) **Water Closets**:—

(*a*) Is it well lighted?

(*b*) Is it disconnected from living rooms by means of a lobby, though small?

(*c*) Is its floor impervious with water-tight joints if tiled, and no cracks if of concrete?

(*d*) Does the flush work well? It should be of a 3-gallon tank with a chain pull. If of wheel valve or tap on a pipe connected to the overhead tank at roof level, it is not satisfactory.

(*e*) Is the w. c. basin cracked? Is it much incrusted?

(*f*) Is there any foul odour?

(*g*) Is the overhead tank supplying the water to w. c. s separated from the tank supplying water for other domestic needs?

(*h*) Is there an anti-siphonage pipe provided and connected properly to the vent pipe?

(ii) **Lavatory Basins**:—

(*a*) Is there a lead trap provided with a screw plug for cleaning?

(*b*) Does the waste pipe discharge on the top of a gully outside the house?

(*c*) Is it well ventilated with an anti-siphonage pipe joined to a vent pipe?

(iii) 'Nhanis' in Kitchen; and 'Moris' in Bath and Other Rooms:—

(*a*) Is it 60×60 cm. (2 ft.×2 ft.) minimum? Is it occasionally used for bathing?

(*b*) Are the walls adjacent to it soaked with water on account of absence of impervious surface lining either of tiles or at least of cement plaster?

(*c*) Is there a *nhani* trap fixed, with the floor sloping towards it? Is its grating intact?

(*d*) Is the bend connected to it on the outside provided with an inspection eye (Plug-bend)?

(*e*) Is the bath room used also as a urinal? If so has it got a trap with a deeper seal?

(*f*) Is the room well lighted and ventilated?

(iv) Urinal:—

(*a*) Is it either of fireclay or glazed china?

(*b*) Has it a lead trap with a deep seal and cleansing arrangement?

(*c*) Is there an adequate flushing arrangement?

(*d*) Is it connected directly to the drain pipe?

(*e*) Has it an anti-siphonage pipe?

(v) European Bath Tub:—

(*a*) Is it of fireclay or of metal enamelled?

(*b*) Are there three separate pipes—(1) a waste pipe at the bottom of the tub provided with a trap, and an anti-siphonage pipe, discharging on the top of a gully on the outside? (2) an overflow pipe near the top connected to the waste pipe *above* the trap and also discharging on top of the gully, and (3) a floor waste pipe in the bath room provided with a *nhani* trap?

(*c*) Is the waste pipe of minimum 50 mm. (2 in.) diam.? Is it provided with a bend having a cleaning eye?

(4) After this test the main drain, branches, soil, waste, and ventilating pipes as described in detail below :—

Testing of Drains :—When a drain is newly laid, before it is covered by filling the trench, the local sanitary authority may test it in the course of inspection of the drainage before issuing a permit. There are a number of tests such as, olfactory or smell test, smoke test, hydraulic test, etc.; but out of these hydraulic test is the best and most usually applied.

In the *olfactory* or *smell test* about an ounce of any pungent chemical such as oil of peppermint, is poured into the highest w. c., followed by a bucket of hot water. The person who does it should close the room and remain inside, till the test is completed Otherwise, he may carry the smell with him outside and spoil the whole test. If there is any leakage, it will make itself evident inside the house or along the drain or soil pipe by the smell.

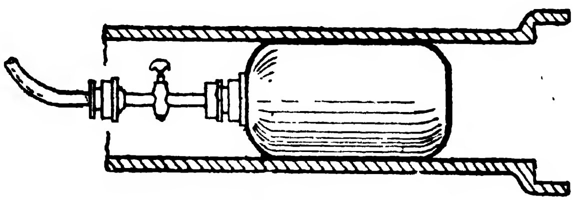


Fig. 157—A rubber bag with a cover of canvas.

This is not a positive test and is not well suited to an underground drain which has been already covered up.

To apply the *hydraulic test* the drain requires to be securely plugged at its lower end. There are two sorts of plugs in common use. The simplest type of a drain plug is a cylindrical bag of rubber inside another of canvas. To the inner bag a rubber tube is attached with a tap valve at one of its ends as shown in Fig. 157. The empty bag is placed in position at the lower end inside the drain, and after opening the tap, air is pumped into it by a cycle pump so as to inflate it. It then resembles an elongated football, and exerts a pressure all round the pipe to dam it and prevent any leakage of water from it. The drain is then filled with water by turning on the taps in the house which finally discharge into the drain. In order to increase the hydraulic pressure still further, very often the other type of drain plug is fitted into the pipe in the inspection chamber at the head of the drain or at the head of the section to be tested, if the drain is very long.

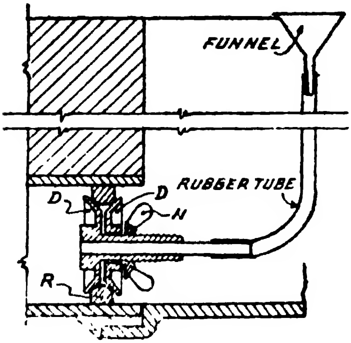


Fig. 158

The other type of drain plug consists of two metal discs, *DD*, mounted on a hollow tubular axle. The discs hold a rubber ring *R*, between them near the rim. The rubber ring has a diameter slightly less than that of the drain. There is a wing nut *N*, screwed on to the axle, which when turned, presses the discs close together; and this causes the rubber ring to expand, so that the plug fits tightly into the drain. To the hollow tubular axle is attached a rubber tube about 3 to 4 ft. long with a funnel inserted into its other end. The funnel is raised and kept in a vertical position, and water poured into it up to the top. If the level does not sink down appreciably within two hours, the drain is sound. If it sinks, all the successive joints should be examined to trace the leakage.

This is rather a severe test and most drains do not stand it unless some reasonable allowance is made.

In making the smoke test, smoke is pumped by a special smoke machine through the tube of a drain plug like that shown in Fig. 158 above, at the lower end of the drain. The upper end is plugged by a canvas and rubber plug. When sufficient smoke is pumped so as to exert some pressure, the joints should be examined. Leakages, if any, will be evident by the appearance of smoke through the joints.

Smoke test is particularly suitable for testing soil, and vent pipes. Smoke is first pumped into the system of pipes until it rises freely through the tops. The latter, if satisfactory, shows that there is no blockage. Then the top ends of the vent pipes and anti-siphonage pipes are lightly plugged with wet cloth, and smoke is pumped again slowly so as to maintain some pressure. However, care should be taken that this pressure does not blow the seals of traps. If there are any defective joints, smoke will ooze out through them.

Sometimes special smoke rockets in the form of fire-works which produce large quantities of smoke are used. A long string is tied to one of their ends for facility of withdrawal when the test is completed. The paper pasted on their top is lighted and while they are still smouldering, they are placed in the drain pipe.

Questions

(1) What checks will you apply to find that a w.c. installation is in order from a sanitary point of view ?

(2) Why is it necessary that the overflow pipe of a bath tub must be connected to the waste pipe above the trap and not below it ?

(3) How is hydraulic test applied to drains ? Show by means of a sketch.

(4) Why is smoke test suitable for testing soil and vent pipes ?

CHAPTER X

DRAINAGE OF SMALL AND MEDIUM TOWNS

THE most important part of the work, which a sanitary engineer is called upon to do in connection with the drainage of small and medium towns which cannot be sewered, mostly for want of funds, consists of the efficient collection, removal, and disposal of:

(1) Night soil from privies on the conservancy system.

(2) Sullage, i. e. all liquid waste from houses, including urine and ablution water from privies.

(3) All refuse solid matter which constitutes the contents of a dust bin, and

(4) All rain water which flows off the ground surface in the neighbourhood of a town, called *storm water*. If this is not removed away from the town, it would not only form ponds, breeding mosquitoes, but the land will be water-logged with water containing putrefactive matter.

Conservancy System:—In this the night soil from house privies is collected in pails and carried on head by sweepers to central depots, from where it is transported in bullock carts or motor vans to a place away from the town for final disposal. The liquid and semi-liquid mass of filth which frequently overflows the receptacles in privies is swept away by the sweepers to drain from the privies, which carry it to drains along public lanes or streets.

This system, even though carried out on strictly sanitary principles is fundamentally wrong for the following reasons :

(*a*) Even though the night soil is removed from house privies, the urine and ablution water must either soak into the ground, or discharge into the open drains. The presence of decomposing matter close to houses, attracting flies, is a serious danger to health apart from the constant foul smell and pollution of air. Besides, cleaning privies, emptying baskets, carrying sewage in carts through streets, etc., which give out foul smell cannot be avoided.

(*b*) The essence of practical sanitation is the *immediate* removal of all putrescible matter from human habitations, but in this system it is not practicable to remove the night soil more than once in 24 hours at the most, unless at a prohibitive cost.

(*c*) To leave the most vital question of public health to the mercy of the sweeper, who does not appreciate the first principles of sanitation, involves great risk. He often makes unreasonable demands, and if they are not satisfied, goes on strike, throwing the health of the entire town in jeopardy.

(*d*) There is, again, a social aspect to the subject. Why should a class of fellow human beings be subjected to do this filthy work all their life, and be damned for it as unclean and untouchable? It is a shame to civilization. It is only in this country on the earth's surface that these people as a class are employed to do this work.

(*e*) Lastly, one who has examined the budget of any municipality will tell how expensive it is to maintain the necessary establishment, and still, the result is most disappointing.

The only satisfactory system is the water carriage system in which the ideal of *immediate* removal of fæcal matter without manual labour is accomplished. But it is very expensive. In the first place there must be ample piped water supply under sufficient pressure for which funds are required. Then the laying of underground system of drains and sewers with sufficient number of inspection chambers, manholes, ventilators, flushing tanks, etc., and the disposal works at the outfall, and in addition, the maintenance of all these from year to year costs a further good deal. In the absence of these funds, the conservancy system for removing night soil, and surface drains for removing sullage and storm water are the only solutions to be accepted as a compromise.

The Privy:—The requirements of a good privy are :

(1) It should be away from buildings on the leeward side.

(2) The floor of the basket, walls at least 4 ft. above the floor on the inside, and the platform of seat, should be of impervious material.

(3) It should be well lighted and ventilated.

(4) The receptacle to collect the excreta should be of sufficient capacity to hold at least 24 hours' excreta, urine and ablution water.

(5) The whole thing should remain closely covered so as to exclude flies.

(6) There should be facilities of removal of both the solid and liquid contents at least once in 24 hours.

(7) As far as possible, the contents should not be visible to the user.

(8) The solids should remain separate from the liquid as far as possible, since water causes putrefaction to set early in night soil.

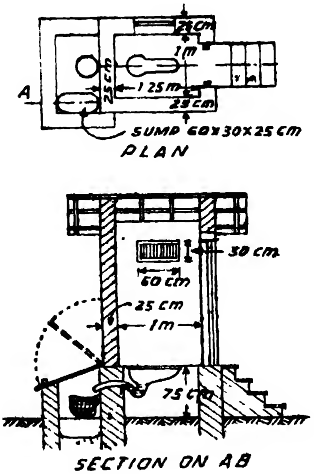
(9) The cost should be within easy reach of the poor house-owner.

There are a number of different types of privies enforced by different municipalities. But most of them are not entirely satisfactory. The one suggested by the writer in his book *Cheap and Healthy Homes for the Middle Classes* does not materially differ from the average, but it has got certain features which make it highly useful. It is shown in Figs. 159 and 160. Its outstanding features are:

(1) A stoneware closet basin just below the seat. It is glazed on the inside. (White glazed would be still better, but is more costly). It has a trap. This sort of closet is available in the market. Its bottom is sloped at a greater angle than that of the usual closet pans, and hence the contents easily slide down and fall into the water in the trap. The ablution

water further pushes them out into the basket placed in the adjoining chamber. The trap prevents the gases from entering the privy and the basket is hidden from view. Those who cannot afford to buy this basin with a trap, may fix a 150 mm. (6-in.) half-round stoneware glazed pipe in a steeply inclined position. This is the next best arrangement.

(2) The next feature is the brick-in-lime chamber, on the rear, cement plastered on the inside, and at one of its ends is a sump or pit also cement-lined, 60 × 30 × 25 cm. (2 ft. × 1 ft. × 9 in.) with rounded corners. The floor is sloping towards this sump. The chamber has a cover of g. i. sheet hinged at the plinth. The basket may be of metal with perforated bottom resting about 2·50cm. (1 in) above the floor on feet. Instead of perforations a layer of coke breeze or porous earth or sand would cause the water from the excreta to filter to the floor and would cause the fæces to be cleanly removed while emptying the basket. But it would add to the bulk, and a constant supply of this material would be a problem. The sweeper has to lift the lid, empty the basket into his pail, scavenge the floor, fill the liquid contents of the sump also into his pail, and replace the lid before he moves to the next house.



Figs. 159, 160.

The efficiency of this privy lies in the following facts :

(1) As the chamber is always covered, there is no chance of flies sitting on the filth.

(2) The solid contents are separated from the liquids from the beginning, and thus would not start putrefying early and would make the cleaning also easy.

(3) The whole thing remains hidden from view.

Occasionally a coat of coal tar or still better, of pesterine should be applied to the cover and the inside of the chamber.

The *collection of night soil* is made by the sweeper. He is expected to do 8 trips of about 800 m. (½ mile) each, from the houses to the car depot, carrying 20 kg. (40 lbs.) of night soil each time.

In suburbs the houses are scattered, and daily scavenging may not be practicable. In that case the house-owners should be required to build cess-pools of adequate capacity with a close-fitting lid, away from the building, in which all the solid and liquid contents of the privy are collected, to be removed in municipal cars once in two or three days.

Disposal of Night Soil:—The night soil may be disposed of in one of the following ways :—

(1) Dumping into the sea or a river.

(2) Burning in an incinerator.

(3) Trenching into (*a*) Shallow trenches, (*b*) Deep trenches.

(4) Composting.

(1) **Dumping into the Sea or River** :—If it is the sea, it must be done at such places that the excreta will not be washed back ashore during tides. In the case of a river the flow, even during the summer, must be sufficiently large so as to dilute the sewage sufficiently, and purify it within a short time by the natural agencies such as sedimentation, sun light, wind, dissolved oxygen, and a few aquatic flora and fauna. However, this must be vigilantly watched from time to time as there are bound to be a large number of people and cattle slightly downstream, drinking the water.

(2) **Incineration** :—This is a very costly, and still, unsatisfactory method, if not carried out on strict sanitary principles. In the first place, to reduce the cost, the solid excreta must be separated from the liquid, for which the excreta must be collected while yet fresh. For, once the sewage starts putrefying it tends to become liquid. Secondly, plenty of dry

combustible refuse must be available for burning. This presents a great difficulty, especially in the rainy season. Thirdly, strictest supervision is required for burning the night soil. Otherwise, foul odour becomes a great nuisance.

(3) **Trenching**.—This is found by experience to be the most economical and also very satisfactory method for Indian conditions, if conducted on proper sanitary principles. The prime need is of sufficiently large area of arable land containing loamy soil, and that it should be situated on the leeward side of the town, and not far from it. Further, there should not be any wells in the surrounding area, as they are likely to be contaminated. If there be any, they should be acquired and either closed, or if they are close to the trenching ground they may be utilised, as a large quantity of water is required for washing carts, tools and receptacles.

There are two methods of trenching :—(*a*) Shallow trenching, and (*b*) Deep trenching.

(*a*) **Shallow Trenching**:—This is definitely more efficient, provided there is sufficient land of the proper type available at a reasonable rate. The area of land required may be calculated from the following figures if the present population is known, and the prospective population is calculated from it :–

The daily average excreta of people of this country living on mixed diet (mostly vegetarian) is 1 kg. (2 lbs.) per adult, and ½ kg. (1 lb.) per child. On an average, it may be taken as 1·25 kg. (2½ lbs.) per head of mixed population, including urine and ablution water. If all the liquid including urine is separated, the above figures are 115 and 55 gm. (4 and 2 ounces) per adult and a child respectively, with an average of 85 gm. (3 ounces), besides about 0·85 kg. (30 ounces of liquids). Solid fæces weigh 4 kg. (8¾ lbs) and those mixed with liquids, 1 kg./litre (9½ lbs. per gallon). The capacity of the trenches should be roughly 50 per cent in excess of the volume of the night soil to be treated, provided the land is of suitable type. From this the area of land can be calculated.

The land is divided into three plots, each plot being capable of dealing with the night soil of the whole year, so that, while one plot is being used for the trenches the remaining two will be under cultivation, and the plot on which crops have been raised for two successive years will be ready for trenching again during the third year. The trenches should be parallel to each other, and the road serving them should be so placed that carts can be tipped easily into any one of the trenches.

The length of the trench is governed by the shape of the land. There is no restriction on the length. If the quantity of the daily night soil is small, the width should not be too large. Generally a width of 1 to 1·5 m. (3 to 5 ft.) is sufficient. The depth should not exceed 45 cm. (18 in.) in any case. If the soil is of a stiff, clayey nature, the depth should not exceed 25 cm. (9 in.). The micro-organisms which render the night soil harmless, live in the porous layer of the top soil, and therefore, the looser it is, the more satisfactorily they do their work. The distance apart between the edges of the trenches should be a minimum of 45 to 60 cm. (1½ ft. to 2 ft.). As a general rule, it should be sufficient to hold the loose earth excavated from the trench in a long, narrow, parallel heap without any possibility of slipping into the trench unless drawn by a phaorah.

The night soil should be dumped into the trench by tipping a cart. It should then be evenly spread by a wooden phaorah with a long handle to fill three-fourths of the depth. Immediately afterwards, the excavated earth should be filled into it until a long ridge is formed on the top, of at least 15 cm. (6 in.) height above the surrounding ground surface. If the soil is porous, about 3 to 4 months are required in summer and about 6 months in the rainy season for the night soil to be converted into harmless humus without any smell. It is an ideal fertiliser, and is in great demand by cultivators.

(*b*) **Deep Trenching**:—This is not really an efficient method, but in places where plentiful land is not available, or if available is either very costly, or of stiff clayey soil, and thus not suitable for shallow trenching, this method has to be resorted to.

The principle on which this method works is different from that underlying shallow trenching. For, whereas in the latter the ærobic bacteria present in the porous top layer of fertile soil do the purification by oxidation, in deep trenching greater stress is laid on liquefaction by the anærobic bacteria. That is why a stiff clayey soil and greater depth is permissible.

There is no restriction on the length of the trench, though 3 to 5 m. (10 to 15 ft.) lengths are better manageable in disposing of night soils of small towns. The width may be 1 to 1·5 m. (3 to 5 ft.), and the depth anything up to 1·5 m. (5 ft.). Even deeper depths are allowable but the cost of excavation and filling deeper trenches increases. The sides of trenches in stiff soil remain vertical unless they are exposed to the sun for a long time. Night soil is poured into trenches by emptying the carts by tipping up to about 60 cm.(2 ft.) depth. As the night soil is in most cases in semi-liquid condition it spreads itself evenly. It is then covered with about 15 cm. (6 in.) of refuse collected from dust-bins, consisting of ashes, floor sweepings, road scrapings, rags, waste paper, litter from stables, etc. It floats on the top and thus effectively protects the mass from flies. Septic action soon starts in full vigour and as a result sometimes there may be a few gaps made in the surface by eruptions caused by gas, exposing the night soil in the course of the next two or three days. Under such circumstances the sweeper in charge throws a few shovelfuls of litter and closes them. One or two more layers of night soil, each followed by one of refuse may be deposited in the same trench. The top is finally covered with loose earth. It takes about a year to change the night soil into humus, which then resembles ordinary earth and does not give out any bad smell.

In the rainy season care should be taken to divert rain water from higher ground to preclude flooding of the trenches. In the process of purification, deep trenching is likely to cause considerable nuisance of foul odour as compared with shallow trenching, which, under favourable conditions may give out very little or no smell at all.

(4) **Composting** :—This has been dealt with later in this volume in the chapter on Collection and Disposal of Refuse.

Questions are given at the end of the next chapter.

CHAPTER XI

SURFACE DRAINAGE

THE **object of surface drainage** is to prevent land near human habitations from being saturated with water containing putrescible matter.

The surface of land near human habitations unless systematically drained, is full of organic matter, both in the form of sullage, part of which is absorbed by the soil, and also solid matter dried by the sun lying scattered on it. Rain water flowing along the surface dilutes the former, and wets the latter causing it to decompose, and by spreading them on a larger area further helps the soil absorb a large part of them. However, a given area of land can absorb only a certain quantity of water containing putrefactive matter and will purify only a small part of it. In and around towns where houses are built close together, the space of land unoccupied by buildings and roads, which alone is useful in absorbing and purifying the putrefactive matter contained in the surface water, is small. If arrangement of draining this systematically is not made, the land may become water-logged and also sewage-sick and thus be a source of danger to health.

Existing Conditions:—The towns in India may be divided into two categories: (1) Those which derive their water supply carried on head from wells, rivers, etc. i. e. in other ways than by supply pipes, and (2) Those which have got a piped water supply.

(1) In the towns which have no piped supply of water the drains consist of ditches dug in earth on sides of roads in the localities inhabited by poor people and of pucca stone or brick gutters along the main roads where better classes of people live. In both cases they are not built or excavated to any designed level or gradient, and almost invariably without any reference to either each other or to a complete scheme. In the bazaar area the originally open drains spanned by a few

approach culverts are covered subsequently by stone slabs by shop-keepers to increase their shop-fronts to serve as platforms. It is the habit of every householder and shop-keeper to throw all the house sweepings and rubbish into these gutters. All the waste water from kitchens, baths and also the urine and ablution water from privies is discharged into these gutters, in which it stagnates, forming a putrefying black mass causing nuisance of offensive smell, flies and mosquitoes.

(2) In the towns which are fortunate in having a piped water supply, the conditions are perhaps still worse. All the waste water from houses (and with a piped supply this is much more), including liquids from privies, is discharged into open gutters usually at right angles to the flow. These street gutters may be either two, one on the either side of the road, or only one in the centre; in the latter case it is built underground and covered by stone slabs. They are usually rectangular in section built of rough stones, and not properly designed in respect of either size or gradient, and no proper means are provided to facilitate inspection, cleansing or repairs. The result is that they frequently get choked up, water continually soaks into the soil, and makes the soil and subsoil saturated with the decaying matter, making the whole town unhealthy. The sullage is ultimately turned loose into low ground outside the town to form a foul-smelling, black morass.

The Requirements of an Efficient System of Surface Drains:— These are: (1) Theoretically there should be two separate systems of drains—one for sullage water and the other for storm water. But this is impracticable, the main reason being that apart from the high cost, the two systems of drains would occupy a very large strip of land which, with the existing narrow roads between rows of houses, would be impossible. Thus only one system is possible. If it be for sullage water only, the drain would be so small as cannot be easily cleaned and kept free from obstruction, and particularly in the hot weather season instead of flowing, it would form an extended, narrow cess-pool. Besides, the question of disposing of storm water would remain unsolved. If it be for storm water only, the sullage water must be collected in cess-pits and the latter must be emptied by carts at frequent intervals. This would be not only very expensive, but objectionable from the sanitary point of view. It is therefore, necessary to make a compromise by providing surface drains to carry both storm water and sullage water. This arrangement is neither perfect nor free from objection, but is the only practicable solution, when water carriage system is out of the question.

The main advantages of the combined system are that, (i) It makes the drains sufficiently large to allow ease of cleaning; (ii) It obviates provision of cess-pools as all liquid wastes including those from house privies can be conveyed by them. (iii) The cost of the combined system is bound to be less than that of the two separate systems, and (iv) The increased volume of the combined drainage would mitigate the nuisance which would otherwise have been caused by the meagre and sluggish flow of a system of sullage water drains.

(2) The section adopted should be such as would make the cleansing of drains easy and would keep down the cost of maintenance. This will be discussed later.

(3) All the discharge should reach the outfall within 4 to 6 hours before it starts putrefying. For achieving this end (*a*) the velocity must be high enough, and as the velocity depends upon the bedfall, the latter must be sufficient. The velocity should be at least self-cleansing. As a rule, a velocity of 1 to 1·25 m./sec. (3 to 4 ft. per sec.) is deemed sufficient. This requirement presents a great difficulty in a very flat country like that in the plains of Northern India.

Surveys.—Generally a map of the Municipal area showing all the lanes, streets, outlines of houses, cultivated areas, parks and gardens, existing main and subsidiary drains with their outfalls, etc. is available. If so, a lot of labour will be saved. The accuracy of the map should however, be tested. The new roads and blocks of new houses, if any, erected since the previous survey was made to prepare the existing map, should be shown on it. If such a map is not available a traverse survey of the boundary and a detailed survey of the roads, lanes and drains, etc. with a chain and prismatic compass will be necessary.

Levelling:—Before starting levelling it is necessary to run a series of very accurate fly levels along the roads with a view to fixing permanent bench marks at intervals of about two furlongs on some permanent objects. These levels should be checked and rechecked, if necessary, until the error is within permissible limits, viz. 1 cm. in 1 km. (0·05 ft. per mile) in very flat country like the Plains of N. India, and double this in the parts with sufficienr ground slopes like the Deccan.

While levelling, the following points should be borne in mind:

(1) The lanes and roads should be chained, and staff readings taken along their centre line at every 50 m. (200 ft.) and more important than these, *at every summit or ridge and every hollow or depression* of the road.

(2) While doing the above, staff readings should also be taken at every 50 m. (200 ft.), on the bed of drains or gutters running parallel to the roads. The width of the road, and the side widths upto the municipal boundary line of the roads should be measured and recorded in the field notes. This information would show if the existing land is sufficient for the proposed drains, or more will have to be acquired.

(3) If the centre of the road is either higher or lower by more than 25 cm. (9 in.) than the ground surface at road sides, then the levels of ground surface at these places should be taken.

(4) Cross sections at every 100 m. (400 ft.) should be taken at right angles to the centre line of roads and extended to 50 m. (200 ft.) on either side wherever possible with staff readings at every 20 m. (50 ft.).

(5) All the main valley lines (*nallahs*) and minor water courses should be surveyed with a prismatic compass and a chain, taking levels at every 20 m. (50 ft.) if the bed is steeply sloping or at 25 m. (100 ft.) if very flat, with cross

sections at every 50 m. (200 ft.) at right angles to the centre line and extended to 25 m. (100 ft.) on either side.

(6) When a cross drainage work such as an arched culvert, a slab or pipe drain, etc., is met with, a neat sketch should be drawn in the notes showing the following information: (*a*) the bed level of the *nallah*, (*b*) the width, and the height up to springing if it is an arched culvert, or the depth or the diameter, if it is a slab drain or a pipe, (*c*) the road level at the top, (*d*) if any repairs are required, their nature and extent.

(7) While surveying the valley lines, the bed width, top width of the *nallahs*, the nature of the soil and subsoil as seen exposed on the slopes, the ordinary flood level and the highest flood level should be ascertained and recorded. The highest flood level should be verified from old residents, checked and then recorded.

(8) Where the roads cross each other, levels should be taken at the toes of the roads on both sides near the junction, and a neat sketch should be drawn in the notes.

(9) The bed levels of the open drains of individual houses either in the front or back yard.

(10) The bed levels of any local ponds which must be drained.

When all these levels are plotted on the Municipal map, they should present a net-work of points in a close mesh. If there are large blank spaces left, a few spot levels should be taken in addition to fill them up. Our ultimate object is to draw accurate contours.

Three different colours should be used for recording these levels. For instance, the levels along the centre line of the road should be written in red, ground levels in burnt sienna, and the *nallah* levels in blue.

Contours:—This is the most important part of the work, and indispensable to the Engineer. On its accuracy depends not only the efficiency but also the cost. The closer they are the better. They should be drawn very carefully, and if any doubt arises, checking and verification should be done on the site. When the contours are drawn, the main water-shed and valley lines would be obvious to the eye. These should be accurately marked by lines. It requires great skill and experience to mark the subsidiary valley and ridges, but they are very important. The care and labour spent on their correct demarcation would be amply repaid particularly if the ground is very flat. If necessary, these should be inspected on the site with the map in hand.

An attempt should be made to make the main drains follow the main valley lines, and as far as possible to make them intersect the contours at right angles, and to arrange the subsidiary drains to flow along the contours. When the main drains are marked on the map, the outfalls at which the sullage water will be discharged will be apparent.

The Area Plan:—The watershed lines determine the boundaries of the blocks which will drain the area into the portion of the valley between them. These blocks should be serially numbered, and their areas, measured by a planimeter in acres, up to two places of decimals, should be recorded in each block. Very often for the sake of clarity a separate block area plan is made on which are shown the boundaries of the main and subsidiary blocks, their areas, the main and subsidiary drains and the outfalls.

Quantity of Sullage:—The quantity of sullage which would enter the drains is very small—almost negligible in the case of the average small and medium town in this country, and can be readily calculated more or less precisely. For, in the case of towns without piped water supply, the average consumption per head per diem hardly exceeds 25 litres (5 gallons) depending upon the effort required to either haul the water up from a well or to carry it from the river bed. Even in the case of towns supplied with piped water very few of them can afford more than 45 to 75 litres (10 to 15 gallons) per head per day. Of this not more than 75 per cent finds its way to drains. For a town of 50,000 population this will be roughly :—

$$\frac{50000 \times 75 \times 0{\cdot}75}{24 \times 60 \times 60} = 32{\cdot}55 \text{ lit./sec.}$$

Taking the peak discharge as twice the average, a maximum of a little over two cusecs will flow in the final (outfall) drain at the end of the town. This is very small indeed.

Quantity of Storm Water:—This is very large as compared to sullage, and therefore important. When rain falls on a certain area, part of the water is absorbed by the soil, part is evaporated, and the remaining part flows off towards the bottom of the valley as storm or flood water. The drainage engineer is concerned with the latter only and that too, not with the total quantity, but, with the maximum rate of the run-off at any particular moment. The run-off from catchments depends upon a number of factors most of which are of a complex nature. Thus it increases with (1) the area of the catchment, (2) the steepness of its slopes, (3) the imperviousness of its surface, (4) the area occupied by buildings, paved yards and road surface of non-absorbent nature like asphalt or concrete, (5) the bareness of the surface, i, e. freedom from vegetation like grass, (6) the extent of the moisture present in the surface soil prior to the rainfall, (7) the heaviness or the intensity of the rainfall, (8) the duration of the rainfall, and (9) the compactness or the concentration of the area of the catchment. If the catchment is compact, water from all distant points flows quickly to the valley.

On the other hand, the factors which tend to reduce the run-off to the minimum are: porous, dry soil; flat ground covered with vegetation like grass; irregular surface forming small ponds and depressions; long, scattered catchment; a high wind and warm atmosphere which tend to evaporate water readily; and light rainfall.

The exact determination of the run-off even for one particular catchment area is not possible as the factors which affect it are very variable.

Until about 30 years ago, the estimation of storm water was done even in U. S. A. and England by adopting some empirical formulæ or by assuming a certain arbitrary co-efficient of run-off. This method has still been followed in this country. The run-off coefficient varies from 0·2 in the case of a flat catchment with meagre rainfall, to 0·75 in *Ghat* catchments. In the case of large catchments, where, as a result of the establishment and observation of a number of standard rain-gauges and also of annual flood discharges gauged over a number of years, the empirical formulæ based on the latter tally fairly well with the actual conditions. But in the case of small catchments it is simply a guess work. While working out projects for surface drainage a run-off 50 to 150 mm. ($\frac{1}{4}$ to $\frac{1}{2}$ inch) per hour intensity has hitherto been taken and it was further assumed that this took place over whole area of the catchment, both of which may be wrong.

Recently a new method, called the rational method, has been evolved in the Western countries and America. It is so called because it is based on information collected after taking measurements and estimating each factor affecting the run-off separately. The general equation of the run-off according to this method is :

$$Q = c. \ A. R.$$

where Q = the run-off in cub. ft. per sec.; A = area of catchment in acres; R = intensity of rainfall in inches per hour, and c = the coefficient of run-off called the impervious factor. Let us first investigate how R is obtained.

Intensity of Rainfall:—For determining this, the first requisite is the installation of a number of automatic recording rain-gauges in the main valley and large sub-valleys. These are quite different from the ordinary standard rain-gauges. The Provincial Governments of this country have established standard gauges and maintained their records of daily rainfall for the past 30 to 40 years. But as they give only the cumulative quantity of rain during the period of 24 hours from 8 A. M. of the previous day to 8 A. M. of the following day, they are practically useless. What we need for more accurate, rational method is the intensity and duration of each individual storm during this period.

The automatic recording rain gauge registers these individual storms by an automatically moving pencil on a sectional paper wound round a drum worked by clock-work. From amongst the storms recorded, those of greater intensity than 15 mm. (½ in.) per hour are selected and a table framed of all these storms which are plotted on a graph paper with the intensity p. h. in mm. (inches) as the vertical, and the duration of time in minutes as the horizontal ordinates. Suppose, for instance, the chart of a certain automatic rain gauge has registered a storm which precipitated a rainfall of 90 mm. (0 35 inches) in 20 minutes from 9-15 P. M. to 9-35 P. M. This

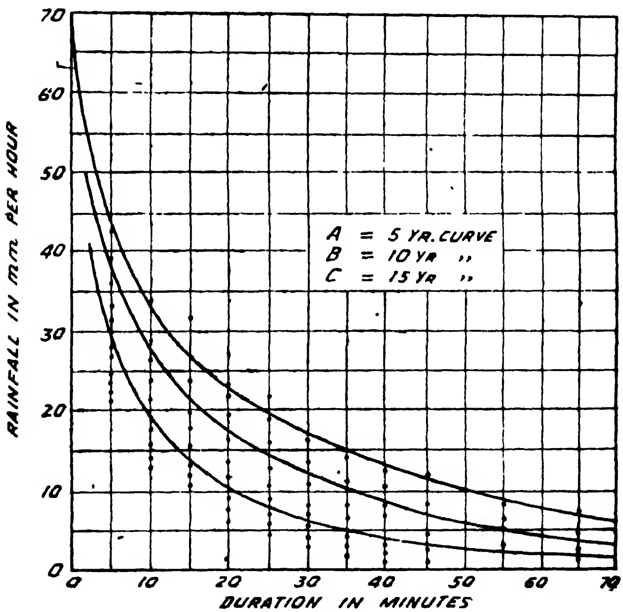


Fig. 161.

means rainfall of 270 mm. (1·05 in.) p. h. intensity and would be plotted as a point 270 mm. (1·05 in.) as the vertical and 20 minutes as the horizontal ordinates. If r = rainfall in mm. of a particular storm precipitated in t minutes, then the intensity of rainfall per hour, $R = \frac{60 \times r}{t}$. When a number of such points are plotted, mean curves can be drawn from them incorporating all the storms of intensities above 15 mm. (½ in.) with which only the engineer is concerned. These mean curves should represent frequency curves of 5, 10, 15 years and so on, according to the period over which the observations are spread. A 10-year frequency curve means that the relation expressed by it between the rainfall intensity and its duration is likely to be equalled or exceeded once in 10 years.

Fig. 161 shows three typical intensity-duration curves of 5, 10, and 15 years frequency of a certain hypothetical catchment area. It will be noticed from the curves that the rainfall intensity, R, varies inversely as the duration, i. e. the shorter the duration of rainfall, the greater will be the intensity during that period. From the design point of view, the relation which gives the maximum flood discharge is the most important. The equation of the curve is of the order of either $R = \frac{a}{t+b}$ or $R = \frac{a}{t^b}$ where R = intensity in mm. p. h., t = time in minutes, and a and b = constants. Each curve has its own equation.

Then there are two further factors to be considered which affect the maximum discharge of storm water. They are: (1) Time of entry, and (2) Time of concentration.

(1) **Time of Entry** :—This is often also called *inlet time*. This is defined as the time which the first drops of rain-water from the distant points of watershed take to flow to the head of the drain. In built-up city areas, the rain water which falls on roofs flows through roof gutters or down-take pipes to the paved yards, and from there to the street gutters, and from the latter again, to the drains. For this a minimum time of 3 to 5 minutes is required. In the area other than that occupied by buildings and paved yards, there is agricultural land, or

land under lawns, etc. The flow from these may take a much longer time, say 20 minutes or more, to reach the drain on account of the long distance and the roughness of the surface. The time of entry, therefore, depends upon two factors : the resistance offered by the surface to the flow, and the distance of the water-shed line from the head of the drain.

(2) **Time of Concentration**:—This is the time required for the collection of flow of rain water in sufficient volume from the various channels and sub-drains so as to make the effect of the flood felt. In other words, it is the time required for the flood discharge to reach the maximum limit. It is in fact the sum of the time of entry, t_e, and the time t required by the discharge to flow from the head of the drain to the point where the concentration is considered for purposes of design of that section. Thus time of concentration. $T = t_c + t$, time of flow.

Obviously the larger the catchment area, the longer is the time of concentration, and the less is the chance of flooding. The engineer is concerned with the maximum rate of run-off, and this occurs when the rainfall continues for such a length of time as would cause every part of the area of catchment to contribute its quota of water. Obviously, this length of time is the duration equal to the time of concentration.

The factor, t, the time of flow, can be easily calculated by dividing the distance from the head of the drain or sewer to the point where the section of the drain is to be designed, by the velocity of flow. The latter depends upon the gradient of the street.

The British Ministry of Health have recommended the following formulæ for varying times of concentration :

(1) $R = \dfrac{30}{T+10}$ where R = intensity of rainfall p. h. and T = time of concentration between 5 and 20 minutes.

(2) $R = \dfrac{40}{T+20}$ where R has the same meaning and T = time of concentration between 20 and 100 minutes,

Run-off Coefficient:—This is in fact, the impervious factor of run-off. As a result of intensive research work done by eminent engineers like Kuichling and others in America, and Lloyd Davies in England, it has been proved that the impermeable area in a particular catchment or district of a town expressed as a proportion of the total area, called the impervious factor, is directly proportional to the run-off. It has, therefore, been the practice in those countries to measure, as accurately as possible, the various impervious surfaces, such as roofs, paved yards, asphaltic, concrete and other road-ways, lawns, gardens, etc., and after applying the corresponding coefficient of imperviousness from the table given below, add up the percentages, and express the result as the impervious factor or the run-off coefficient.

TABLE NO. 6

Kuichling's Coefficients of Run-off from Various Types of Surfaces.

Type of Surface	Coefficient
Water-tight roof surface	0·70 to 0·95
Asphalt pavement in good order	0·85 to 0·90
Stone, brick, wood-block pavement with tightly cemented joints	0·75 to 0·85
Same with uncemented joints	0·50 to 0·70
Inferior block pavement with uncemented joints ...	0·40 to 0·50
Macadamised road-ways	0·25 to 0·60
Gravel road-ways and walks	0·15 to 0·30
Parks, gardens, lawns and meadows, depending on the surface slope and character of sub-soil ...	0·05 to 0·25

The areas are estimated not within the existing limits of the town, but those at the end of some period, usually 30 years from now when the probable full development of the town will have taken place.

The actual procedure adopted will be clear from the following examples:—

Example 1 :—An automatic recording rain gauge shows that the maximum rainfall of a particular storm in a year was 20 mm. (0·75 in.) in 10 minutes. Find the intensity of rainfall per hour.

$$R = \frac{r \times 60}{t} = \frac{20 \times 60}{10} = 120 \text{ mm. p. h.}$$

Example 2:—A certain district of a town covers an area of 50 hectares* (123·5 acres). The analysis of various impervious surfaces measured is given in the following table :—

TABLE NO. 7

Item	Existing	Future extension in 10 years
1. Houses (average roof area = 100 sq.m.)	150	250
2. Concrete or asphalt roads (hectares)	5·2	3·4
3. Macadam roads ,,	1·2	3·5
4. Paved yards ,,	0·8	1·6
5. Lawns and gardens ,,	2·0	1·4
6. Agricultural land (balance) ,,		

Find the impervious area taking Kuichling's coefficients.

The answer is worked out in the following table :—

TABLE NO. 8

Item	Area in hectares	Percentage of total area	Kuichling's coefficients	Percentage of impervious factor
1. 400 houses × 100 sq. m.	4·0	8·00	0·825	6·60
2. Concrete roads	8 6	17·20	0·87	14·96
3. Macadam roads	4·7	9·40	0·42	3·95
4. Paved yards	2·4	4·80	0·80	3·84
5. Lawns and gardens	3·4	6·80	0·15	10·20
6. Agricultural land (balance)	26·9	53·80	0·10	5·38
Total	50·0	100·00		44·97

* 1 hectare = 10,000 sq. metres = 2·47 acres.

The impervious factor is 44·97 per cent. or the impervious area is 50 × 4·497 = **22·485** hectares.

The conclusions arrived at by Lloyd Davies are :

(1) The total volume of storm water is proportional to the maximum rate of flow.

(2) The total discharge of storm water is proportional to the maximum rainfall during the time of concentration.

(3) The storm water discharge of any particular district is proportional to the percentage of impermeable area expressed as a proportion of the total area of the district.

(4) The maximum rate of flow is expected when the maximum precipitation occurs in the minimum time of concentration.

Example 3:—A drain is to carry surface water from a district covering 10 hectares (25 acres). The impervious factor is 35 per cent. If the 5-year record shows a maximum rainfall of 13 mm. (0·50 in.) during 15 minutes of time of concentration, find the discharge in cusecs for which the drain must be designed.

$$Q = \left(\text{Rainfall in } \frac{\text{mm./hour}}{1000}\right) \times \text{area in sq. metres}$$

$$\times \text{ Impervious factor} \times \frac{1}{60 \text{ min.}} \times \frac{1}{60 \text{ secs.}}$$

$$= \frac{13 \text{ mm.}}{1000} \times \frac{60}{15} \times \frac{10 \text{ hect.} \times 10{,}000 \times 3{\cdot}5}{3600}$$

$$= \mathbf{5{\cdot}05} \text{ cub. m./sec.}$$

Questions on Chapter X

(1) What are the evils of conservancy system ?

(2) What are the requirements of an ideal privy on the conservancy system ?

(3) What are the practicable methods of disposal of night soil ? Describe the one amongst them which is most popular in India What is the difference between shallow and deep trenching ?

Questions on Chapter XI

(1) Why are separate drains for sullage and storm water not suitable for Indian conditions ? What are the advantages of the combined system ?

(2) Write out detailed instructions to a surveyor before undertaking a surface drainage project.

(3) What is the rational method of estimating storm water discharge from a district ?

(4) The C. A. of a certain drain is 8 hectares (18 acres) ; the impervious factor is 40 per cent. The time of concentration is 10 minutes, and the equation of the intensity of rainfall curve is $R = \frac{120}{t + 20}$. What is the maximum discharge ?

Solution : Substituting $t = 10$ in the equation, $R = 4$.

$$Q = 8 \times 0{\cdot}40 \times 4 = \mathbf{12{\cdot}8}.$$

(5) A channel drains an area of 20 acres. The impervious factor is 32 per cent. The maximum R on record = 5·5 in. p. h. Find Q

Solution: $Q = 60{\cdot}5 \times 5{\cdot}5 \times 32 \times 20 = 3146$ cft per minute

$= \mathbf{35{\cdot}5}$ **cusecs.**

CHAPTER XII

DESIGN OF DRAINS

Gradients and Velocity:—The velocity of flow varies directly as the gradient or the bed-fall, and inversely as the frictional resistance offered by the surface of the channel or conduit in contact with the flow. The general formula used for determining velocities is the following, known as Chezy's formula :—

$$V = c\sqrt{RS}$$

where V = velocity in m./sec. (ft./sec.), R = hydraulic mean depth, i. e. the area of water section divided by the wetted perimeter, S = slope, or the fall of the water surface divided by the length in ft. and c = a constant depending upon the hydraulic mean depth and the roughness or smoothness of surface. For determining the value of c, the following Kutter's formula is used :—

$$c = \frac{23 + \frac{1}{n} + \frac{0{\cdot}00155}{S}}{1 + \left(23 + \frac{0{\cdot}00155}{S}\right)\frac{n}{\sqrt{R}}}$$

in which R and S have the same meanings as above, and n = a constant, the value f which depends upon the rugosity of the surface. For earthen channels n = 0·022, and for stoneware or brickwork channel n = 0·013. For the sake of simplicity the expression $\frac{0{\cdot}00155}{S}$ may be omitted. It affects the result less than an increase of 0·001 in the value of n.

While calculating velocities the slope is always referred to as the hydraulic gradient,* and not the bed-fall. In the

* Hydraulic gradient is defined as the line connecting the points to which water would rise in vertical pipes open to the atmosphere, if inserted in the liquid running in a pipe.

case of open channels the hydraulic gradient corresponds to the slope of the water surface. For construction purposes, however, the slope of channel is that of its invert.

Velocity of flow is not uniform throughout a cross section. In open channels it is maximum at a little below the centre of the open surface, and is minimum near the surfaces in contact on account of the frictional resistance they offer. It is the velocity near the bottom which is significant in transporting solids. The transporting power of a liquid varies as the 6th power of the velocity. Thus if the velocity is doubled, the transporting power is made 64 times as great. For this purpose even a slight reduction in velocity due to either an increase in roughness of surface, resistance at bends or a sudden increase in section, etc. affects the transporting power considerably. The transporting power also depends upon the depth of flow. If the latter is insufficient, in spite of a high velocity, suspended solids like rags, pieces of wood, loose coir, grass, etc., which frequently find entrance to a drain, touch the bottom and on account of the resistance met with there, are first carried slowly, and later, when they meet some heavier deposits which have been already lodged on the invert, they firmly settle there, and are not carried away even when the velocity of flow increases again.

The minimum velocity should be that which is self-cleansing, i. e. at least 1 m. (3 ft.) per second in small channels and 75 cm. (2½ ft.) per sec. in large ones, which run more than half full. This velocity may not remain uniform throughout the day, but it must be maintained for short periods of peak discharge every day.

The maximum velocity is not important as it is almost never reached. Still it should not be so high as to scour the bed of the channel or sewer. Tne following are the maximum velocities permissible :—

Earthen channel	0·6 to 1·25 m./sec. (2 to 4 ft. per sec.) depending upon the nature of the earth.
Channels lined with brick	1·5 to 2·5 m./sec. (5 to 8 ft. per sec.) depending on the quality of bricks.
Concrete	3 m./sec. (10 ft.) per sec.
Stoneware	3 to 4·5 m./sec. (10 to 15 ft. per sec.)

While laying out and designing channels the following points should be remembered :—

(1) The aim should be to grade the channels in such a way as to obtain self-cleansing velocity without running the drain into a heavy cutting in its lower reaches. The latter is disadvantageous in three ways: (*a*) The cost of construction and also that of maintaining the deep cutting in order, increases. (*b*) A deep channel, apart from requiring a large space of ground, is always a source of danger to men and cattle, and (*c*) It reduces the command of land. This is very important if the sullage is to be finally disposed of by treatment on land surface.

(2) The main drains should be graded first, and the subsidiary ones afterwards.

(3) If the sullage is to be finally treated, it is more economical to carry it in as fresh a condition as possible to the outfall works by increasing the grades, i. e. velocities even if the sewage has to be pumped at some intermediate place in very flat ground.

(4) The full supply level (F. S. L.) of the drains when running full should lie at between 8 and 30 cm. (3 in. and 1ft.) below the level of the centre of the street along which the drain is running.

(5) When the ground is flat, it is desirable that the section and the grade should be so arranged that the velocity of flow slightly increases progressively, or at least remains constant as the discharge flows from the head of the main drain to the outfall channel.

(6) If the sullage water is to be treated by either irrigation or land filtration, the outfall should be brought out of the town at as high a level as possible in order to increase the command.

(7) When one drain flows into another the F. S. levels of both should meet in one horizontal plane.

(8) When a small drain joins another of larger section whose invert is at a lower level, the grade of the former should

be steepened in some length at the end, and its sides raised till they are of the same height as the F. S. level of the larger drain. Further, the invert of the smaller drain should meet that of the larger one tangentially in a streamlined curve not only as shown in the plan of an inspection chamber (Fig. 142 p. 81) but also in elevation. If this is not done, and the invert of the incoming drain is ended abruptly in the side of the main drain the small dry weather flow will tumble at right angles into the main drain, cause an eddy and deposit silt. Further, the water in the smaller drain is sure to back up forming a pool when the main drain flows to its capacity.

(9) In very flat country where the necessary grade cannot be obtained without going unduly deep, flushing arrangement should be made to obtain a velocity of 0·75 to 1 m./sec. (2·5 to 3 ft. per sec.) after the flush is added to the dry weather flow.

(10) Instead of collecting all the discharge and carrying it to one point of outfall, it is more convenient to make use of a number of outfalls at different places. This is advantageous in several ways : (i) small quantities of sullage water are better manageable than larger ones. (ii) if the sullage is to be treated by irrigation or land filtration, the several small outfalls together easily command sufficient land than if all the discharge were carried to one outfall only.

(11) Howsoever well designed the sections and grades may be to develop self-cleansing or a slightly higher velocity, it has been the common experience that the drain needs cleansing periodically by a sweeper with a stiff broom in hand, and removing, at the same time, obstructions such as stones from it. For this, provision in the annual maintenance estimate is necessary.

Section of Drain :—An ideal section should satisfy the following requirements :

(i) It should develop self-cleansing velocity with the usual dry weather flow, and still should be capable of carrying the storm water without overflowing, and causing an excessive velocity.

(ii) It should possess structural stability.

(iii) It should be cheap to construct and also to maintain.

(iv) The material employed in its construction should have a smooth but hard surface, and be non-corrodible and capable of resisting erosive action of coarse sand and grit.

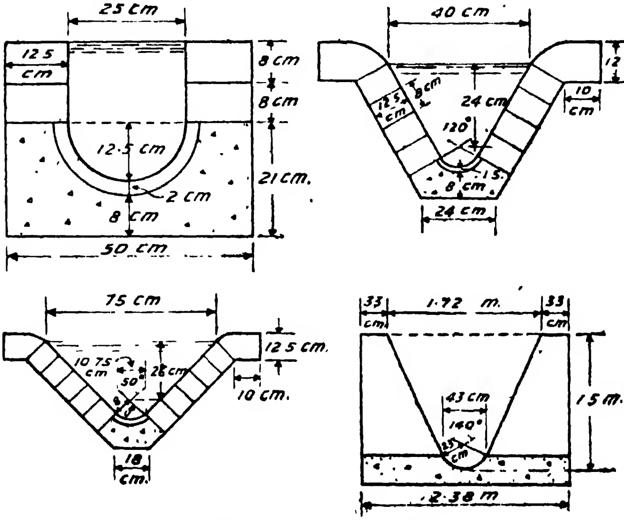
(v) It should be capable of being easily cleaned.

There are four principal sections in common use which have been proved successful by experience :—

(1) **Semi-circular or U-section** :—(See Fig. 162). This is the most common section for small drains on account of its ease in laying, stability and cheapness. It lends itself to the use of half-round glazed stoneware pipes called "agricultural pipes" at the bottom, which impart to it most of its good qualities. However, for developing a self-cleansing velocity for small flows it is not so good as the V-section A semi-circular drain, if deep, has another disadvantage, viz. as most of the drains are unfenced, sooner or later a bullock cart will drop one wheel into the drain, causing damage both to the cart and drain and perhaps breaking a leg of the bullock. This happens because the sides are vertical. In a V-shaped drain as the sides are sloping, there is much less danger. Further in places, where the ground surface is mostly sandy with little or no soil to bind it, as in Northern and Western India, the high wind tends to fill the semi-circular drain with vertical sides with sand more than the V-shaped one.

(2) **V-section** :—(Fig. 163)· This gives greater depth of flow for small discharges, and therefore for small flows it gives a self-cleansing velocity. Stoneware glazed pipes of one-third circumference are used for lining the invert, and the sides above it are lined either with brickwork or flagstones. The angle subtended by it at the centre is obviously 120°. If the grade available is good this is a very efficient section, but with flatter grades there is a tendency, on its part, of collecting silt deposit which fills the narrow width at the bottom and makes it lose its efficiency. Another disadvantage is that as

the side slopes are steep, the section is not quite stable when the earth is not of a firm nature. Sweepers find a V-shaped drain much easier to clean than a U-shaped one.



Figs. 162, 163, 164, 165.

(3) Fig. 164 shows a third common type, which is suitable where the proportion of the dry weather flow to storm water discharge is small, and where there is not much space restriction. On account of its flatter side slopes it remains stable under all circumstances. For this reason the lining on sides need not be *pucca*, just some sort of pitching on earth with joints pointed with lime or cement is sufficient. A piece of stoneware glazed pipe of ¼ circumference subtending an angle of 90° is laid at the bottom. Oftentimes to reduce the cost, instead of a lining of bricks or pitching, the sides on the top of the stoneware invert piece, are made of soil.

(4) The section illustrated in Fig. 165 subtends an angle of 140° and therefore does not lend itself to the use of a stone-

ware lining at the invert. However, the peculiar shape can be very easily given in concrete by a V-shaped mould, on both sides of which concrete can be poured. It has all the advantages of a V-shaped drain, but is expensive to construct. The massive sides of concrete give it a long life.

For carrying larger discharges, sections of large diameter pipes are used for the invert in all the first three sections above and the sides are made to slope in the same way. For all these standard sections, tables and charts giving velocities and discharges for various grades are available.

Instead of brick lining on sides often 4 cm. (1½ in.) thick flagstone lining is found cheaper and more satisfactory. The top is finished with cement concrete coping at least 15 cm. (6 in.) thick.

Sometimes a section formed by combining two sections mentioned above is adopted, e. g. a semi-circular pipe at bottom, and sides sloping as in Fig. 163 or Fig. 164 above.

Design Procedure:—A drain is designed in small lengths from the summit downwards, and as a rule, a length from its summit to an incoming branch, or to a junction with another drain, or from one junction to the next, is taken as a unit for design purposes, and it is the usual practice to keep one grade and one section throughout in each unit length. If the unit is unduly long, the sides are raised towards its tail 8 to 15 cm. (3 to 6 in.) by a brick or two as necessary.

The grades are worked out from the longitudinal sections already plotted. Tentative pencil lines are first drawn, and when the design is satisfactorily made, they are inked in later.

The problem now before us is this: Exact quantities of storm discharges of all unit lengths are known from the areas of catchment; the quantity of sullage is worked out from the population on each unit length, and three times that quantity is added to the storm water discharge (Peak sullage discharge is taken as three times the average). The grades are also more or less definitely known from the longitudinal sections;

one of the four sections described above is to be adopted, and therefore if the diameter of the invert pipe is tentatively assumed, the area of the section, wetted perimeter and from these the hydraulic mean depth can be calculated. From these data the Bazin's or Chezy's coefficient can be found out. What then remains to be done is to see whether the velocities and depths obtainable from the formula are adequate to make the channel self-cleansing when running to the full capacity, and if also the velocity developed, when either three times the dry weather flow is running, or when the drain is running one-third full, is adequate.

If the velocity worked out is not satisfactory, the only alternative is to steepen the grades by going deeper into a cutting till the minimum self-cleansing velocity is obtained. If the final disposal be by treatment on land surface, pumping may have to be resorted to in very flat country.

For illustrating the procedure of design of drains a contoured map of a district of a small town is shown in Fig. 167 in which AB...GH is a collecting drain shown in double parallel lines, to which branch drains b_1, c_1, d_1, etc. join. The longitudinal section represented by Fig. 166 shows the ground levels and all other details such as the grades, velocities, discharges, invert levels of the main and branch drains, etc.

The results of calculations of the design are further shown in the statement in Table No. 9 (vide pages 136, 137) from which the following points will be clear :—

(1) The catchment areas of each section and branch measured by planimeter are recorded in columns 4 and 5.

(2) The storm water discharge is calculated from these areas on the assumption that a maximum rainfall of 3 mm. ($\frac{1}{8}$ in.) p. h. intensity falls on the entire area. This discharge is doubled and is taken for design purposes for the sake of safety and shown in column 8.

(3) Similarly the populations on each section and branch are calculated and recorded in columns 9 and 10. These figures

(Continued on page 134)

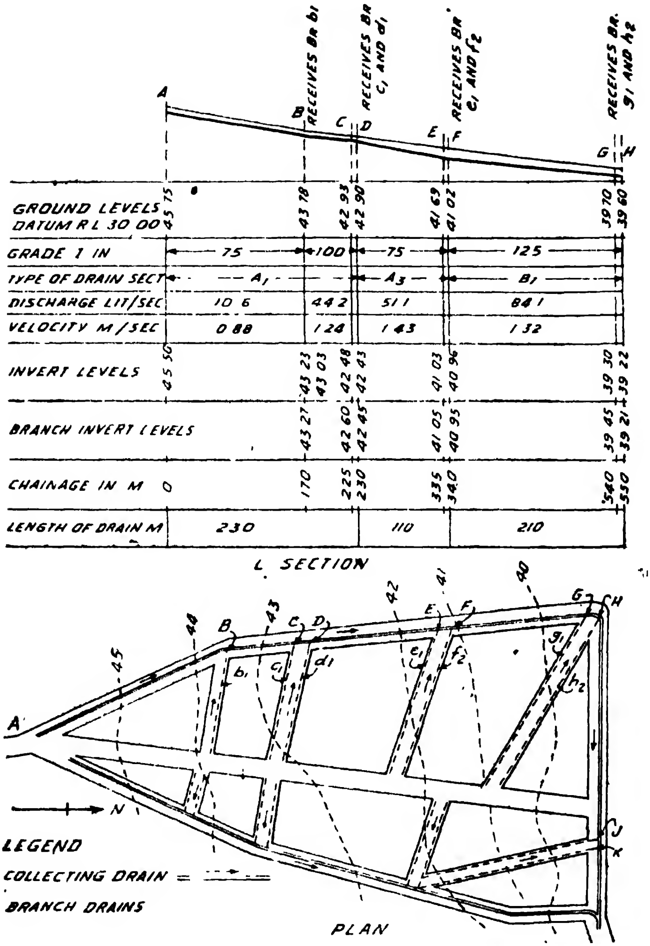


Fig. 166 – Longitudinal section of the collecting drain A B C D E F G H showing most of the details in the Statement in Table No. 9.

Fig. 167 – Plan of a district of a small town showing contours, collecting and branch drains. The dotted lines show the branch drains – two on each side of the road in most cases.

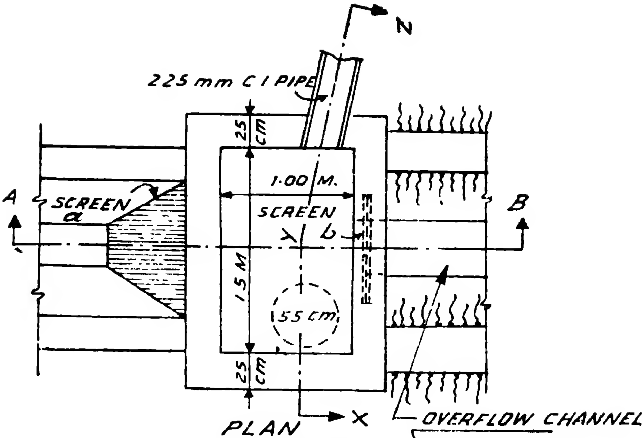
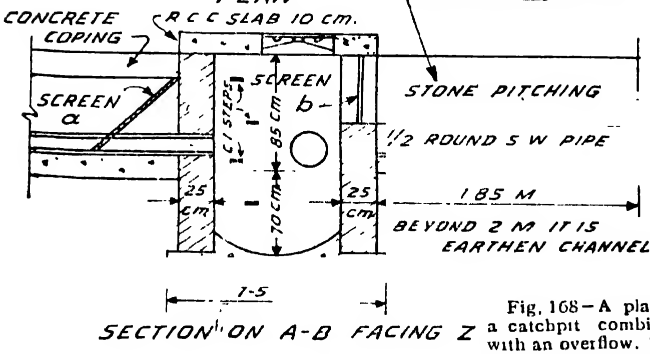


Fig. 168—A plan of a catchpit combined with an overflow. The section of the drain on left hand side of screen '*a*' is U-shaped with half-round 225 mm. (9 in.) S. W. pipe at bottom. The water falls through the inclined screen '*a*' into the pit with bottom curved all round in which the silt collects and the outlet is through the 225 mm. (9 in.) c. i. pipe. The excess storm water flows through the vertical screen '*b*' into the earthen channel below to join the water courses.



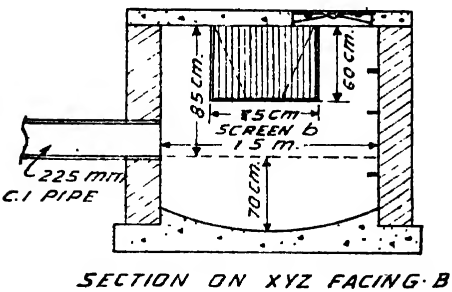


Fig. 169—A section through *A B*, showing sections of both screens.

Fig. 170—A vertical section through *X Y Z* showing screen '*b*' in elevation.

of population are obviously prospective at the end of the design period of 30 years from now.

(4) The quota of water supply is 40 lit. (9 gallons) per head per day and on the assumption that 75 per cent of this would reach the drains, the discharge is calculated on the basis of the population and recorded in column 12.

(5) The above is the average discharge. The peak discharge is taken three times the average for design and is shown in column 13.

(6) The drain is designed for the combined discharge of storm water and sullage (sum of columns 8 and 13) which is recorded in column 14.

(7) The drain sections adopted are A_1, A_3 and B_1. A_1 and A_3 are U-shaped with sills of 100 mm (4 in.) and 225 mm. (9 in.) diameter glazed s. w. pipes respectively, with 8 cm. (3 in.) vertical sides above the sills and are similar to the section shown in Fig. 162, page 129.

Other details are obvious from the longitudinal section (Fig. 166) and Table No. 9 on pages 136, 137.

Overflows:—Where a storm water drain crosses, or approaches a water course or a nallah, a masonry overflow is conveniently provided for keeping the discharge down to a predetermined maximum in the interest of economy. Thus a great deal of storm water is automatically got rid of. This reduces the size of the drain considerably. The maximum storm water thus retained is usually 6 to 12 times the normal dry weather flow, and if the sullage is to be pumped, it should be not more than 3 times the D. W. F.

A typical design of an overflow combined with a catch-pit is shown in Figs. 168, 169 and 170.

Catchpits:—Really speaking, if the grades of the drain are sufficient to ensure self-cleansing velocity, there should be no need of catchpits. But an open drain is a receptacle of anything carelessly thrown into it, which causes silting. The silt is therefore localised in a chamber called a catchpit from which it can be removed economically from time to time. In the absence of such a catchpit the silt would spread in the entire length of the drain and it would be very expensive to remove it. Such masonry catchpits are usually provided at the end of long branches and drains. In Figs. 168 to 170 a catchpit is combined with an overflow. However, they may be separate masonry works also.

If pumping has to be resorted to, a settling tank is necessary in which the heavier suspended matter settles in the form of sludge and only the clear effluent from the top flows to the sump. The sludge is periodically removed and spread in a thin layer on the surface of adjoining land to dry into cakes which are sold either for manure or fuel.

Questions

(1) On what factors does the transporting power of a liquid depend ?

(2) How should a junction of a small drain be made with a large drain and why ?

(3) What are the advantages of a U-section over others ? Draw a section of a U-drain with 225 mm. (9 in.) drain invert of s. w. pipe, sides of 3·5 cm. (1½ in.) flagstone slabs with 15 cm. (6 in.) coping at top. The depth of the drain is 45 cm. (1 ft. 6 in.).

(4) Prepare a table showing different columns of information required for the design of a drain. (See Table No. 9).

TABLE

Statement of All Details

Point on Plan	Chainage m	Length of Drain m	Area Drained Hectares: On Section	Area Drained Hectares: On Branches	Area Drained Hectares: Total	Q in lit./sec. due to Rainfall: Run off at 3 mm. p. h.	Q in lit./sec. due to Rainfall: Double this for safety	Population: On Section	Population: On Branches	Population: Total	Q in lit./sec. due to Sullage: Q of Sullage at 40 lit. p. h. p. d.	Q in lit./sec. due to Sullage: 3 times this in lit./sec.
1	2	3	4	5	6	7	8	9	10	11	12	13
A	0											
		170	0·32	0·90	0·32 0·90	2·67 7·5	5·33 15·0	57	160	57 160	·0264 0·0741	0·0792 0·2226
B	170											
		55	0·18	0·40	1·30 1·70	10·83 14·17	21·67 28·33	32	71	249 320	0·1153 0·1482	0·3459 0·4446
C	225											
		5	0	0·14	1·70 1·84	14·17 15·33	28·33 30·67	0	25	320 345	0·1482 0·1597	0·4446 0·4791
D	230											
		105	0·26	1·28	2·10 3·38	17·50 28·17	35·00 56·33	47	227	392 619	0·1815 0·2866	0·5445 0·8598
E	335											
		5	0	0·17	3·38 3·45	28·17 28·75	56·33 57·50	0	30	619 649	0·2866 0·3005	0·8598 0·9015
F	340											
		200	0·26	0·70	3·71 4·41	30·95 36·75	61·85 73·50	142	25	701 816	0·3246 0·3778	0·9738 1·1334
G	540											
		10	0	0·83	4·41 5·24	36·75 43·67	73·50 87·33	0	153	816 969	0·3778 0·4486	1·1334 1·3458
H	550											

NO. 9

Required for Design of Drains

Total Combined Discharge lit./sec.	Average Q of Section	Type of Drain Section	Grade 1 in	Designed velocity m./sec.	Designed Q lit./sec.	Ground Levels	Invert R. L. s of Main Drain	Invert R. L. s of Branch	Remarks
14	15	16	17	18	19	20	21	22	23
						45·75	45·50		
5·409 15·223	0·110	A_1	75	0·88	10·6				
						43·78	43·23 43·03	43·27	Branch b_1 joins
22·016 28·775	1·135		100	1·24	44 2				
						42·93	42·48	42·60	Branch c_1 joins
28·775 31·149	1·135								
						42·90	42·43	42·45	Branch d_1 joins
35·545 57·190	1·318	A_2	75	1·43	51·1				
						41·69	41·03	41·05	Branch e_1 joins
57·190 58·402	2·210								
						41·02	40·96	40·95	Branch f_2 joins
62·824 74·633	2·566		125	1·32	84·1				
						39·70	39·30	39·45	Branch g_1 joins
74·633 88·076	2·92	B_1							
						39·60	39·22	39·21	Branch h_2 joins

CHAPTER XIII

COLLECTION AND DISPOSAL OF REFUSE*

REMOVAL and disposal of house refuse comes under Public Cleansing, and is a very important and costly item on the Municipal sanitary budget. If it is not removed promptly away from the town it accumulates in large heaps harbouring rats, flies, and vermin which disseminate germs of disease. A good deal depends upon the mutual co-operation between the Municipal authorities and the public. Proper maintenance and use of the dust-bin in the house is the key to the satisfactory solution of the problem of sanitary storage and collection of refuse without causing nuisance. Though the Local Authority may be empowered with legislative acts, their enforcement on an unprepared, resisting, doubting and ignorant community is of no avail. The urge for sanitary reform must come from within. Success in this respect can be achieved by awakening the civic consciousness of the community by means of distribution of free leaflets, exhibition of placards, pictures, cinema slides, lantern lectures, etc. Householders can greatly assist in simplifying the problem of storage, collection and disposal and thus reducing the cost and ultimately the taxes.

House refuse means and includes ashes, cinders, breeze, rubbish, night soil and filth, but does not include trade refuse not even dung from stables, which it is incumbent on the manufacturers and owners of stables to carry away and dispose as the Local Authority may direct.

Both the quality and quantity of house refuse vary from place to place and season to season depending upon the habits of the people.

The problem of dealing with house refuse resolves itself into four parts: Storage, Collection, Transport and Disposal.

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* By courtesy of Mr. N. V. Modak, Special Engineer, Bombay Municipality, from whose report to the Corporation, on the subject most of the information in this Chapter is drawn.

(1) & (2) **Storage and Collection**:—The ideal requirements in this respect are:

(*a*) There should be a bin—preferably two bins, maintained by every house, one for garbage and other organic matter and the other for mineral matter as is the custom in many towns in U.S.A. where the contents of the bin of organic matter are fed to hogs.

(*b*) Each house-holder should be compelled under law to use a bin of approved type and size.

(*c*) All waste papers should be bundled up and kept separately to be collected by the dust-man.

(*d*) The receptacle must be kept in a good condition, and sanitarily clean by frequent washing and disinfecting.

(*e*) The bin should have a close-fitting cover, lest stray dogs, pigs and cattle might scatter the refuse.

(*f*) The place where the receptacle is located should be fixed and be easily accessible to the collector. As far as possible the Municipality should insist on the owner to show it on the building plan while submitting the same for sanction.

In addition to the bin to be provided by each house-owner the Municipality should provide a number of them on footpaths of streets for facility of pedestrians to throw whatever rubbish such as paper wrappings, tram tickets, cigarette ends, etc., into them instead of scattering them on the road surface. These bins should better be fixed to posts one or two feet above the ground so as not to be within reach of dogs, etc.

For collection of refuse from dust-bins dust-men are employed in most countries by the Local Authority. The emptying should be done either by night or very early in the morning between 5 and 6 A. M.

The present system of providing cisterns at suitable places on street edge in this country is open to objection unless the people are taught to throw the refuse carefully into them instead of outside, which is invariably scattered by stray animals, and, in consequence, the entire street surface near it is made unsightly.

The collection should be made at least once in 24 hours, and it should be done in such a way as to minimise nuisance of smell and dust during filling into carts or vans.

(3) **Transport**:—All the refuse collected from house to house must be carried away from the town to a safe place where it can be suitably disposed. When the lead is within 2·5 km. ($1\frac{1}{2}$ miles), experience has shown that animal-drawn transport is the cheapest. For longer leads petrol-driven vans are cheaper than those in which steam or electricity is the means of tractive power.

The van should have a plane surface without angles or recesses for facility of cleaning. It should be strong, durable, silent in operation, simple to drive and control, with quick acceleration, and large reserve power. It should have a low maintenance cost and large capacity. The latest van in use in Western countries has a capacity of 13·75 cu. m. (18 cub. yards). It should have a tipping gear and a low loading line (maximum 1·4 m. or 4 ft. 8 in.) so that a man can easily lift a bin to that height to empty it into the van. It should preferably have some compacting device such as a hydraulically operated ram to increase its carrying capacity. It should be capable of being loaded from sides, as rear loading is a great disadvantage in as much as the men have to climb each time, in which time is lost. Lastly, it should be a closed one so that the contents are not visible and are protected from wind.

(4) **Disposal**:—The methods of disposal are :

(1) Tipping—ordinary and controlled.
(2) Bargeing out into sea.
(3) Pulverization.
(4) Incineration.
(5) Destruction by bacterial agency.
(5*a*) Composting.

(1) **Tipping** :—Tipping, or rather indiscriminately dumping carts or motor vans into depressions, low lying lands, abandoned quarries, etc. is the oldest method, and was universally practised in most European countries until about 30 years ago. Unfortunately it is still practised in almost all towns in this country. It is open to the following objections :

(*a*) It gives rise to nuisance from objectionable smell from decaying organic matter.

(*b*) It harbours rats, flies and vermin which are likely to spread diseases.

(*c*) It is capable of contaminating underground water supply, such as of wells, by percolation.

(*d*) It is liable to catch fire as the material is inflammable.

In spite of these objections it was practised for the following advantages :

(1) It is the most economical method of all, particularly in towns where suitable land is available for reclamation, within reasonable distance.

(2) It does not require large initial expenditure for implements and plant.

(3) There is no added cost of disposal of its by-products, as unlike some other methods there are no by-products.

(4) Vehicles can tip and return without delay, as compared with destructor plant on which delays in unloading are unavoidable.

(5) Low lying land, disused quarries, and swamps can be reclaimed, and thus not only the sources of mosquito breeding are destroyed, but converted into first class properties.

However, the nuisance created was so great and it affected the sanitation of towns to such an extent that England and several other countries abandoned the method in spite of its economic advantages and sought other methods such as destruction by burning or by bacterial agency. But they all proved to be so costly that ultimately the Ministry of Health held a conference in London in 1922 to consider whether it was possible to overcome the defects of the method. The precautionary measures suggested by them are given below. When these precautions are applied to the old method of ordinary tipping, the latter came to be known as "controlled or constructive tipping" in Europe and "Sanitary Fill" in America. The precautions are based on the assumptions that flies do not penetrate a layer of earth more than 20 cm. (8 in.) thick, that odours of decomposition are absorbed by 90 per cent of inorganic refuse and the cover of earth, and that spontaneous combustion of the refuse is prevented by the earth cover which excludes the air needed for combustion.

The precautions recommended by the Committee, as well as those found necessary by experience are :—

(1) Each layer shall not exceed 2 m. (6 ft.) in thickness.

(2) Each layer shall be covered on all surfaces exposed to air with at least 25 cm. (9 in.) of earth or other suitable material.

(3) Each layer shall be allowed sufficient time to settle before the next is added.

(4) Except in positions to fill depressions, the tip shall be well battered to an angle not exceeding 45°.

(5) The tip shall not exceed a height 6 m. (20 ft.) above the surrounding land surface.

(6) For dealing with "cricket" nuisance the tip shall be sprayed with 50 per cent solution of creosote or paraffin.

(7) If the material deposited at any one time consists entirely or mainly of fish, animal or other organic refuse, the cover of earth or other suitable material shall be at least two feet in depth.

(8) For preventing any paper or other light debris from being blown by wind away from the place of deposit a suitable arrangement, such as a screen, etc., must be provided.

Controlled tipping differs from ordinary tipping in that the concentration of dumping occurs along a relatively short and narrow face instead of spreading it over a wider area. Only one tipping face is operated at one time and no refuse is visible anywhere else but at the tipping point. The refuse is tipped in 'lanes', 'terraces' or 'fingers' each about 7·25 m. (24 ft.) × 1·25 to 1·75 m. (4 ft. to 6 ft.) thick. They are wholly covered in 24 hours with soil, ashes, road sweepings, etc., free from paper in order to form an effective seal. In these terraces the refuse is ultimately converted into harmless material by biological action. The tipping face does not usually exceed 6 m. (20 ft.).

Large tins, carpets, rags, etc., are taken out and either sold in the market, or are spread at bottom to minimise heat production.

A 2 m. (6 ft.) layer of refuse compressed by wagons is reduced to 30 cm. (1 ft.) in 6 to 12 months depending upon the nature of the refuse. The settlement is greater after the wet weather.

(2) **Bargeing out into Sea** :—Under suitable conditions this is the most economical method. The town must be situated on sea coast and the place selected must have currents uniformly seaward. The depth of water must be at least 35 to 40 m. (20 to 22 fathoms) and the distance must be reasonable.

The drawbacks of the system are :—

(1) Difficulty of getting rid of light and bulky constituents which tend to spread flat on the surface and are carried to the shore by flowing tides.

(2) During stormy weather when barges dare not go out into the sea provision must be made for either storing the refuse, or tipping it into some low-lying land during the interval.

(3) Even under most favourable conditions at least a small part of the refuse is bound to return and deposit on the shore.

(3) **Pulverization** :—In this method the refuse is mechanically reduced to fine particles by grinding in machines. Pulverization changes only the physical character and appear-

ance of the refuse and reduces the bulk, but no chemical change takes place. It being finely divided, a fairly uniform mixture which is odourless and unattractive to the fly and rat is produced. Though it contains the essentials of a fertiliser, viz. nitrogen, phosphorus and potash it is not suitable as a manure to any and every lánd but only to lands possessing certain characteristics. This defect allows it a limited field for sale, and makes it unproductive.

(4) **Incineration**:—By 'incinerator' is meant a furnace intended to burn refuse of a few houses, on a small scale whereas the term 'destructor' is used for a furnace employed for burning the whole city's refuse.

There are a number of destructors in use all over the world, most of them covered by some patent or other. While using a destructor plant the moisture content and calorific value of the refuse are the most important factors. The less the moisture content and the greater the calorific value, the more valuable is the refuse. The heat produced during combustion is invariably utilised in rising steam, which is employed in generating electricity, which in turn, is utilised as a motive power for either pumping sewage, or compressing air, etc. Due to the variation in the character of the refuse in respect of the moisture and the calorific values from hour to hour the rate of generating steam also varies, and this necessitates the provision of a stand-by plant to make up the deficiency. This ultimately results in increasing the capital outlay of the scheme.

Besides, before putting the refuse into the destructor furnace, it is economically advantageous to sort it out with a view to salvaging the useful materials. For this, a separate separation plant is required in addition, which further adds to the initial outlay. Separation has the following advantages.

(1) The separation of dust alone helps in reducing the load by 45 to 50 per cent. This dust is mostly incombustible. The dust, if salvaged, is very useful for reclaiming and improving land.

(2) The refuse left after separation of dust and other things which is known as 'tailing' is about 25 to 40 per cent of the original and can be more easily dealt with.

(3) As the quantity to be burnt is thus reduced, lower capital outlay and lower operation cost are the result.

(4) As the dust is separated, there is less risk of nuisance.

(5) Clinkers are of much better quality.

(6) The salvaged material such as bottles, broken glass, china, metal, bones, rags, etc. fetch some money to meet part of the operation cost and also help industries.

The only product of combustion is the clinker which is harmless.

It was once thought that destruction by incineration was the most efficient method, apart from the high cost. But experience has shown that it is not so. As a result, there is a greater tendency on the part of towns in Europe to dump refuse on lands or throw it into the sea rather than destroy it by incineration. These reasons are :—

(*a*) Nuisance created by the discharge of dust from chimneys though considerably reduced by the process of separation.

(*b*) Emission of burning odours particularly when the refuse is charged with considerable moisture.

(*c*) Variation in calorific value due to the variation in seasonal yield.

(*d*) High initial cost and heavy recurring expenditure.

(*e*) Unsuitability of certain refuse for destruction without preliminary conditioning.

Though the moisture content of Indian refuse may be less on account of the tropical climate, it is in most cases unsuitable for combustion. It was experimented in Bombay a few years ago, and it was found that the results were not encouraging.

(5) **Destruction by Bacterial Agency**:—For this process cubical rooms called "cells" are built of either brick or concrete provided with a trap door in the roof for charging and a side door in a wall as an outlet for discharging the final product. A grating for æration and drainage is also provided at the bottom. When the cells are filled with refuse they are made air-tight. There are three phases in the process of destruction.

(1) *Bacterial Infection Phase*:—When the refuse is filled in the air-tight cells bacterial culture, like activated sludge, prepared outside is sprayed all over this sutface by a centrifugal pump.

(2) *Anærobic Phase*:—In this the cells are not only completely sealed, but an oxygen-consuming fungus is also introduced inside for removing whatever oxygen may be present in the voids. The temperature then begins to rise steadily to about 70° F. on the 7th day. This promotes fermentation.

(3) *Ærobic Phase*:—On the eighth day air is pumped through the grating at the bottom which causes complete oxidation and also dehydration by the heat generated by the bacterial activity. At the same time the vapours arising out of the refuse are exhausted by means of an extractor pump.

The product when discharged is of a fibrous, cellular nature, slightly moist, having deep, brown colour. It is almost odourless, rich in humus, and quite free from pathogenic germs on account of the high moist temperature developed.

This method has not been tried in this country. But it is doubtful whether it would prove a success considering the climatic conditions and the character of the refuse.

(5*a*) **Composting**:—This method is the best of all, and best suited to Indian conditions, especially for small and medium towns. Its special advantages over other methods are that it solves three main problems at the same time, viz. (1) disposal of night soil, (2) disposal of town refuse, and (3) production of valuable manure for crops, which is the most urgent need at present for increasing food production of the country.

It is, in fact an old art practised by our agriculturists from time immemorial though in an unsystematic way. The scientific principles underlying it were first clearly shown by Hutchinson and Richards during their investigations at Rochamsted which resulted in the Adco Process (1920). They showed that the breaking down of lignins and celluloses in the vegetable refuse is due to the action of fungi in the initial stages, and to various ærobic bacteria in the later stages. But that to be effective these organisms require an adequate amount of combined nitrogen and phosphorus, and alkaline reaction. To supply this want, a preparation under the name "Adco", was devised by them, which hastens decomposition, and forms humus or "compost". In this country experiments were made at Indore and Bangalore at first in 1934. Subsequent large scale experiments made at many places have conclusively proved that night soil, dung from cattle stables, sewage, sullage, etc., supply the necessary nitrogen and phosphorus and that if conducted on scientific lines the method yields valuable fertiliser, and thus instead of a drag on municipal finances it is sure to prove a paying proposition by the sale of manure.

The essential requirements of successful composting are :—(1) Organic refuse such as dustbin contents, street refuse, agricultural wastes like litter, weeds, stubble, fodder residues, roots of crops, sugarcane bagasse, etc., (2) Suitable nitrogenous matter such as night soil, cattle dung, sewage, etc., (3) Moisture in the form of water, and (4) Air.

The site selected for compost depots should be away from the town at a reasonable distance and on the leeward side of it. In the case of large cities it is advisable to have two or more depots situated on different sides in order to reduce the transport charges.

Trenches, 5 to 10 m. (15 to 30 ft.) long, 1·5 to 2·5 m. (5 to 8 ft.) wide and not more than 1 m. (3 ft.) deep should be excavated leaving between any two successive trenches a vacant space of at least 2 to 2·25 m. (6 to 7 ft.). The earth excavated from the trenches should be stacked in heaps parallel to the longer sides. Roughly for an Indian town of 10,000 population, 180 trenches each 4·5 × 4·5 × 0·75 m. (15 ft. × 5 ft. × 2½ ft.) would be required for the whole year. If the cost of the land is not high, it is advisable to reduce the depth to 75 cm. or even 60 cm. (2½ or 2 ft.) since the ærobic action takes place better with shallow depth.

Large pieces of broken glass, porcelain, stones, brickbats and such other coarse mineral substances which would not decompose, should be excluded. Then a layer of 15 cm. (6 inches) of refuse followed by one of 5 cm. (2 inches) of night soil, cattle dung, etc., should be alternately spread into the trench one upon another. By the time the night soil is carried to the trenches it will have sufficiently liquefied but if there are any lumps in it, or if the cattle dung is in a solid state, water must be added to it in the proportion of 1 of solids to 4 of water to make a paste which will easily flow from buckets. The alternate layer should be spread till the heap rises about a foot above ground surface. A cover of 5 to 8 cm. (2 to 3 inches) of earth should be spread at the top. This will protect the heap from flies and also from being blown by wind. Such a layer of earth should be spread on the top at the end of each day's work irrespective of whether the trench is full or half full.

In the course of 2 or 3 days, decomposition will start and progressively gather strength by the very development of micro-organisms, accompanied by considerable heat, which may often exceed 65·5°C (150°F). The heat is the measure of the microbial activity, and serves rapidly to disintegrate all organic matter and destroy all pathogenic germs. It prevents also the breeding of flies, by killing maggots, if any.

In course of time it may be possible that the surface will sink by a foot or so. In that event alternate layer of night soil or cattle dung and refuse should be spread.

At the end of 4 to 6 months, depending upon the season, the manure is ready for application to land and the resulting product is brown, odourless, innocuous, powdery humus of high fertilising value superior to farm yard manure. If desired, it may be strained through an expanded metal sieve of 12 mm. ($\frac{1}{2}$ in.) mesh to exclude broken glass, small stones, brick bats, etc.

Frequent turning of the mass in the trench hastens decomposition but increases the cost.

During rainy season rain water should be diverted away from the trenches by small ridges across low-lying places and channels in high ground.

Questions

(1) What are the requirements of the proper methods of storage and collection of refuse so that it should cause the least nuisance?

(2) What are the essentials of the van employed in transporting refuse from the economical and sanitary points of view?

(3) What is controlled tipping and what are its advantages?

(4) What precautions are necessary if the refuse is to be dumped into the sea?

(5) Describe the method of composting and explain why it is most suitable to Indian conditions.

CHAPTER XIV

EXISTING CONDITIONS & AIMS TO BE SOUGHT

THE problem of rural sanitation is both acute and urgent. Great as is the interest being taken by Government in this subject in recent years, it is worth noting that we are making no substantial advance towards its solution. The real impediment to progress is the age-long habits and ignorance of the people. The only remedy of overcoming these is to educate the general public particularly in the elementary principles of hygiene and public health. The best way of doing this is by means of lectures on sanitary matters in simple homely language, illustrated by lantern slides, or educative health films. It is necessary to present both sides of the picture to them, such as the advantages of light, ventilation and cleanliness, and the disadvantages of living in overcrowded, ill-ventilated, dark, filthy homes in the midst of insanitary surroundings. It should be brought home to them how in the former manner of living, people and particularly infants live a healthier life, free from sickness, and get a chance of longer life. Any amount of legislation is of no avail so long as the people themselves do not appreciate the value of sanitation and are not in earnest to help themselves.

The fundamental principles underlying rural sanitation apart from the question of housing, are stated below in an extract taken from Dr. Poore's Rural Hygiene, with slight alterations to suit our special conditions :—

"(1) Every cottage ought to have a bit of garden—either a flower or vegetable garden, or a farm adjoining it, about one half of an acre, or more, and adopt the following system of sanitation :—

(*a*) All excrement should be kept out of drains ; for, by doing this the putrefaction of the solid is prevented and the purification of the liquid by filtration through earth is effected with ease, which is proportionate to the thinness of the fluid.

(*b*) All solid matter should be removed every day from the immediate neighbourhood of the house, and buried in the top layer of the cultivated ground. This surface layer is full of living organisms which rapidly disintegrate and oxidise any substance deposited in it, until in a very short time—in summer in less than a week in this country, the filth becomes fertile "humus" or mould. Household slop should be poured on the surface of the garden, and the mistake of attempting what is called sub-soil irrigation should not be made.

(*c*) Earth closets, of whatever description, should be away from the dwelling house, approached by a covered passage, with cross ventilation. Sifted garden mould taken from the top surface and dried in shed is most suitable for use. If earth closets are specially constructed as in Denmark, Sweden and Norway, so as to separate liquid from solid deposits, and if kept from household slop and other liquids, they are not only free from nuisance, but will provide valuable manure.

(*d*) With regard to other solid refuse, the rules must be :—

(i) Whatever is capable of rotting must be put in a heap to humify.

(ii) Whatever is not capable of rotting must be burnt.

(*e*) As for domestic slop water, it must never be discharged from the house below the level of the ground. The coarser impurities must be strained out by passing it through a filter of gravel, cinders, or hay put in a bucket with holes at the

> bottom, and in its transit to the filter it should be kept freely exposed to air in its entire course. If this is done, the exposure to air, sun, heat, cold, and drying winds, hold putrefaction in check, and render impossible the escape of foul gases into the house. The key to success is the separation, in every possible way of solids from liquids."

Our villages urgently require an all round improvement in the following respects :—

(1) Housing accommodation.
(2) Provision of wholesome water supply.
(3) Efficient disposal of sullage and storm water.
(4) Proper disposal of dry refuse and cattle dung.
(5) Efficient conservancy or disposal of night soil.

The efficient disposal of the night soil is perhaps the most important, since it is at the root of most of the evils as will be seen later. It is, therefore, dealt with in greater detail later in this volume. It is taken as the last item here, only for the sake of convenience.

The Existing Conditions :—(1) Housing Accommodation :— Houses have not been built according to any fixed plan on a properly selected site, but they are clustered together at random with 3 to 3·5 m. (10 to 12 ft.) passages between two rows called 'roads'. In most cases there is some open space on the rear side, which generally abuts directly on fields, but there is none in the front, and very narrow gullies on sides between two houses. These gullies are invariably full of debris of all sorts.

The walls are in most cases of mud, either cob, i. e. lumps of mud heaped in layers one upon another, or sun-dried bricks, or in a very few cases of stone chips or bricks in mud. In some parts of the country they are of split bamboos, saplings of cotton, *tur* or similar plants, leaves of cocoanut trees, etc. tied horizontally to vertical posts of jungle wood buried in ground, and plastered over with mud on both sides.

The roof consists of either thatch or flat country tiles laid on split bamboos or similar material, in parts where there is heavy rain, or of mud laid flat on jungle wood boards, or *Sarkand*, *Samlu*, etc. in N. India, or palm leaves in the South, where the rainfall is light.

The floor is invariably of mud, occasionally leaped with cow-dung.

In the majority of cases there are no windows as such. In a very few cases small holes about 30 cm. × 30 cm. × 30 or 25 cm. (1 ft. × 1 ft. × 1 ft. or 9 in.) with wooden square bars and in some cases round country tiles are inserted in walls.

The average cottage has an accommodation of two rooms and an open verandah. One of the rooms or the verandah is generally occupied by bullocks and cows.

There is usually no bath-room, and very few houses have a sink of stone in mud. Bath, whenever necessary, is taken in the open space on the rear side, and in houses where there is no sink, the slop water from the kitchen is thrown either on the front road or in the back yard.

There are no privies. Use is made of the open space for answering calls of nature. This aspect will be described later.

(2) **Provision of Wholesome Water**:—As regards water supply, in majority of cases it is derived from one or two wells. The interior of these wells is not made water-tight by cement rendering, with the result that the surface water from the surrounding ground which is polluted by organic matter, gains admission to the well. At first this surface water is filtered and purified by the layers of soil and sub-soil, but in course of time these layers get saturated with contaminated matter, and then raw sewage is likely to find its way directly to the well. Sometimes the wells are close to privies, or drains and water courses or *nallas*, which are repositories of filth, and the danger of contamination is aggravated.

Often the wells are provided with steps so that people can get direct access to the water. In that case the chances of contamination are very great. People wash their mouths, clothes, cooking utensils, etc. in them.

Other sources of water are surface tanks which are more liable to contamination than wells. Even animals get direct access to them. People pass urine and stools on the banks. Rivers and streams are also open to contamination of all sorts in the same way as tanks, and generally are used as latrines on account of the facility of water for ablution they afford. Besides, rain water from the surface which feeds the tank has all sorts of filth accumulated on the surface dissolved in it.

Guinea Worm:—Water supply, particularly of a step well is liable to be affected by guinea worm. It is a common disease in the villages of this country caused by a worm. The female guinea worm which is 60 to 90 cm. (2 or 3 ft.) long and thin like a cotton twine, develops inside the human body and breaks through the skin on the foot or leg when a person infected with it goes to a storage of water like a step well or river, and ejects thousands of larvæ in the form of milky fluid, and infects the water. There are cyclops or water spiders present in the water which devour these larvæ. The latter then develop in their bodies. If the water of these wells is drunk by people without filtering or even mechanically straining it through a cloth they are swallowed with it. The cyclops are digested and the maturing worms are set free to enter the tissues in which they flourish and complete their development, producing long, mature females, sometimes two, three or even more, which break through the skin into the water, and thus the cycle is completed. The person affected suffers from acute pain for months together, and becomes debilitated and crippled during that period. A draw well may also be affected if feet or legs are washed near the well and water allowed to spill or flow into it. The measures necessary to successfully prevent the out-break of the disease are (1) to convert the step well into a draw well, (2) destruction of cyclops by adding quick-lime to the well water, in the proportion of one drachm of lime per gallon of water, (3) straining water through a muslin cloth before it is used for drinking, or (4) using boiled water, as the larvæ and cyclops are destroyed by heat.

(3) **Sullage and Storm Water**:—As for sullage water, most of the villages having very meagre supply of water for domestic purposes, quantity of sullage is very little. Still, if the water from bath rooms is allowed to soak into the soil just outside the walls of the house, it is likely to cause damp. In course of time the ground gets saturated and the water is neither absorbed, nor does it flow away as there is no regular drain provided and, if provided by excavating earth, it is blocked. Dogs and poultry tread on it and bring the filth back into the house. It forms a cesspool which stinks and breeds mosquitoes.

Regarding storm water if the village is situated on an elevation, the rain is a blessing in as much as it washes away all the dirt. But if it is low lying, not only the dirt is not washed away, but all the organic matter accumulated on the surface, dried by the sun, putrefies; besides ponds are likely to be formed causing malaria to spread.

(4) **Refuse and Cattle Dung**.—In respect of the refuse and cattle dung, villages are still worse. For, the quantity of refuse produced in connection with agriculture is far greater than the house refuse in towns. There is also a large quantity of dung from cattle stables. Some of the agricultural refuse is fed to the cattle, still there is so much other refuse which is not edible by cattle, such as husk of ground nuts and rice, sugarcane bagasse, etc. The cowdung is ordinarily used for making cakes to be sold as fuel. But in the wet weather there is rain and no sufficient sun to dry it. It is, therefore, dumped into a pit close to the house indiscriminately which causes great constant nuisance of foul odour and flies. Occasionally it is covered with some refuse, but it is done too haphazardly to keep out flies.

(5) **Conservancy**:—The condition of villages is the worst possible in this respect. There are no privies either attached to houses or public ones, nor are there any sweepers. The adults seek open spaces behind prickly pears or other hedges or standing crops, on banks of tanks, in ditches, rivers and *nallas* and similar places where some degree of privacy is

obtainable. The children have the privilege of using the front or back yard of the house or street edges for answering the calls of nature. The old and the sick seek some privacy around the house. During night time, even the adults in health find the same place very convenient. Thus there is always lot of excremental matter both human and that of cattle lying scattered about the houses.

This excremental matter contains bacteria of certain diseases like cholera, typhoid, dysentery, etc. The epidemic ravages of these diseases make life in the villages uncertain. The germs of these diseases are actually swallowed either with food or water. Hundreds are the ways in which this is unwittingly done. For example, flies sit on rotting filth and then settle on food with bacteria of dangerous diseases sticking to their feet. The germs may be carried to the sources of water supply even directly or by infiltration through the soil saturated with it. The dry excreta might also be crushed under feet, blown by wind, and then settle on the surface of food, bazaar sweets, water, milk, etc., as dust, and find direct entrance into human intestines.

In propagating germs of diseases the innocent looking common house fly plays perhaps the greatest havoc, which on account of its familiarity is not properly appreciated. It will be seen from the following description that it is not only the dirtiest animal, but it is no exaggeration to say that it is the harbinger of Death :—

Fig. 171 shows one of its six legs highly magnified. It will be seen how full of hair they are. Besides each leg has two pads of very soft velvet-like hair—in all twelve pads.

The female fly deposits its eggs on a heap of rubbish, such as cow-dung, human excreta, putrefying animal or vegetable matter, etc. One female fly lays about 120 eggs at a time, which hatch out in 6 to 8 hours into larvæ (maggots). The latter develop in 4 or 5 days into hard, brown pupa, which in five days more open and the baby fly comes out for a season of activity covering several weeks. There are as many as 12 generations produced in a single season. Thus if each fly lays

120 eggs at a time, it is possible that millions of flies may be produced by it in a season. The duration of a fly's life is about 2 months.

A fly cannot eat solid things. In order to feed on dry substances, like sugar, dry specks of milk, or nasal discharges etc. it first liquefies the substance by secreting saliva on its surface, helped by rapid movements of its proboscis on it. It is such a voracious animal that it goes on feeding until the stomach is distended to an uncomfortable degree. Then it regurgitates, or vomits part of the food eaten to relieve distension, and starts feeding again. Often it deposits its fæces on it. When hungry, a fly will eat the vomit or excreta of its own or other flies.

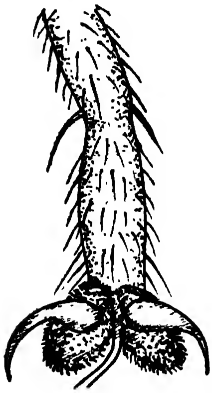


Fig. 171 – A leg of a fly highly magnified.

The fly carries bacteria and spreads infection in three ways:—

(1) Firstly, when it rests for feeding on any infectious material such as filth in gutters or latrines, or open wounds, innumerable bacteria are bound to stick to its legs, hairy pads, wings, etc., which are sure to be introduced into the food, milk, open wounds, etc. It is a common phenomenon that swarms of flies sit on the filth exposed in latrines, and when tired of feeding on it they enter the kitchen and sit on food for a change !

(2) By feeding on infectious matter their whole alimentary canal becomes a temporary resting place for the germs. From there the infection may be distributed in two ways : (*a*) The contents vomited by the mouth contaminate the entire food on which it is done. (*b*) The excretions of the fly which are full of bacteria are mixed with the food. As already mentioned, when hungry, flies will suck the fæcal matter or the vomit of other infected flies, and thus clean, uninfected flies also will pick up infection from other flies.

(3) By sitting on the lips of infants, or exposed wounds on human bodies. The germs left on the lips are carried into the mouth with saliva and diseases like infantile diarrhoea are produced.

Thus this familiar, ubiquitous animal, companion of man in his wanderings over the face of the globe, seemingly innocent, is responsible for the spread of cholera, typhoid, tuberculosis, dysentery, infantile diarrhœa, small pox, ophthalmia, oriental sores, etc., and thus it is truly a harbinger of Death.

Another effect of the excrementitious matter lying scattered about the house is the spread of the hook-worm. It grows in the intestines of human beings and its eggs are thrown out in enormous numbers in their excreta. One worm produces about nine thousand eggs per day. The worm develops into the larvæ stage in warm, damp earth. When persons walk bare-footed on such a ground, the larvæ which are picked up by the foot, enter through the skin into the blood stream and are first carried to lungs, when they break through air sacs, pass up into the throat, and are swallowed. Thus they finally reach the intestine where they develop into the worm stage. Sometimes the larvæ are directly swallowed with green vegetables eaten raw. Though the disease is not fatal, it lowers the vitality of the victim, who then easily falls prey to other diseases like malaria, tuberculosis, etc.

These are all preventable diseases, and the only way to prevent them is to remove the foul refuse matter continuously and promptly, and dispose of it in a suitable manner.

Questions

(1) What are the fundamental general principles of rural hygiene in respect of excremental matter and solid and liquid household waste matter ?

(2) What are the common sources of contamination of village well water ?

(3) How does the common house fly spread diseases ?

(4) Write brief notes on (*a*) guinea worm ; (*b*) hook worm.

CHAPTER XV

THE REMEDIES

(1) **Housing**:—Firstly, a complete housing survey should be made of all the houses in villages, and the existing houses should be classified into the following groups:

(1) Those which are defective but not to such an extent as to be unfit for human habitation.

(2) Those unfit, but repairable by making alterations.

(3) Those which are unfit and it is radically impossible to make them fit.

A house may be regarded as unfit *(a)* when apart from its dilapidated condition, there is total absence of ventilation, or *(b)* when there is some ventilation, it is not through, e.g. in a back to back house there may be some ventilation from the front but it is not through, or *(c)* when there is marked damp.

A committee of experts should be appointed in each province who should travel in all parts of the country, and taking into consideration, the climatic conditions, social and religious habits of the people, their limited resources, the materials available, the building practice in different provinces, etc. should make recommendations regarding the minimum standards for different parts in respect of *(a)* the area of plot, *(b)* the space surrounding houses, *(c)* minimum accommodation, *(d)* the floor area and cubic space of each room, *(e)* height of plinth, *(f)* minimum ventilation, *(g)* the sanitary conveniences to be provided, *(h)* the minimum distance from house to cattle sheds and manure pits, etc. These standards should be different for (1) the existing houses, and (2) new houses to be erected in future.

As the people living in villages are expected to spend most of their time out of doors, unlike the labourers residing in an urban industrial area, such high standards of light and ventilation as are necessary for the latter, need not be rigidly insisted on for rural areas. It should be insisted that no cattle—not even young calves are allowed to occupy any space inside the house.

The standards will generally vary from province to province if not from district to district. The variations are partly due to the different economic conditions but mainly to the climatic environments, sociological conditions, building traditions, topographical features, and occupier's profession. They should, however, be based on considerations of sanitation, comfort, convenience, safety, and social and national objective, such as promotion to efficiency in labour and human values.

A healthy, adequately sloping, elevated site with sufficient area for expansion should be selected in the first instance. The minimum width of the main roads should be 15 m. (45 ft.) and that of all inner roads 10 m. (30 ft.).

Amenities:—Sites for all civic requirements such as those for medical relief, education, recreation, administration, shopping, and the like should be provided.

On the basis of the recommendations made by the committee of experts as indicated above, Rural Housing Legislation should be enacted on lines similar to those in England* and other Western countries, and should be enforced through the Village Panchayats under the control of the Taluka and District Local Boards and the Collectors of districts.

Provision should be made in the act for making it compulsory for every house-owner to provide sanitary conveniences of some type or other such as an earth closet, bore-hole, trench latrine, etc., as described later in the chapter which follows.

* Refer to (1) "Housing of the Working Classes Act (1885)" of England revised in 1890 and 1903, further revised and passed under the title : "Housing, Town-Planning, etc. Act (1909)". (2) "Memorandum with respect to the Provision and Arrangement of Homes for the Working Classes," (3) "Christopher Turner's Small Holdings Committee Report (1914)", and (4) "Housing Act (1924)."

In addition, each Village Panchayat should provide adequate number of trench latrines for public use.

Until the people appreciate the value of ventilation, and keep windows open, without fear of draught, positive, fool-proof means, such as roof ventilators, small holes dotted all over in the exposed walls, etc., should be made compulsory.

The Central Government should give loans, *Takavi* advances, etc. at a low rate of interest repayable in 10 to 15 years to house-owners for carrying out the alterations. In some instances Government should build cheap model cottages and offer them on low rentals. Priority should also be given for certain materials such as steel, cement, c. i. sheets, etc. which are not easily available.

(2) **Water Supply**:—If it is derived from wells a parapet wall all round the well at least 1 m. (3 ft.) high and a paving 1·5 m. (5 ft.) wide of any impervious material, sloping towards a *pucca* gutter should be constructed. The gutter should carry the waste water at least to a distance of 15 m. (50 ft.) from the well which should be suitably treated there, by growing vegetation. The area within a radius of at least equal to the depth of the well should be regarded as 'protected area' and should be kept clean, keeping out cattle from it by a fence, if necessary. If the well has access steps, the entrance to them should be closed, and it should be converted into a draw-well. Nobody should be allowed to draw water except with the bucket and the rope or chain, provided by the Village Panchayat for public use. A still better arrangement would be to provide one or two hand pumps. Nobody should be allowed to swim in the well.

Pumps are rather costly and liable to get out of order by constant rough use. Therefore, the following more practicable and cheap arrangement is suggested :—

A high level tank should be built, and it should be fed by means of the usual "*mot*" or "*charsa*" arrangement consisting of an inclined bank for the bullock tread, pulley and a leather *mot*. The actual quantity of water hauled up depends upon the lift, but on an average about 35000 to 45000 litres (8,000 to 10,000 gallons) can be easily hauled up by one pair of bullocks in one working day. A *mot* is a time-honoured, familiar thing in villages, and usually does not get out of order, and if it does at all, the village craftsmen can easily and promptly put it into order. It is very easy to obtain a pair of bullocks by turn from the villagers on a co-operative basis, so that the expense would be very little. Such wells are usually either in the centre of the village, or at least close to them, so that the cost of piping would be small. Two or three stand-pipes should be installed at central places, and the villagers should be trained not to waste water. If this is done, not only so much manual labour on the part of the villages would be saved in fetching water, but the supply of pure water would be guaranteed.

Small, shallow village tanks storing surface water are very difficult to keep clean. For, not only the tank, but all its catchment area, rain water from which flows down to feed the tank, must be constantly kept free from contamination. The best course is to close such tanks and provide ordinary wells or tube wells instead.

It is still more difficult to keep rivers, particularly those with slender flow in the summer, free from contamination. A length of the river at least ¾ km. (½ mile) upstream of the village, should be proclaimed to be 'reserved' or 'protected' and any washing, bathing, watering of animals, etc. in that portion should be made punishable.

Once in three months and particularly, at the time of the village fairs, the water in the well should be disinfected with either potassium permanganate, or bleaching powder. The manner of doing this is as follows :

Potassium Permanganate :—One way is to calculate the quantity of water in the well by ordinary mensuration and put P. P. in it in the proportion of 5 parts of P. P. per million parts of water. The other depends on the colour test only. A sufficient quantity is said to have been added when after half an hour a red tint is still present. In all cases enough should be added to produce a faint pink colour lasting 24 hours.

The mode of mixing P. P. is as follows: Put the crystals into a bucket and fill it nearly half with the water to be treated. Stir it up and pour the solution into the well leaving the undissolved crystals at the bottom of the bucket. Repeat this till all the P.P. has been dissolved. If the P. P. is added at night, the water will be fit for drinking the following morning. If by this time the water has a red colour, it will have a slightly unpleasant taste for some time, but it is perfectly harmless.

Bleaching Powder :—This is a whitish grey powder with a characteristic chlorine smell. It consists of slaked lime saturated with chlorine, and is a powerful sterilizing agent. Its strength, however, deteriorates by storing unless it is done in air-tight sealed cans. The dose depends not only on its strength, but also on the amount of organic matter present. Roughly one part of bleaching powder of 25 per cent chlorine strength is required to sterilize one million parts of average water.

Make a 1 : 20 solution of 1 gm. of powder (25 per cent strength) in 20 c. c. of water or 1 kg. of powder in 20 cu.m. of water (one ounce in one pint of water) and keep it in a well stoppered bottle in the dark. The well treated with it should be allowed to stand for 24 hours for its action. The test of the sufficiency of the dose is that there should be free chlorine in it appreciable to the taste. The presence of chlorine can be tested also chemically by adding potassium iodide and starch to the sample of water, when a bright blue colour will appear. The advantage of using bleaching powder for disinfecting water is that its disinfection is completed rapidly in about 20 minutes.

(3) **Sullage and Storm Water** :—The disposal of these should present very little difficulty in villages. For, bathing which requires a comparatively large quantity of water is not a daily affair in most families, and if practised, it is done in the open area in the back yard, where the water is absorbed by surface soil, and is subsequently dried by the sun. The slop water from the kitchen is very small, and as it is collected and thrown on the ground surface it is also absorbed by it. However, in a few families, where there is a bath room

inside the house, and a sink in the kitchen and where bath is taken by every member daily, a *pucca* open drain at least 5 m. (15 ft.) long from the house, consisting of half-round stoneware pipe and cement-lined brickwork at top should be constructed with a bedfall sufficient to prevent stagnation, and the water from it should be collected in a movable vessel, which should be emptied daily and used for watering plants. In no event it should be allowed to collect in a cess pit to soak into the ground.

The sink in the kitchen need not be larger than 60 cm. × 60 cm. (2 ft. × 2 ft.). If it is to be used only as a kitchen sink, i. e. not for occasional bathing, even 45 cm. × 45 cm. (18 in. × 18 in.) will suffice. The flooring should be of flagstone in one piece with the slope towards the outlet side. A piece of pipe at least 500 mm. (2 in.) in diameter should be laid for leading the water to the outside. It should not be provided with an elbow to divert the course of water downwards, and should drop the water on the top of grass put into a bucket with perforations at bottom. Thus all the solids including fats will be arrested by the grass allowing only the slop water to trickle down. There should be another chamber lined with cement inside just 15 cm. (6 in.) deep below the perforated tin for collecting water and allowing it to run through the drain.

The storm water is, in fact, a blessing if the site of the village is on an elevation. When it rains, the water washes all the accumulated dirt and carries it away. Thus no elaborate system of drainage is necessary in such a village. But if the site is low-lying and the ground surface is flat, swamps may be formed in the land adjacent to the houses. In such cases a system of surface drains as described in Part II of this volume may be necessary. However, such cases are very rare.

(4) **Disposal of Dry Refuse and Cattle Dung** :—The best way of disposing of this satisfactorily both from the economic and sanitary points of view is to resort to composting as described in Chapter XIII. This may be done by the Village Panchayat just in the manner of town municipalities, or by individual house-holder on a small scale. In the latter case a difficulty may be experienced in finding sufficient quantity of bulky refuse to cover the dung and other organic putresci-

ble matter. Another difficulty may also be felt, viz. whereas when composting is done on a collective basis the services of a sweeper may be available, when it is practised on a small scale by an individual, the responsibility of doing it systematically, without causing any nuisance falls upon the house-owner.

To obviate the first difficulty dry earth may be used either with or without bulky refuse for covering the cattle dung. The site for the compost depot should be as far away from the house as possible, and at least 10 m. (30 ft.) away from a well. It should be in such a direction that wind from it will not blow towards the house. A layer of about 10 to 15 cm. (4 to 6 in.) thickness of solid refuse should be spread at the bottom of the pit, which should not be more than 75 cm. (2½ ft.) deep. On this, cattle dung thinned with water sufficiently, so that it will flow easily, should be spread in an even layer of 5 cm. (2 in.). Upon the latter a layer of 15 cm. (6 in.) of refuse or 8 cm. (3 in.) of dry earth should be spread alternately with the final layer at top of 15 cm. (6 in.) of earth. If dry earth is used, the compost should be ready for application to land as manure within three months, otherwise in 6 months. The same pit can be used again for a fresh compost depot.

If by chance some part of the dung is left exposed and nuisance of flies is suspected, crude oil should be sprayed on the top every fortnight.

Questions

(1) What factors must be taken into account in determining the housing standards in villages of different provinces ?

(2) What precautions are necessary to prevent contamination of village wells ?

(3) Describe the process of treating the water of a well with potassium permanganate. How is the correct dose determined ? In what respects is bleaching powder superior to P. P. ?

(4) Describe the simplest way of disposing of urine and dung from a cattle shed.

CHAPTER XVI

DISPOSAL OF NIGHT-SOIL

THE ideal method suitable for disposal of night soil or sewage must satisfy the following requirements:—

(1) It should be cheap, both in initial cost and maintenance, so as to be within easy reach of the average house-owner in villages. Otherwise, it will not appeal to him as his means are very limited.

(2) Its construction and subsequent operation should be so simple as to be within the capacity of the village carpenter or mason either to make or mend it.

(3) It should not give access to flies for obvious reasons discussed in a previous chapter

(4) It should not give out foul odours, which are not only unpleasant, but very often detrimental to health.

(5) It should not cause any splashing of sewage over ground surface to preclude the danger of spreading hook-worm or causing nuisance of flies.

(6) It should keep out dogs, pigs, rats and other animals. Otherwise they might spread infection by contaminating food or water supply.

(7) It should not contaminate the source of water supply such as that of streams or wells.

(8) It should require the least quantity of water, should this be necessary, for its cleansing, dilution, or purification; for, there is generally scarcity of water in villages.

(9) It should be automatic in action. No constant attention should be required for its proper maintenance. This condition is necessary in view of the social and religious prejudices of the people that none but a person of the sweeper class should handle such a disposal plant or installation.

(10) It should be fool-proof, and if anything goes wrong at all some time, it should give a fair warning in good time before it causes practical adverse effects on health.

Although domestic sewage is very simple in composition, and thus easy to treat as compared with that from a large town where industrial and chemical wastes, soap water from laundry establishments, waste from slaughter houses, etc., are freely admitted to the drains carrying sewage, small private installations have certain heavy handicaps. A large town can afford to pay the salary of a trained and experienced supervisor. Secondly, a town or a large establishment can generally find a suitable land for disposal in the neighbourhood; at least the Local Authority can acquire it under the Land Acquisition Act, whereas, the land in the vicinity of private houses may not be of the suitable type in the first instance, or that too may be very much restricted in area. Thirdly, the house may not be situated at a sufficient elevation with respect to the land available so as to obtain the necessary fall in the drain for the conveyance and purification, and so on.

Methods of Purification :— Whatever method is employed, the ultimate purification takes place by the process of oxidation. The methods suitable for rural areas may be classified into two divisions.

(*a*) Those in which earth is used for purification.

These are:—(*i*) Earth closets.
(*ii*) Bore holes.
(*iii*) Trenches.
(*iv*) Land filtration.
(*v*) Irrigation.

(*b*) Septic tank with further purification of the effluent.

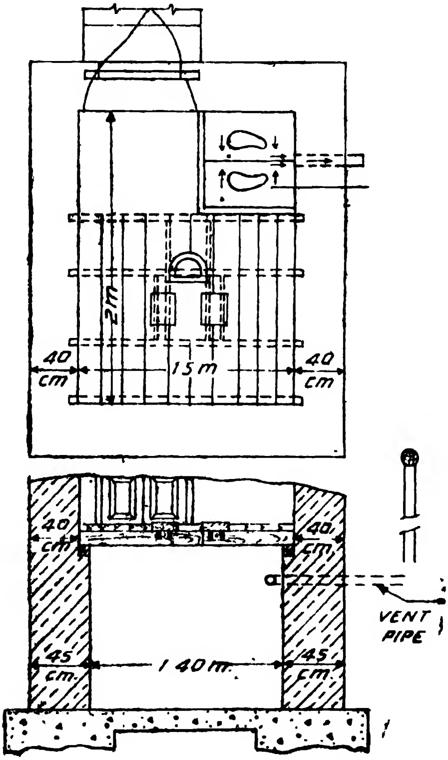
(*i*) **Earth Closets** :— Dry earth, particularly from the surface of arable, cultivated land possesses the property of both deodorising and oxidising organic matter. The latter it does through the agency of the myriads of living micro-organisms present in it. This method has been most successfully used in rural districts in England. In fact, it is the only method employed where there is not sufficient running water available to resort to the water carriage system. In India there are two disabilities viz., the tropical hot climate sets putrefaction very early, and that the habits of the people are such that they use water for ablution in most cases, sometimes in large quantities which encourages putrefaction. Still, if earth of the right type is used in sufficient quantity, next to water carriage system this is the best from the sanitary point of view ; and from the economic point of view this is even superior to it since it yields very good manure.

The type of earth closet shown in Figs. 172, 173 is found by experience to give excellent results. It consists of a masonry chamber 1·25 to 1·5 m. (4 to 5 ft.) deep with 15 cm. (6 in.) of concrete at bottom and 45 cm. (18 in.) side walls of stone or brick-in-lime. The chamber is lined with cement plaster one inch thick on the inside. At the plinth level the thickness of walls is reduced to 40 cm. (15 in.) leaving an off-set of 5 cm. (1½ in.) all round. On this ledge a wooden frame is placed, and a rigid platform is made on it with 5 cm. (1½ in.) teak boards, leaving a gap 18 cm. (7 in.) wide in the centre with foot-rests on both sides of it for squatting. A suitable basin with a hole at the bottom towards which its bottom is sloping is provided in the front to allow the urine to pass through it into the chamber. In order to exclude the ablution water, a small sink is made on the front side in the right hand corner of the room. As soon as the closet is used, dry, friable earth provided in a pail near the seat is to be spread by the user in sufficient quantity to cover the excreta, and the ablution is to be done in the sink in the corner. The water from the latter is diverted into a separate soak-pit filled with boiler clinker, overburnt bricks, stone rubble, etc. with a layer of hay on it, and on the top of the latter a layer of earth 15 cm. (6 in.) thick is spread. Thus the ablution water is treated separately.

As only the urine, and no water is allowed into the chamber, the quantity of dry earth required to treat the night soil is small, and therefore the chamber lasts for a long time, Sometimes ashes are mixed with dry earth. They absorb moisture and check putrefaction, but the purification is done by the micro-organisms present in the earth.

An earth closet should not be inside the house, but separated from it by a well ventilated passage.

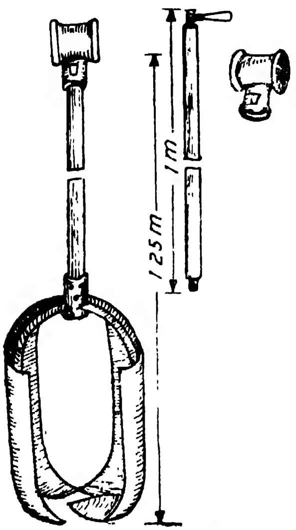
When the chamber is filled up to say, about 15 cm. (6 in.) below the top, a layer of dry earth should be spread on the top below the boarding and kept for a month. By this time the night soil would be converted into excellent manure free from any smell.



Figs. 172, 173.

(*ii*) **Bore-holes** :— A bore-hole is a much cheaper and more convenient method than a closet which requires a masonry chamber. But it is not possible where there is rock or *muram* at surface, or where there is loose sandy soil. The ideal conditions are that the soil should be of a firm nature and 3 to 5 m. (10 to 15 ft.) deep. Heavy clay soil (not black cotton soil which cracks) is the best. The sub-soil water level should be as low as possible.

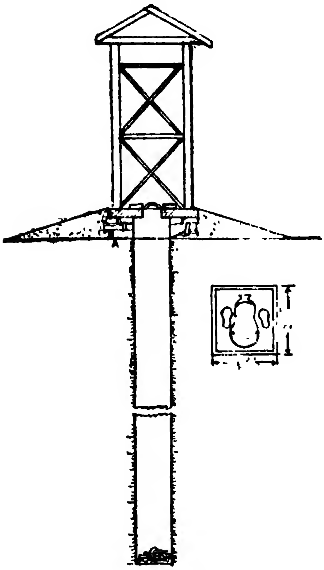
The site selected for the bore should be on an elevation with slopes on all sides. If such a site is not available, one should be artificially made by filling earth.



Figs. 174, 175 & 176—Auger, lengthening rod with cotter pin, and T-piece.

A hole 20 to 40 cm. (9 to 16 in.) in diameter is drilled vertically in the soil by an instrument called an earth auger illustrated in Figs. 174–176. It consists of four fan-shaped fins of steel about 30 cm. (12 in.) long having cutting edges at bottom, with a vertical rod riveted at their top. The total length of the piece is 1·25 m. (4 ft.) including the drilling auger and the vertical rod. On the top of the latter is fitted a hollow 'T' by means of a cotter pin. The rod can be lengthened to any extent by removing the T-piece and screwing down lengthening rods each 1 m. (3 ft.) long. First a small pit about 30 cm. (1 ft.) deep is excavated by a pick-axe. The auger is held vertically in its centre, and by inserting a wooden or iron bar horizontally into the hollow T-piece at the top the auger is rotated by two men going round and applying some pressure downwards on the rod. This causes the instrument to drill a hole. At about every ¼ m. (foot) the instrument should be lifted and the earth core collected by the auger removed. Incidentally this core of earth indicates the sample of the strata met with. When a depth of about 75 cm. (2 to 2½ ft.) is reached a 1 m. (3 ft.) lengthening rod should be connected and further work resumed. Four able-bodied men are required for a bore-hole, so that while one pair is working, the other is taking rest. In this way about 3 m. (10 ft.) long bore can be drilled by them in one day.

When the bore is completed, a seat either of wood, stone or brick masonry, or specially moulded concrete with a 18 to 20 cm. (7 or 8 in.) hole in the centre should be placed on the top and a privy with walls of bamboo matting or hessian cloth nailed to a wooden frame and a roof on top should be built on it as shown in Figs. 177, 178.



Figs. 177, 178–Section of a bore-hole latrine and plan of the seat.

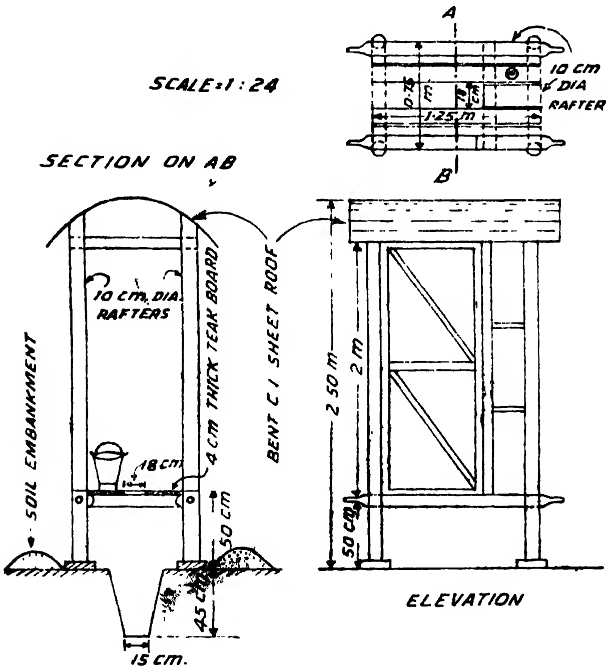
A bore-hole latrine does not require earth to be spread on the top of the fæces, nor is it necessary to exclude ablution water from it. When filled up to about 45 cm. (18 in.) below the top, it should be filled with earth forming a heap of about 15 cm. (6 in.) height on the top, on which should be placed a heavy stone. In about 2 or 3 months the bore hole will be ready for being emptied. The latter can be done by the same earth auger. This time the work should be very easy and can be done only by two men in half a day. The material brought out is a very valuable fertiliser and does not give out any smell. The bore thus emptied can be used again.

Though the sides of the bore which are of earth, help in deodorising and oxidising the fæcal matter, actually the bore-hole works more on the principle of a septic tank. The solid organic matter is partly liquefied, the liquid together with the water used for ablution being absorbed by the earth. A bore-hole gives satisfactory work even if the sub-soil water rises in it in the rainy season.

It may happen that when the bore is filled to within 1 m. (3 ft.) below the ground surface, it may attract blue flies. In that event about ½ to 1 kg. (1 or 2 lbs.) of quick-lime should be put into it to stop the trouble.

The bore-hole satisfies all the requirements of an ideal system except one, viz., it is likely to contaminate the supply of a well, if close by. It should not, therefore, be drilled within at least 10 m. (30 ft.) from a well, and further the same bore-hole should not be reused if it be near a well, but another should be drilled away from the well.

(*iii*) **A Trench Latrine**:—This is a very convenient and cheap method and may be used on a small scale for an individual family or for the whole village community on a large scale.



Figs. 179, 180 & 181.

For domestic use a portable trench latrine as shown in Figs. 179-181 is a very cheap design. The squatting platform consists of a frame made like that of an ambulance stretcher but only half as long. It is 1·25 m. × 0·75 m. (4 ft. × 2½ ft.) with projecting handles like those of a stretcher for the facility of lifting it when necessary. The platform consists of 4 cm. (1½ in.) boarding nailed on the frame with a lengthwise gap in the centre, 18 cm. (7 in.) wide and 60 cm. (2 ft.) long. The wooden platform should then be fixed horizontally between four vertical wooden posts at 60 cm. (2 ft.) from the bottom. The posts should be 7·5 cm. (3 in.) square and 2·5 m. (8 ft.) long. The frame of the latrine thus formed should be enclosed either with bamboo matting or hessian cloth nailed on to it and cement washed on both sides. A door should be made of the same material on one side fitted preferably with a self-closing spring. A suitable roof may be formed on the top.

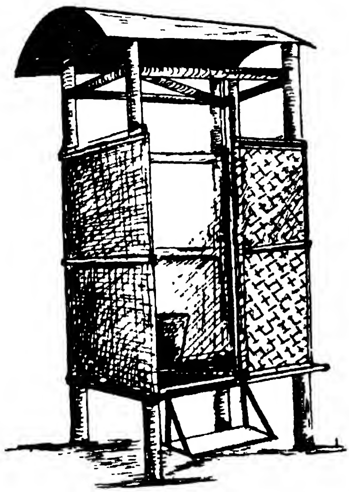
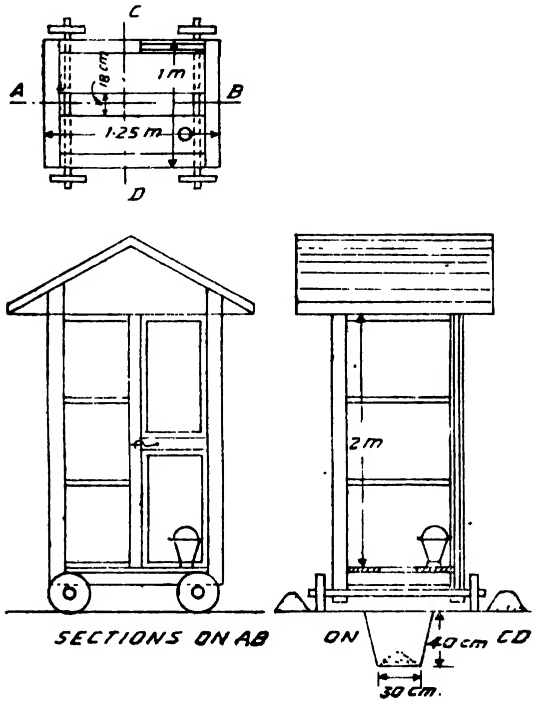


Fig. 182—Sketch of a stretcher type trench privy.

The portable latrine should be placed centrally above a trench 25 to 30 cm. (9 in. to 1 ft.) wide at bottom and 45 cm. (18 in.) wide at top with sloping sides, and about 45 cm. (18 in.) deep. The earth excavated from the trench should be heaped in long ridges on both sides to exclude surface flow of rain water.

A bucket, full of dry earth collected from the surface of a cultivated land, with an iron scoop in it, should be placed inside the latrine. The user of the privy should spread the earth by means of the scoop in sufficient quantity to cover the fæces completely. When the portion of the trench below the privy is nearly filled up to the ground surface the portable privy should be lifted by means of the handles and placed a few inches forward or backward, and some earth from the side ridges should be drawn to fill the portion of the trench previously used up to a few inches above the ground surface.

A trench of the above size 3 m. (10 ft.) long would last for one year for a family of six souls. Fig. 182 shows a sketch of such a privy.



Figs. 183, 184, 185.

Figs. 183–185 show an improved design of a portable privy, which may cost a little more. In this, instead of a stretcher-like frame with posts resting on the ground, there are four wooden wheels with iron axles. The latter make it very easy to push the privy forward or backward without much effort.

Precautions:—(1) Choose a site on the leeward side of the house so as to preclude the possibility of nuisance of bad odour if anything should go wrong at all.

(2) The site of the trench should be as far away from a well as possible. As a further precaution, the trench should not be deeper than a foot, and more earth should be used. The aim being not to allow sewage to be concentrated at one place.

(3) Proper precautions should be taken so that surface flow of rain water will not enter the trench, or at least will not form a pond on its surface.

(4) Once a week some crude oil should be sprayed by means of a D. D. T. pump over the trench and floor of the privy to prevent flies sitting. Another way to prevent flies is to screen the hollow portion underneath the trench by means of pieces of gunny cloth nailed on all the sides below the platform so as to exclude light from it.

Advantages :—(1) If the above precautions are taken and earth regularly spread in sufficient quantity, the system is most satisfactory from a sanitary point of view.

(2) It affords the best privacy. Even the *purdah* ladies, children, and sick persons would find it very handy.

(3) It is very cheap, both in the first instance and also in maintenance.

(4) The construction is very simple, the materials required for its upkeep, viz. dry earth and occasionally crude oil are easily available. There is nothing likely to go wrong.

(5) The capacity of an earth closet described on page 168 is limited. That of this trench is unlimited, since the bed and sides are all of absorbent earth, and so less earth is required than in an earth closet. There is no necessity of ablution being made in a separate sink.

(6) As the latrine is moved from place to place the concentration of sewage is prevented, and thus there is very small chance of contamination of the water of a well. The excreta are converted into harmless humus within 8 days.

(7) It is not necessary to empty the trench as in the case of an earth closet, or a bore-hole, and still the benefit of the valuable manure can be fully derived, since, whatever crops or vegetable or flower plants are grown on or near the trench their roots will obtain the nourishment.

(8) As the same trench can be reused, a very small space, which is usually available on the rear side even in the smallest house, is sufficient.

This method can be used on a large scale for the benefit of the whole village community also. The site for the trenches should be just outside the village on two or three sides of it for the convenience of the public. Instead of a single privy, light units of two or three seats mounted on wheels should be made. If a Village Panchayat could afford some initial expenditure a better and permanent arrangement would be to build a large shed and on its floor construct rows of long and narrow masonry pits plastered on the inside with cement. On these should be placed privy units each of 3 or 4 seats mounted on wheels, separate for males and females. A kerosene oil tin with the top removed, filled with dry earth should be kept in each compartment with a piece of cardboard in it. A sweeper should be maintained to put earth on the fæces if any user neglects to do it. He should also be responsible for keeping the premises clean. There should be two sets of pits so that while one is being used, the other will be under rest prior to being emptied. A large quantity of valuable manure would be available, the sale of which would meet at least a large part of the expenditure.

Statistics collected at the residences of industrial labourers have shown that only about 40 per cent of the people including children are in the habit of answering the calls of nature in the morning, the remaining 60 per cent doing it some other time during the day. Thus in a village of 500 population, supposing that there are no private privies attached to any of the houses, provision must be made for 200 people, and at the rate of one seat per 15 persons, 14 privies—7 for males and 7 for females would be required. From this it will be seen that the problem is not so difficult as it looks at first sight.

(*iv*) **Land Filtration** and (*v*) **Surface Irrigation** :—These are treated in Part II under Disposal of Sewage.

(b) **Septic Tank** :—This is dealt with in Part II under Sewage Disposal.

PART II

Sewerage and Sewage Disposal

CHAPTER I

INTRODUCTION

ONE OF the fundamental principles of sanitation of community is to remove all putrescible matter, whether solid, liquid, or gaseous, away from the premises of dwellings as fast as it is produced, to a safe place, without causing any nuisance, and dispose of it in a suitable manner so as to make it permanently harmless.

It has now been universally acknowledged that sewerage, which is essentially based on water-carriage system is the only method, which in points of convenience and hygienic efficiency, is not excelled by any other method. For, it not only meets the requirements mentioned above—it removes all house-wastes, and removes them immediately too—but it performs one more additional function of no mean importance, viz. of removing surface water, and often draining wet soils also. As compared with other methods, viz. conservancy, cess-pools, bore-holes, earth-privies, etc. it is not only more efficient, but also more economical in the long run, apart from the blessing it confers on the community, in obviating the dangers to public health, which these other methods potentially involve, viz. pollution of soil under and around dwellings, contamination of underground water-supplies, fly nuisance, and the attendant possibility of spread of epidemics.

In this very important work, the public health engineer is called upon to do two distinct tasks: the first is of sewerage, or collecting sewage that is received at numerous points along its routes, and conducting it to an appointed outfall as rapidly and continuously as possible, without allowing any part of it to be retained in any portion of the system, for any considerable time, either in its liquid form or in the shape of solid deposits, upon the bottom of conduits, or their appurtenances. For, such retention may cause putrefaction of the organic matter in the sewage or solid deposits. This part of the work calls forth skill and efficiency on the part of the engineer.

The other part, viz. of disposal or purification of sewage at the outfall is still more difficult, which the engineer, howsoever experienced, is not alone competent to deal with. He has to seek close and earnest co-operation of the chemist and the bacteriologist, and still, however great his skill and experience may be, he has more to learn and fresh difficulties to overcome. It is necessary to see that the sewage is purified to such an extent, before it is discharged into streams that not only the suspended solids but also the organic impurities are removed from it to such an extent as to render secondary decomposition impossible after the effluent is discharged and mixed with the volume of the diluting water of the stream.

Efficiency and economy in both the above tasks depend upon the extent to which the natural forces or processes are utilised under proper controls. The natural agency in the first part, viz. of sewerage, is the gravitational force. It must be so controlled and utilised that self-cleansing gradients are secured for the sewers, producing uniformly high velocities and thereby the sewage is rapidly conveyed to the outfall in as fresh a condition as possible. If a little pumping has to be resorted to, it should be just to help the general gravitation scheme.

The natural processes to be utilised under adequate control in the second task are (1) the biological action which causes conversion of animal wastes ultimately into plant food, and (2) the self-purifying power of rivers.

In respect to (1) if any waste product of animal origin such as cow-dung, for instance, is buried under soil in a shallow trench, it undergoes complete metamorphosis in the course of a few days by biochemical action, by which it loses all its original properties such as colour, odour, etc., and is transformed into what we call manure, hardly distinguishable from soil, and yet full of fertilising value, in a readily assimilable form by plants. This transformation is made in nature by the myriads of bacteria living in the soil. This same bacterial action can be controlled and artificially adopted for purposes of purification of sewage, so that under the very favourable environments, artificially created, this process which ordinarily takes days and sometimes weeks for completion, if left to nature, can be hastened and accomplished within a few hours with better results, i. e. without causing any nuisance.

(1) The potential power of bacteria in sewage purification was recognised by scientists more than 75 years ago when they observed that the purification of sewage spread on land surface was carried out by bacteria, which developed in the sewage itself, and that these bacteria were identical with those called soil organisms, which were capable of converting any organic matter into harmless humus. The history of the evolution of the modern methods of sewage purification clearly shows that since then each advance has resulted from attempts at improving the methods of producing and maintaining conditions favourable to the bacterial growth.

Thus when it was observed that porous land gave the best results, efforts for improvement led to the construction of artificial beds of stone metal, clinker, etc. inside watertight tanks, called "contact beds", which were expected, and actually proved to be more efficient, on account of the higher percentage of voids, and more effective æration in them than in land surface. These beds were intermittently kept filled with sewage for a short time, and then emptied and allowed to rest for a little longer period, during which a slimy gelatinous deposit of bacterial film gathered on the surfaces of the aggregate. This provided the habitat and food for the bacteria to feed upon and breed, and intensify their action. This was a precursor of percolating filters which marked a further improvement in the means to bacterial growth. These filters with continuous supply of air in the interspaces of the filtering media proved more efficient than contact beds. A further improvement in the design of spraying system, which ensured uniform distribution gave still better results, and at one time percolating filters enjoyed the topmost popularity.

However, these too, had their own limitations. The first was that immense masses of aggregate covering large areas of land were required to provide the necessary colonising ground for bacterial life. Secondly, a nuisance was caused by flies feeding and breeding on the fungi, grown on the filtering media. As a result of experiment it was observed that the finer the filtering material, the better was the purification, due perhaps to the fact that the finer material provided greater gross superficial area of the bacterial film, with consequent greater number of bacteria to intensify the action. But such fine material inevitably tended to clog the filters, requiring frequent cleaning and renewal.

The success of percolating filters gave a further stimulus for research in quest of still better methods of utilising bacterial energy, and in course of time Dr. Fowler discovered that it was possible to produce the bacterial film in the sewage itself without the medium of stone ballast or clinker, by blowing air through sewage repeatedly. This fact is at the root of all the theory and practice of the present biological treatment. All the later advance was merely towards the development of the technique.

Starting from this very important result, Dr. Ardern and Mr. Lockett of Manchester later developed what is known as the activated sludge process. Activated sludge consists of extremely fine particles of sewage flocs formed from the suspended solids and colloidal matter in the sewage itself, by ærating the latter in the presence of sludge that is already activated, i. e. oxygenated by æration. If a small quantity of this activated sludge is introduced in an æration tank containing raw sewage for "seeding", and the contents mechanically agitated for the purpose of a close interfacial contact between the particles of the sludge and sewage, while being at the same time ærated, the action is speeded up.

The fundamental difference between the percolating filter system and activated sludge process is that whereas in the former the biological film adhering to the surfaces of the filtering media is immobile, in the activated sludge process the light, extremely fine particles of sewage floc which are surrounded by the same film are constantly in motion.

Though the activated sludge process has revolutionised the earlier methods of sewage treatment, it has not solved the problem completely. So much still remains to be done. Firstly, the process is very costly in maintenance, and demands close, highly technical supervision. It is very sensitive to fluctuations of sewage character, and above all, of all the methods of secondary treatment, it produces the greatest amount of sludge, which offers a difficult problem in respect of its disposal.

(2) For taking advantage of the other blessing offered by benign nature, viz. self-purifying power of rivers and streams, it is necessary, in the first place, to determine the quantity of oxygen dissolved in the water into which the sewage, either crude, or partially treated, is to be discharged. The quantity of dissolved oxygen though influenced by the area of water surface, depth of the stream, wind, temperature velocity, turbulence, etc. is more important than mere volume of the diluting stream. For maximum economy, the degree of purification must be so adjusted as would balance the diluting or purifying power of the volume from season to season, though not from day to day. In other words, for economical working, the treatment of sewage should not be carried beyond that point which is necessary to maintain the stream free from pollution under worst conditions. Obviously, the worst conditions prevail during summer, when the flow of the stream is reduced to a minimum and the temperature is high. It should be noted at the same time, that the present trends are towards more exacting standards of maintaining purity of streams than ever before.

CHAPTER II

DEFINITIONS AND GENERAL

Definitions :—*Sewage* is the water-borne waste of community, and includes the following three classes:

(*a*) Liquid wastes from kitchens and bath rooms, called *sullage* and excremental matter such as urine and night-soil. The wastes of this class are called *domestic sewage.*

(*b*) Industrial wastes from manufacturing processes.

Classes (*a*) and (*b*) generally go together and are called *sanitary sewage.*

(*c*) Such surface water including rain water, which may be admitted into underground conduits. The sewage of this class is called *storm sewage.*

Sewer is the underground conduit which carries sewage of one or more of the above three classes.

Sewerage implies collecting and carrying away sewage by water carriage system, through underground sewers to a safe place, preferably away from inhabited areas, for disposal, in order to render it harmless.

A sewerage system resembles a river system with the *main*, *trunk* or collecting sewer representing the main river, the various *branch sewers* or *laterals* representing tributary rivulets and *nallas*, and the *house drains* representing the innumerable water courses.

The length of the main or trunk sewer below the point where the lowermost branch joins it, is called the *outlet sewer* and the place where the sewage is finally disposed of, is called the *outfall.*

The bottom surface of a sewer or a drain along which sewage flows is called the *invert.*

Self-cleansing velocity is that velocity which causes all solids, both floating and heavy, to be transported easily with the flow.

Historical :—The earliest drainage in India, so far traced dates back to more than 4000 years B. C. The excavations made a few years ago at Mohenjo Daro have unearthed covered rectangular brick sewers laid to grade under streets, and open drains also of brick, from bath rooms of houses connected to them. Hiuen Tsang, the celebrated Chinese traveller, about the year 600 B. C. has made several references in his memoirs to *pucca* drains along streets. However, sewerage as such on scientific lines as understood today, does not date back beyond 75 years.

General Outline of a Sewerage Scheme :—The essential features of this are :

(1) Adequate piped water supply under sufficient pressure.

(2) A sewerage system as described above including efficient house drains laid to grade to produce self-cleansing velocity to carry the sewage rapidly to the point of outfall in as fresh a condition as possible.

(3) Outfall site, and outfall works for disposal of the sewage.

(1) **Water Supply** :—This is the soul of the scheme. If there is no sufficient supply of water, no sewerage scheme would be possible. Because, the latter is primarily based on water carriage system which alone can remove all the household wastes immediately after they are produced. In order to verify whether the water supply is sufficient, the following points must be investigated :—

(*a*) The source of supply.

(*b*) The minimum quantity available in the hottest part of the year.

(c) The quota in gallons allowed at present per head of population per day, and to what extent it would be possible to increase it not only for the present population but for the prospective one. It is found again by experience that after the execution of a sewerage scheme there is always an increase of from 50 to 75 per cent in the consumption of water for the same population.

(*d*) The head available at the highest point of the town.

(*e*) What parts of the town are not served by the present supply and if there are any such parts, the probable expense of constructing high level tanks with pumps to command them.

(2) **Sewerage System**:—This may be either *separate*, when only the sanitary sewage is carried in a system of sewers, or *combined*, when the same system of sewers carries storm water in addition. Between these two there is a third system, called the *partially separate* or *mixed system*, in which in addition to the sanitary sewage, rain water from roofs and house yards is also admitted into the sewers of the separate system, the storm water from street gutters and open areas other than house yards being cared for separately.

A separate system is desirable, under the following circumstances:

(i) Where rainfall is restricted, as in our country, to one season only, in which it falls in heavy torrents. In this case, if combined system were adopted, the large sewer designed to accommodate the torrential flow of storm would be too large for the comparatively small dry weather flow (D. W. F.) in other seasons. In consequence, both velocity and depth of flow would be insufficient to transport the heavy and floating solids in the sewage, except where it rains.

(ii) Where the sewage is to be pumped and/or to be treated. For, it would cost less to pump and/or, treat the small quantity of sanitary sewage than if large volume of storm sewage were added to it.

(iii) Where there are basement floors of houses to be drained. In this case the sewer for draining them must be at a lower level than those of the basements, and if it is the large combined sewer, the excavation will be much more than if it were a separate one.

(iv) Where sewers are to be laid in rock. As blasting or rock excavation in the midst of occupied area involves potential danger, apart from the expense of chiselling rock for a large combined sewer which is sure to be high.

(v) Where the funds at the disposal of the Local Authority are limited, and it is not justifiable to undertake storm water drainage, which could wait for some more time or even indefinitely.

For Indian conditions the separate system* is found suitable, for the most important reason that the rainfall is confined to one season only. Still, in most cases the mixed system is preferred, since, in addition to carrying away the sanitary sewage, the premises of houses also could be drained and kept dry at a small extra cost.

The aim to be sought is that all the sewers and their appurtenances must remain clear for all the time, and that the sewage must reach the outfall before it loses its freshness.

The design of the sewerage system requires precise information in respect of the quantity, location, depth, sizes, and grades of the sewers to produce self-cleansing velocity.

In addition to the underground sewers, a sewerage system requires for its efficient functioning, certain appurtenances, some for regulation, and others for facility of inspection, cleansing and repairs, such as manholes, lampholes, inlets, overflows, flushing tanks, siphons, lifting devices such as pumps, ejectors, air-lifts, etc.

(3) **Outfall and Methods of Disposal** :—This is perhaps the most difficult point to decide, and it is so important that very often it controls the entire nature of the scheme. If the town to be sewered is fortunate in having a large body of water close by, such as tidal sea currents, a lake, or a river, the problem becomes comparatively easy, still the dilution furnished during the hottest part of the year, the behaviour of the tides (if it is sea), the direction of the prevailing wind,

* The present trends, even in temperate regions, are to adopt the separate system for all new developments, even though the outfall may be into the sea.

the character of the water with respect to its effect upon the sewage discharged into it, the possibility of nuisance arising from sludge banks, or offensive smell near bathing *ghats*, temples and other religious or recreational places, whether the water is used for potable purposes, down below, the relative difference of levels between the outfall and the highest flood level (H. F. L.) etc., must be thoroughly investigated. If on the other hand, the stream has a slender flow and therefore, it is dangerous to discharge raw sewage into it, there is no other alternative except of treating the sewage, either partially or fully, at great initial and running expense.

The exact method of treatment which would suit a particular case depends upon a number of factors, such as the character and strength of the sewage, the amount of diluting water available, the area of land available, the nature of the soil and sub-soil, the material such as crushed stone, sand, etc., obtainable in abundance and at a cheap rate, the head available above the H. F. L. of the stream etc., and the last but of no small importance, the financial condition of the Municipality. The question of site and area required for out-fall works as well as the different methods of treatment of sewage are discussed in detail in a special chapter at a later stage.

For preparing a sewerage project the following details are required :—

(1) Quantity of sewage, i. e. the average discharge as well as the peak discharge on each branch and main based on the population served by it, if only a separate system of sewerage is to be adopted.

(2) Quantity of storm water on each branch and main based on the area drained and the intensity of rainfall and runoff, if combined system of sewerage is contemplated.

(3) Accurate levels all over the town from one end to the other in all directions for preparing a contoured plan and longitudinal sections of roads for deciding the location, depth, sizes, and grades of sewers, and designing the appurtenant works.

These will be discussed in the chapters that follow.

CHAPTER III

QUANTITY OF SEWAGE

THE quantity of sewage will vary according to the system of sewerage adopted. It will consist of sanitary sewage, i. e. domestic sewage and industrial wastes, if a separate system is contemplated. In a mixed system surface water from the premises of houses will have to be calculated and added to it, and in a combined system, storm sewage under conditions of maximum flow must be calculated and added for designing the sizes of the sewers. We shall discuss all these separately, taking the separate system first.

The sources of domestic sewage are :

(1) The supply made by the Local Authority according to a predetermined quota of so many gallons per head per day. This, when multiplied by the number of people served, will give the total quantity. But all this water does not reach the sewers. A large quantity of it is lost in cooking, gardening, or washing, street watering, evaporation, etc. and also in various industrial processes, and in boilers, condensers, etc. However, it would be erring on the safe side if these losses are neglected.

(2) The supply made by the Local Authority to various industries. This can be known either from the records of the Municipality or the industrial concerns.

(3) Water drawn and used from wells in some houses. This cannot be much and may be safely neglected.

(4) Supply derived by some industries from local ponds, canals, lakes, wells, etc. by pumping. This may be considerable. But most industrial concerns usually keep a record of such supplies. If not, rough calculations can be made from the capacity of the pumps used and the number of hours they work per day.

(5) Ground water which infiltrates into the sewers through leaky joints. When it rains, a portion of the water flowing along the surface of ground percolates into the soil and sub-soil, and raises the sub-soil water table. If the sewers are below this level, some of this ground water enters the sewers by seepage through the joints, unless the pipes used are of cast iron with water-tight lead joints. The quantity of infiltration water depends upon the season, the length of the sewer, the area served, the permeable nature of the soil, and also the topographical conditions of the surface and is steady throughout 24 hours. In America it is estimated to vary from a minimum of 15000 to a maximum of 300,000 lit./km. (5000 to 100,000 gallons per mile) of sewer per day. In the Deccan on account of the steep surface slopes of the ground, rain water quickly flows away to valleys. Thus the percolation is much less, and as the rivers are deep and the sub-strata permeable, the small quantity of percolation water is continually flowing to feed the rivers, and therefore there is usually no necessity of making any provision for ground water in design of sizes of sewers. The conditions at other places may be different. Still, in a tropical country like ours owing to constant evaporation from the surface by capillary attraction in the scorching heat of the sun, except in the rainy season, the sub-soil water table is generally low. Still it is possible that in the rainy season some water might be infiltrating into sewers; besides, during rains, street water may enter man-holes through covers. It may, therefore, be necessary to study each case on its individual merits and make adequate provision of from 0 to 5 per cent of the dry weather flow for infiltration water in the design.

Population:—The sewerage system must be designed for the quantity of sewage not only of the present population, but of that a few years hence. Otherwise, the present sewers will soon be found to be insufficient to cope with the increased flow. It is generally the accepted practice to design the branch and main sewers for the population which may occur at the end of one generation of 30 years. This period of 30 years is called the *design period*, The estimation of the prospective population is rather a difficult thing. There has been recently a marked tendency of great migration of population from villages to industrial towns. The reasons may be many, such as lack of educational, medical, banking, and marketing facilities in villages. Recently with the introduction of food rationing in towns, there had been a distinct tendency on the part of village population to flock to towns where there is an assured supply of food, and also possibility of employment. At the same time there is another tendency of depopulation of centres of cities and towns, and of spreading out in extension areas to develop suburbs. The frequent visitations of plague started this tendency a few years ago. People then gradually came to prefer living in open suburban areas, to dingy, high-rented houses in cities. The improvement in the local fast train services, or extension of tram and bus routes further promoted it. The fear of ærial bombing in future warfare is another contributing cause for this tendency to spread still more for the greater safety afforded by scattered suburban development.

The advent of a new industry or the opening of a new railway line causes a sudden increase in population which is bound to upset all previous calculations. It requires, therefore, uncommon shrewdness on the part of the engineer to predict population with a certain degree of accuracy.

The first thing towards this end is to estimate the existing population by one of the following methods:

(1) The latest census report, or the voters' list is the first sure guide. But if more than 3 or 4 years have elapsed since the census was made or the voters' list prepared, the figures cannot be taken as reliable.

(2) The food rationing system gave equally accurate figures, during the period it was prevalent.

(3) The number of houses, and the number of families living in each, may be found out from the Municipal records and a rough estimate of population made by multiplying the number of families by 4·5. In this a child below 10 is counted as ½ adult.

Predicting Future Population :— There are a number of methods in use for forecasting population, but none of them is absolutely reliable. The important amongst them are :

(1) *The Graphical Method* :—In this the population figures of all the past census reports are plotted on a graph-paper, the average curve drawn between the points, and the same extended to the end of the design period. This method is suitable for towns which are developing steadily in the normal manner and presupposes that the rate of increase will be the same as in the past.

(2) *The Arithmetical Method* :—In this it is assumed that the present population will increase each year by a constant figure during the period of design. It must, therefore, be a straight line. Mathematically, if P = present population, i = the rate of annual increase, and n = the number of years,

Population at the end of n years = $P + n \cdot i$.

This method is suitable to forecast the population of old cities or small towns with only a few small or no industries.

(3) In still another method called *incremental method* the percentage of increase during the past decades is calculated and from that and from the present trends a suitable percentage increment is selected and applied to three future decades of design period. If the trends of increase during the past three or four years are taken for guidance, this method would give more rational figures.

(4) Then there is one more method which has found much favour recently with engineers. It is based on the experience gained of similar or larger cities. In it the growth of population of the town in question is plotted on a graph paper, with years as the horizontal axis and the population as the ordinate. Curves of growth of similar or even larger cities are plotted on the same graph, in such a way that they all pass through the point of the present population of the town under question, and with these as guides, the curves for the future population are interpolated for the next thirty years.

* This is treated in greater detail with examples worked out in the Author's *Water Supply Engineering*.

The best course is to watch carefully the present trends, see in what direction and at what rate the town is developing, investigate the possibility of constructing hard-surfaced roads, extension of water mains, electric lines, bus routes, etc. in that direction, the possibility of opening any industries etc. and in this way study the individual case on its own merits. Instead of predicting the population of the entire city, it would be more appropriate to do so of the districts or small units which promise to develop soon. Zoning ordinances may affect the development. If a properly designed town planning scheme is available, the work would be easier and more correct.

The total average discharge of sanitary sewage, based on the prospective population, and the probable infiltration water is called the *dry weather flow* (D. W. F.).

Variation in the Flow of Sewage :—The engineer is more concerned with the maximum and minimum flows at certain regular hours of the day rather than the total quantity of sewage. The flow varies according to the season, the atmospheric temperature, the nature of the district, such as residential, commercial, industrial, etc. On certain days of the year, for instance, on the *Diwali* day among the Hindus, it is maximum. In residential areas the flow rises by about 6 a.m. and reaches the maximum between 8 and 10 a. m. Then it falls steadily until the minimum is reached between 1 and 4 a. m. Again, the peak flow in a residential district may be as high as 225 per cent of the D. W. F. In a commercial district there is concentration of people in offices, hotels, stores, restaurants, etc. for a longer period, and the peak flow may be about 175 per cent of the D. W. F. and may occur between 10 a. m. and 3 p. m. In an industrial district the flow is practically zero from the closing down time in the evening to the next morning, unless there are night shifts in some factories. The flow here is maximum at lunch time in the noon and at washing time at the close of the work, and between these the peak may be 150 per cent of the D. W. F.

The effect of these fluctuations results in smoothening down the peaks and does not reach the outfall sewer so markedly, as the entire system of sewers offers considerable capacity to store the sewage and it takes a long time for the sewage to flow to such a long distance. However, the branch sewers and laterals must be designed of the full capacity to accommodate the peak flow. Otherwise, sewage may back up and cause the lower plumbing fixtures of buildings to be flooded. Fig. 186 shows a typical curve of the hourly variation of sewage.

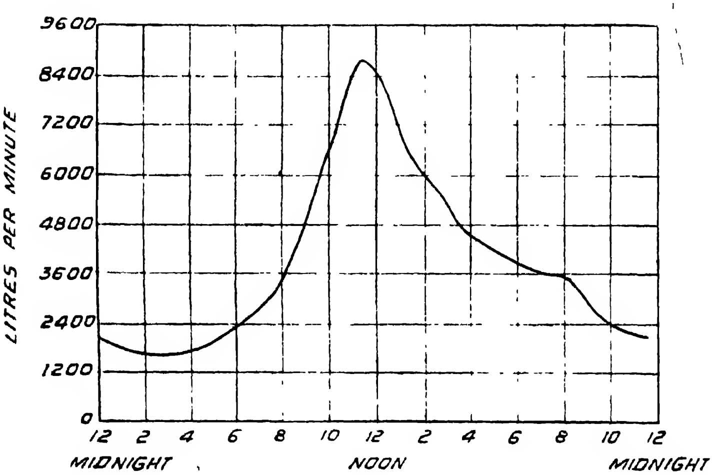


Fig. 186—Hourly variation of sewage.

Basis of Design:—For the basis of design in a separate system of sewerage the capacity of sewers is provided to accommodate 6 times the D. W. F.

In a combined system, and even in a partially separate system, the sewers should be designed to carry at least two times the D. W. F. in addition to the storm water, or, such surface water as may be admitted into them. Any flow in excess of this is accommodated by surcharge, i. e. by allowing the hydraulic gradient to rise above the crown of the pipe, and allowing pressure to develop temporarily in it.

In both these, over-flow weirs are provided for discharge of sewage over and above 6 times D. W. F., at points where the sewer passes by a *nalla*.

Where there is possibility of surcharge as in storm sewers, at all intersections of sewers, or changes of diameter, the crowns of sewers of different diameters are kept, as far as possible, in the same line, the change of diameters in that case causes a step or slope down in the invert at the point of connection. Nevertheless, in practice, it is the invert and not the crown levels that are shown on the drawings, and calculations of gradients are made according to the difference of invert levels over the length concerned.

Questions

(1) What is ground water and how does it affect sewer design ?

(2) What are the usual means employed for estimating the present population ? What are the methods of forecasting future population ?

(3) How does the variation in sewage discharge affect the design of sewers ?

(4) What is the capacity usually provided while designing sewer sections on

(a) Separate system,

(b) Partially separate system, and

(c) Combined system ?

CHAPTER IV

QUANTITY OF STORM WATER

COMPARED with the dry weather flow of sanitary sewage, the quantity of storm sewage is very large. Even on the partially separate system, the run-off from roofs and paved yards only, which is admitted into sewers, is 15 to 20 times as great as the D. W. F. This will be seen from Example 2 worked out elsewhere in this chapter.

When rain falls on a certain area, part of the rain water is absorbed by the soil, part is evaporated, and the remaining part flows off towards the valleys as storm or flood water. The drainage engineer is concerned with the maximum rate of this run-off at any particular moment. The run-off from catchments depends upon a number of factors most of which are variable and of a complex nature. Thus it increases with (1) the area of catchment, (2) the steepness of its slopes, (3) the imperviousness of its surface, such as the area of buildings, paved yards, road surface of non-absorbent nature like asphalt or concrete, etc. (4) the bareness of the surface, i. e. freedom from vegetation like grass, (5) duration of rainfall, (6) the extent of moisture present in the surface soil prior to rainfall, (7) the heaviness or the intensity of rainfall, and (8) the compactness or the concentration of the area of catchment. If the catchment is compact, water from all distant points flows quickly away to the valley.

On the other hand, the factors which tend to reduce the run-off are: porous, dry soil; flat ground covered with vegetation like grass; irregular surface forming small ponds and depressions; long scattered catchment; high wind and warm atmosphere which tend to evaporate water readily, and light rainfall.

The exact determination of the run-off even for one particular catchment is not possible as the factors, which affect it are very variable. For instance, during a storm, the intensity of run-off, seldom if ever, remains uniform for any considerable length of time. The precipitation may also vary from a mere drizzle in one part to a heavy down-pour in another close by.

Until about 30 years ago, the estimation of storm water was done even in U.S.A. and Great Britain, by adopting some empirical formulæ or by assuming a certain arbitrary coefficient of run-off. This method has still been followed in this country. According to this practice the run-off varies from 0·20 in the case of a flat catchment with meagre rainfall, to 0·75 in *ghat** catchments In the case of large catchments where, as a result of establishment and observation of a number of rain gauges, and also arrangements for gauging flood discharge, over a number of years, the empirical formulæ based on the latter tally fairly well with the actual conditions. But in the case of small catchments like those of cities and towns to be sewered, it is simply a guess work. While working out projects for draining or sewering these catchments, a run-off of 5 to 15 mm. ($\frac{1}{4}$ to $\frac{1}{2}$ in.) per hour intensity has hitherto been taken, and it is further assumed that this precipitation occurs over the entire area of the catchment.

The Rational Method :— In recent years a method, called the "rational method," has been evolved as a result of considerable research work done by Fruhling in Germany, Kuichling in America and later Lloyd Davis in England. It is called rational, because, there is very little room left for guess work. All the factors affecting the run-off are calculated by actual measurements. The general equation of the run-off according to this method is,

$$Q = c.A \cdot R$$

in which c = a coefficient of run-off depending upon the extent of areas having different imperviousness to water, A = the area of catchment obtained by adding together areas of different permeabilty, and R = intensity of rainfall in inches per hour.

* Mountainous area along sea coast.

Run-off Coefficient:—This is in fact the impervious factor of run-off. After a large number of experiments and observations, Fruhling and Kuichling independently prepared tables of values of imperviousness of different surfaces and proved that the impermeable area in a particular catchment or district of a town, expressed as a proportion of the total area, called the impervious factor, is directly proportional to the run-off. A few important values are given in the following table.

TABLE NO. 10

Kuichling's Co-efficients of Run-off from Various Surfaces

Type of Surface	Coefficient
Water-tight roof surface ...	... 0·70 to 0·95
Asphalt pavement in good order ...	... 0·85 to 0·90
Stone, brick, wood-block pavement with cemented joints ...	... 0·75 to 0·85
Same with uncemented joints ...	... 0·50 to 0·70
Macadamized roads ...	... 0·25 to 0·60
Gravel roads and walks ...	... 0·15 to 0·30
Unpaved streets, vacant land ...	... 0·10 to 0·30
Parks, lawns, gardens, meadows, etc.	... 0·05 to 0·25
Wooded land ...	... 0·01 to 0·20

TABLE NO. 11

Additional Run-off Coefficients from Fruhling's Table

Extreme suburban areas with 20 to 40 per cent parking and widely detached houses ...	... 0·35
Suburban area with widely detached houses	... 0·45 to 0·55
Area with 50 per cent attached houses and 50 per cent detached houses ...	... 0·65
Areas closely built up ...	... 0·75
Business areas ...	... 0·85

For a sewerage project the impervious factor must be estimated not as it is at present, but what it will be after development at the end of 30 years hence.

Example 1 :—The C. A. of a district is 60 hectares made up of the following :—

1.	Roof area	...	15 per cent
2.	Asphalted pavements and roads	...	15 ,, ,,
3.	Paved yards	...	5 ,, ,,
4.	Macadamized roads	...	20 ,, ,,
5.	V[illegible]nt plots	...	25 ,, ,,
6.	Parks, lawns, gardens, etc.	...	20 ,, ,,

Calculate the impervious factor. If the maximum intensity of rainfall is 50 mm. per hour, find the discharge of storm water.

Solution :—The figures are tabulated below :

Item No.	Area in Hectares	Run-off Coefficient	Impervious Factor Percentage
1	60 × 15% = 9	0·82	7·38
2	60 × 15% = 9	0·87	7·83
3	60 × 5% = 3	0·80	2·40
4	60 × 20% = 12	0·42	5·04
5	60 × 25% = 15	0·10	1·50
6	60 × 20% = 12	0·15	1·80
	Total 100 60		25·95

The impervious factor is **25·95**.

$$\text{Storm water} = \frac{60 \times 10000 \times 50 \times 25{\cdot}95}{60 \times 60 \times 1000 \times 60}$$

$$= \mathbf{3{\cdot}6 \text{ cu. m./sec.}}$$

Example 2 :—If in the above example the density of population is 250 per hectare and the quota of water supply per head per day is 200 litres, calculate the quantity of (1) sewage for separate system and (2) storm water for partially separate system.

Solution :— Population $= 60 \times 250 = 15{,}000$

Average discharge of sewage $= \dfrac{15{,}000 \times 200}{24 \times 3600}$

$= \mathbf{52.1}$ **lit./sec.**

The peak discharge will be twice this, i.e. $= 104{\cdot}2$ lit./sec.

Storm water

= run-off from roofs + run-off from paved yards.

$$= \frac{9 \text{ hectares} \times 10{,}000 \text{ m.}^2 \times 50}{60 \text{ mts.} \times 60 \text{ secs.} \times 1000} \times 0{\cdot}82 \text{ Imp. factor} +$$

$$\frac{3 \text{ hectares} \times 10{,}000 \times 50}{60 \times 60 \times 1000} \times 0{\cdot}87 \text{ Imp. factor}$$

$= 1025 + 362{\cdot}5 = \mathbf{1387{\cdot}5}$ **lit./sec.**

This is nearly 13 times as great as the peak sanitary sewage discharge viz. 104·2 lit./sec.

Intensity of Rainfall :— The intensity of rainfall does not remain uniform for any considerable length of time, and it has been observed that the greater the intensity, the shorter the period of the storm, or the reverse: the shorter the duration, the more intense is the rainfall, is also true. The drainage engineer is interested in the conditions that tend to produce the maximum flow reaching the sewer. These conditions are: (1) the rainfall must fall on the already soaked ground, (2) the intensity must be high enough, and (3) the storm must last just long enough till the water from the most distant parts of the catchment reaches the sewer. The greatest flow will occur when a storm of a certain intensity is moving in the direction of the flow towards the sewer. Thus the factors involved are the intensity of rainfall, its duration, and the distance from the most distant part of the catchment, or better still, the time required for the flow to run from the extreme end of the C. A. to the sewer.

Automatic Recording Rain-gauges :— The rainfall records which give so many mm. of cumulative precipitation during 24 hours are not of much use in calculating the flood discharge. What is required is the maximum rate of rainfall for short durations of 5, 10 or 15 minutes, as we have seen that the greatest intensity lasts only a few minutes. To obtain this information of each individual storm, self-registering rain-gauges are very useful. A typical automatic rain-gauge consists of a standard receiver, or container, open at the top resting on a spring balance. The rain water dropping through the open mouth, when collected in the receiver depresses the balance, and the movement of the receiver is transmitted to a recording pencil, which by means of levers, moves up and down, and draws a graph on a sectional paper wound round a drum rotated by clockwork.

From the charts, storms of greater intensity than 10 mm. (½ in.) per hour, are selected and plotted on a graph paper. Suppose e. g., the chart shows a storm of 8 mm. (0·32 in.)

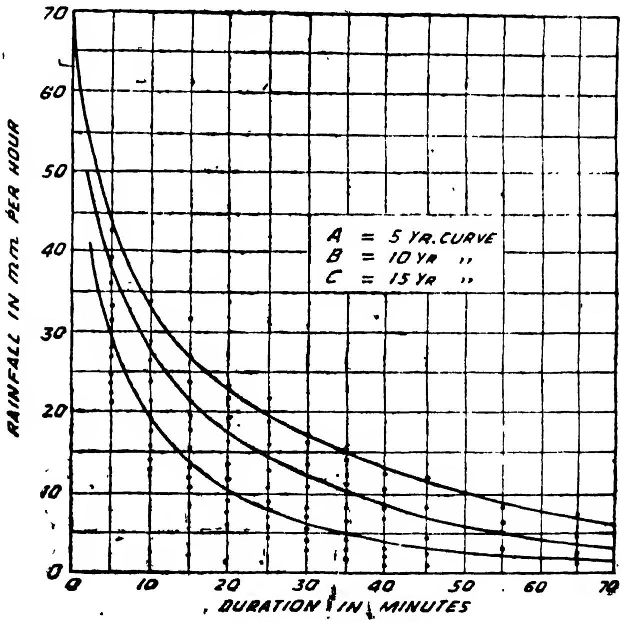


Fig. 187.

on a particular day which occurred between 10-00 and 10-15 a. m. This means that 8 mm. (0·32 in.) of rain fell in 15 minutes. Its intensity was therefore 32 mm. (1·28 in.) per hour. This will be a point on the graph with 15 minutes as the horizontal, and 32 mm. (1·28 in.) as the vertical ordinate. Generally if r mm. of rain falls in time t minutes, R, the intensity of rainfall p. h. will be $= \frac{60\,r}{t}$.

When a number of such points are plotted, mean curves can be drawn from them incorporating all the storms of intensities above 10 mm. (½ in.) p. h. These curves should represent frequency curves of 5, 10, 15 years and so on, according to the period over which the records are spread. A 10-year frequency curve means that the relation expressed by it between rainfall intensity and its duration is likely to be equalled or exceeded once in 10 years.

Fig. 187 shows three typical intensity-duration curves of 5, 10 and 15 years frequency, of a certain hypothetical catchment. It is clear from the curves also that R, the intensity of rainfall varies inversely as the duration, i. e. the shorter the duration of rainfall, the greater will be the intensity during that period. The equation of the curve is of the order of either $R = \frac{a}{t+b}$ or $R = \frac{a}{t^b}$ where R = Intensity in mm. p. h., t = time in minutes, and a and b are constants. Each curve has its own equation.

Then there are two further factors to be considered which affect the maximum discharge of storm water. They are (1) time of entry and (2) time of concentration.

(1) **Time of Entry** :—This is often also called *inlet* time, and is defined as the time which the first drops of rain water from the distant points of water-shed take to flow to the head of the drain or sewer. It depends upon the distance and the velocity of flow. The latter will be rapid if the ground slopes steeply, more rapid over paved, than unpaved areas, more rapid over barren land than over that covered with vegetation and so on. It is rather difficult to estimate it with any degree of accuracy. However, it is never less than 3 minutes, which the rain water from roofs takes to flow through roof gutters,

down-take pipes to paved yards, from there to street gutters, and from the latter to the sewer, in a built-up district. If the area is other than that occupied by buildings and paved yards, and consists of agricultural land or land under lawn with flat surface, the inlet time may be as much as 20 minutes or more. The time of entry, therefore, depends upon two factors : the resistance offered by the surface to the flow, and the distance of the water-shed line from the head of the sewer.

(2) **Time of Concentration**:— It is the time required for the collection of flow of rain water in sufficient volume from the various channels and sub-drains so as to make the effect of the flood felt. In other words, it is the time required for the flood discharge to reach the maximum limit. It is, in fact, the sum of the time of entry t_e, and the time t, required by the discharge to flow from the head of the drain to the point where the concentration is considered for purposes of design of that section. Thus the time of concentration $= t + t_c$, time of flow, plus time of entry.

The factor t, the time of flow, can be easily calculated by dividing the distance from the head of the sewer to the point where the section of the sewer is to be designed, by the velocity of flow. The latter depends upon the gradient of the street.

It should be remembered that the larger the catchment, the longer is the time of concentration, and the less is the chance of flooding. The engineer is concerned, whether designing for irrigation, water supply or sewerage works, with the maximum rate of run-off, and this occurs *when the storm has the duration just equal to the time of concentration*. Suppose a storm of shorter duration should fall on the area, the intensity of rainfall, in that case, would be greater than that of a storm of longer duration, but because the storm would not last long enough for the whole area to contribute, during its duration, the total run-off would be less. If, on the other hand, a storm of greater duration than the time of concentration were to fall on the same area, the run-off would be still less because of the reduced intensity of rainfall, and this would be balanced by the longer period of the storm, because, however long the storm lasted, a greater area than the total could not contribute.

The conclusions arrived at by Lloyd Davis are :

(1) The total volume of storm water is proportional to the maximum rate of flow.

(2) The total discharge of storm water is proportional to the maximum rainfall during the time of concentration.

(3) The storm water discharge of any particular district is proportional to the percentage of impermeable area expressed as a proportion of the total area of the district.

(4) The maximum rate of flow is expected when the maximum precipitation occurs in the minimum time of concentration, i. e. when the duration of the storm is equal to the time of concentration.

The formula derived by him from these conclusions is .

$$Q = \frac{1}{6} \times \frac{60 \times r}{T} \times P$$

or, if R is known from the frequency curve,

$$Q = \frac{1}{6} \times R \times P$$

where Q = Discharge in cu. m. per minute ;

T = Time of concentration in minutes including time of entry ;

r = Total rainfall during time of concentration ;

P = Percentage of impermeable area in acres ;

and, $\frac{1}{6}$ = cu. m. per minute per hectare of 1 mm. rainfall, i. e.

$$= \frac{10{,}000 \times 1}{60 \times 1000} = \frac{1}{6}$$

Example 3 :—If the 10-year record of a district shows a maximum rainfall of 10 mm. during 15 minutes of time of concentration, find the total storm water discharge for which a sewer must be designed if the catchment area is 15 hectares and the impervious factor 0·40.

Solution :—Q = Rainfall in mm./hour × $\frac{1}{1000}$ × area in sq. m. × impervious factor × $\frac{1}{60 \text{ min.}} \times \frac{1}{60 \text{ sec.}}$

$$= \frac{10 \times 60}{15} \times \frac{1}{1000} \times \frac{15 \times 10000 \times 0{\cdot}40}{60 \times 60} = 0{\cdot}66 \text{ m.}^3\text{/sec.}$$

= 666·7 lit./sec.

Questions

(1) What are the factors that go to increase the run-off from catchments ?

(2) What are "time of entry" and "time of concentration," and what is their relation to each other ? How is impervious factor calculated ?

(3) A sewer has a catchment area of 25 hectares. The impervious factor is 0·24. The maximum recorded rainfall per hour is 112 mm. Find the discharge. Ans. 1·86 m.^{3}/sec.

(4) Using an impervious factor of 40 per cent. and taking the rainfall of the 15-year curve in Fig. 187, plot a new curve with R as ordinates and duration up to one hour as abscissa.

CHAPTER V

FLOW OF SEWAGE IN PIPES

NORMAL sewage contains 0·10 per cent (or roughly two lb. per ton) of solid matter, which is too small to affect its specific gravity to any appreciable extent. It can, therefore, be assumed that it obeys all the laws of hydraulics of clear water. Sewers, even though they may sometimes run full, are treated as open channels.*

Velocities—Minimum and Maximum :— The velocity of flow is the most important thing in sewerage design. It is not uniform throughout a cross section. In open channels it is maximum at a little below the surface near the centre of the channel, and is minimum near the surfaces in contact on account of the frictional resistance they offer. It is the velocity near the bottom which is significant in transporting solids. The transporting power of a liquid varies as the 6th power of its velocity. Thus if the velocity is doubled, the transporting power is increased to 64 times as great. For this purpose even a slight reduction in velocity due to either an increase in roughness of surface, resistance at bends or, a sudden increase in section, etc., affects the transporting power considerably. The transporting power also depends upon the depth of the flow. If the latter is insufficient, in spite of high velocities, suspended or floating solids like rags, pieces of wood, loose coir, grass, etc., which frequently find entrance to a sewer, touch the bottom and on account of the resistance met with there, are first carried slowly, and later, when they meet some heavier deposits, that have been already lodged on the invert, they firmly settle there, and may not be carried away even when the velocity of flow increases again.

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* There are a few exceptions to this e. g. when sewage is flowing through inverted siphons, or a rising pipe of a pump. Sewers may also run full and under pressure on account of excessive infiltration of water during storms either underground by leakage through joints or walls of manholes or surface water through street inlets. Sewers are then said to be "surcharged."

In Western countries, a velocity of 0·75 m./sec. (2½ ft./sec.) when a sewer is running full, is deemed sufficient for self-cleansing purposes. But in a tropical country like ours, for reasons explained later, a higher velocity, viz. of at least 1 m. (3 ft.) per sec. is desirable.

The maximum velocity is not so important in drains and pipes of hard materials like stoneware as they never reach the limit at which they might cause damage by scouring. But in sewer construction, softer material like brick or concrete is often used and the sharp-edged grains of sand and gravel which roll on the surface of the invert are likely to cause damage. Hence the following maximum velocities are deemed permissible.

TABLE NO. 12

Earthen channel	..	0·6 to 1·25 m./sec. depending upon the nature of the earth.
Sewers lined with bricks	...	1·5 to 2·5 m. per sec. depending upon the quality of bricks.
Concrete	...	2·5 to 3 m. per sec.
Stoneware	...	3 to 4·5 m. per sec.

The general formula used is called Chezy's formula, viz.

$$V = C\sqrt{RS} \qquad \ldots \qquad \ldots \qquad (1)$$

where V = velocity in m./sec., R = hydraulic mean depth, i. e. the area of water divided by the wetted perimeter, and S = slope, or the fall in m. of water surface divided by the length in m. measured along the pipe, and C = a constant depending upon the hydraulic mean depth and the roughness or smoothness of the surface.

For determining the value of C the following Kutter's formula is used :—

$$C = \frac{23 + \frac{0{\cdot}00155}{S} + \frac{1}{n}}{1 + \left(23 + \frac{0{\cdot}00155}{S}\right)\frac{n}{\sqrt{R}}} \qquad (2)$$

in which R and S have the same meanings as above and n is a constant, the value of which depends upon the roughness of the surface. The following are the values of n for different materials :—

TABLE NO. 13

Average Values of n in Kutter's Formula for Different Materials

Material	Value of n
Planed timber or very smooth plaster	0·010
Common timber boards	0·012
Brick-work, ashlar masonry, common plaster, stoneware, concrete	0·013
Rubble masonry	0·017
Earthen channels in good order	0·022
Natural river beds in fairly good order	0·025
Rivers and streams full of debris or weeds	0·030

Though rather cumbersome, the above formula is very reliable upto velocity limits within 3 m./sec. (10 ft. per sec.). It can, however, be simplified by omitting the expression : $\frac{0{\cdot}00155}{S}$. The latter affects the result much less than an increase of 0·001 in the value of n.

The following formula called Manning's formula is simple and gives equally good results, and is popular in America.

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \text{ m./sec.} \qquad \ldots \qquad \ldots \qquad (3)$$

n in which, agrees closely with the coefficient n in the Kutter's formula. R and S have the same meanings as before.

The following table in which the values of R, $\sqrt{R}$, C (constant for velocity) and A = areas of circles are worked out for n=0·013 in Kutter's formula, makes its use very easy.

TABLE NO. 14

Table of Velocities for Different Diameters Using Kutter's Formula with $n = 0{\cdot}013$

Diam. in mm.	Area in sq. m.	R in m.	$\sqrt{R}$ m$^{\frac{1}{2}}$	C	Diam. in mm.
150	0·01767	0·0375	0·1936	39·28	150
200	0·03142	0·0500	0·2236	42·76	200
250	0·04909	0·0625	0·2500	45·50	250
300	0·07069	0·0750	0·2739	47·76	300
350	0·09621	0·0875	0·2958	49·69	350
400	0·1257	0·1000	0·3162	51·35	400
450	0·1590	0·1125	0·3354	52·84	450
500	0·1963	0·1250	0·3536	54·13	500
550	0·2376	0·1375	0·3708	55·35	550
600	0·2827	0 1500	0·3873	56·39	600
650	0·3318	0·1625	0·4031	57·39	650
700	0·3848	0·1750	0·4183	58·26	700
750	0·4418	0 1875	0·4330	59·09	750
800	0·5027	0·2000	0·4519	60·16	800
850	0·5674	0 2125	0·4610	60·59	850
900	0·6362	0·2250	0·4743	61·30	900
1000	0 7854	0·2500	0·5000	62·53	1000
1100	0·9503	0 2750	0·5244	63·64	1100
1200	1·1310	0·3000	0·5478	64·63	1200
1300	1·3273	0·3250	0·5701	65·56	1300
1400	1·5394	0·3500	0·5917	66·39	1400
1500	1·7671	0·3750	0·6124	67·15	1500

$$C = \frac{23 + \frac{1}{n}}{1 + \frac{23 \times n}{\sqrt{R}}} = \frac{23 + 76{\cdot}92}{1 + \frac{0{\cdot}299}{\sqrt{R}}} = \frac{99{\cdot}92}{1 + \frac{0{\cdot}299}{\sqrt{R}}}$$

Example 4 :—Find the velocity and discharge per second of a pipe 600 mm. diam by Kutter's formula, taking $n = 0{\cdot}013$ laid to 1 in 200.

Solution :— From the table, $V = C\sqrt{RS}$

$V = 56{\cdot}39 \sqrt{0{\cdot}15 \times \frac{1}{200}} = 1{\cdot}544 = 1{\cdot}54$ m./sec.

$Q = A \times V = 0{\cdot}2827 \times 1{\cdot}544 = 0{\cdot}436$ m.^{3}/sec.

Example 5 :— Calculate the velocity and discharge of a stoneware sewer 500 mm. diam. laid at a gradient of 1 in 300.

Solution :— By Kutter's formula,

$$V = C\sqrt{RS}$$

$$= 54{\cdot}13\sqrt{0{\cdot}125 \times \tfrac{1}{300}} = 1{\cdot}105 \text{ m./sec.}$$

$$\text{Discharge } Q = A \times V = 0{\cdot}1963 \times 1{\cdot}105$$

$$= 0{\cdot}2169 = 0{\cdot}217 \text{ m.}^3/\text{sec.} \qquad \ldots \quad (1)$$

$$\text{By Manning's formula } V = \frac{1}{n} \cdot R^{\frac{2}{3}} S^{\frac{1}{2}}$$

$$= \frac{0{\cdot}125^{\frac{2}{3}}}{0{\cdot}013} \times \left(\frac{1}{300}\right)^{\frac{1}{2}} = 1{\cdot}11 \text{ m./sec.}$$

$$\text{Discharge } Q = A \times V = 0{\cdot}1963 \times 1{\cdot}11 = 0{\cdot}218 \text{ m.}^3/\text{sec.} \ldots (2)$$

All the discussion made above and the formulæ quoted relate to pipes running full. But as we have seen in the last chapter, there is so much variation in the hourly discharge, that sewers scarcely run full. Most of the time they run less than half full. Sewers running partly full present an altogether different problem, as discussed below.

We have seen that V varies as $\sqrt{RS}$, or for the same grade V varies as $\sqrt{R}$; and that R = area divided by the wetted perimeter. For a pipe running full, $A = 0{\cdot}7854\, D^2$ and wetted perimeter = $3{\cdot}1416$ D. Hence $R = 0{\cdot}25$ D. Again, when a pipe is running half full $A = 0{\cdot}3927\, D^2$ and wetted perimeter = $1{\cdot}5708$ D. In this case also $R = 0{\cdot}25$ D again. Therefore, the velocities, when the pipe is running either full or half full, must be the same.

As the depth decreases from full to half full pipe, or, from D to $\frac{D}{2}$, the wetted perimeter decreases faster than the area, and consequently the velocity increases to more than what it is when full. As the depth further decreases from that of half D, the reverse takes place, i. e. the area decreases more rapidly than the wetted perimeter, and so the velocity also decreases.

This is shown more clearly in the following table in which or every decimal of a foot decrease in depth, the hydraulic mean depths are worked out.

TABLE NO. 16

Proportionate Depth D	Area of Flow A sq. m.	Wetted Perimeter w. p. m.	Hydraulic Mean Depth R m.	By Kutter's Formula Velocity V m. per sec.	Discharge Q cu.m. per sec.
Full 1·0	0·7854	3·142	0·250	1·00	1·00
0·9	0·7708	2·691	0·286	1·15	1·073
0·8	0·6735	2·214	0·304	1.16	0·98
0·7	0·5874	1·983	0·296	1·14	0·84
0·6	0·4920	1·772	0 278	1 08	0·67
Half 0·5	0·3927	1·571	0·250	1·00	0·50
0·4	0·2934	1·396	0·214	0·88	0·33
0·3	0·1981	1·159	0·171	0·72	0·19
0·25	0·1536	1 047	0·146	0·65	0·14
0·2	0·1118	0·927	0·121	0 50	0.09
0·1	0·0408	0·643	0·0695	0·36	0·03

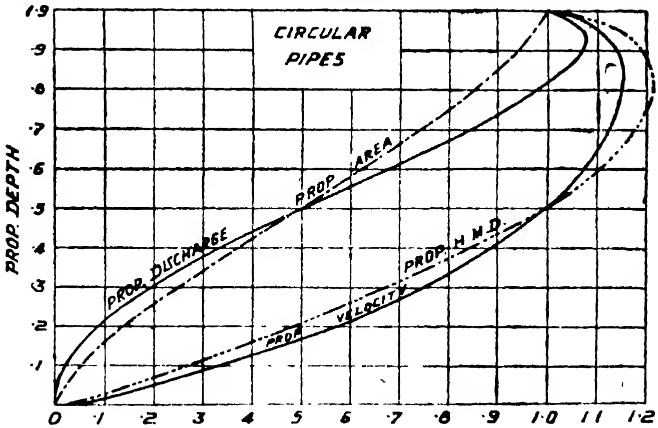


Fig. 188:
Graphs of proportional depths, areas and discharges of circular pipes running partially full by Crimp and Bruges' formula.

The results of the table are shown graphically in Fig. 188. The table and the graph clearly show the following:—

(1) The maximum velocity is attained not when the sewer is running full, but when the depth is 0·80 (actually 0·81).

(2) The maximum discharge occurs when the depth is 0·95D since, when the depth increases to fill the sewer above this, the wetted perimeter, and so the friction increase and the velocity at once falls.

(3) If a sewer is designed for a velocity of 0·75 m. (2·5 ft.) and 1 m. (3 ft.) per sec., when either running full or half full, it will have velocities of 1·625 and 1·95 respectively when it is running quarter full. These velocities are not bad from the point of transportation, or rather non-deposition of solid matter. Thus 1 m. (3 ft.) per sec. or even 0·75 m. (2½ ft.) per sec. velocities for a sewer running full or half full are safe, provided the sewer runs during the course of the day at least once half full so as to cleanse itself of all the solids deposited when the depth of flow was less than quarter full.

The following table based on Manning's ($n = 0{\cdot}013$) formula gives the necessary gradients for pipes of different diameters to produce velocities of 0·75 m. (2½ ft.) and 1 m. (3 ft.) per sec.

TABLE NO. 17

Diameter in mm.	Gradient 1 in	
	For 0·75 m. per sec. Velocity	For 1 m. per sec. Velocity
150	130	75
200	195	110
250	260	150
300	330	190
350	410	230
400	490	275
450	570	320
500	660	370
550	750	420
600	840	470
650	930	525
700	1030	580
750	1130	635

The common belief that a small pipe requires a higher velocity to make it self-cleansing is erroneous. The truth is just the opposite. For, there is a greater turbulence in a small diameter pipe than in a large one, which keeps the floating and suspended solids moving, and prevents them from settling down.

It is also a mistake to adopt a larger-size pipe than required by the flow, with a view to obtaining a self-cleansing velocity on a flatter gradient. The self-cleansing velocity depends upon the flow and not upon the size, and therefore, when the flow is small, a small diam. pipe will keep cleaner than a larger pipe laid to the same gradient.

The formulæ commonly used for calculating the head lost in overcoming friction due to several causes are given below:

(1) Head lost in long pipes $\frac{4 f l v^2}{d \times 2g}$ (m.) where f = coefficient of friction having the following values:

$$\text{For new pipes } f = 0{\cdot}005 \left(1 + \frac{1}{40\,d}\right) \quad \dots \quad \dots \quad (5a)$$

$$\text{For old pipes } f = 0{\cdot}01 \left(1 + \frac{1}{40\,d}\right) \quad \dots \quad \dots \quad (5b)$$

d = diameter of the pipe in m.; l = length; v = velocity (m. per sec.) and g = acceleration due to gravity = 9·81 m./sec.^{2}

(2) Head lost at bends of very short radius, or elbows

$$0{\cdot}30\ \frac{v^2}{2g} \qquad (6)$$

for bends of radius 2·5 to 5 times the diameter of the pipe or elbows turning through 90°.

(3) Loss of head due to sudden contraction

$$0{\cdot}5\ \frac{v^2}{2g} \qquad (7)$$

where v = velocity in contracted pipe.

(4) Head lost by sudden enlargement of section

$$= \frac{(v_1 - v_2)^2}{2g} \qquad \cdots \qquad \cdots \qquad (8)$$

where v_1 = velocity before enlargement, and v_2 = that after enlargement.

(5) Head lost at entrance to pipe

$$= 0{\cdot}5 \frac{v^2}{2g} \qquad \cdots \qquad \cdots \qquad (9)$$

where v = velocity at entry.

(6) Head lost in overcoming obstruction in a pipe

$$= \left(\frac{A}{0{\cdot}66\,(A-a)} - 1\right)^2 \times \frac{v^2}{2g} \qquad \cdots \qquad (10)$$

where A = area of the pipe in sq. m.; a = area of obstruction in sq. m.; v = velocity in m. per sec. in the unobstructed portion of the pipe under normal conditions.

It is the usual practice to allow the necessary drop in the invert level at the manhole at which a bend or increase in the section of pipe occurs. For example to overcome the resistance due to a bend a drop of 1 cm. (½ in.) is given.

Example 6 :— A town having a population of 8,000 has a total drainage area of 150 hectares. The water supply allowed is 360 lit. per capita per day. If an increase of 25 per cent in population is expected at the end of the next 30 years, find the total average discharge, and design the outfall sewer for a gradient of 1 in 475.

Solution :— Prospective population = 10,000

$$\text{Quantity of sewage} = \frac{10{,}000 \times 360}{24 \times 60 \times 60} = 41{\cdot}67 \text{ lit./sec.}$$

Sewers on separate system are designed for 6 times the D. W. F. i. e. for $6 \times 41{\cdot}67 = 250$ lit./sec. = 0·25 cu.m./sec.

From Table No. 17 for a gradient of 1 in 470, a 600 mm. pipe is appropriate for producing a velocity of 1 m. per sec. Ours is a slightly steeper gradient, and therefore a smaller pipe would perhaps suffice. Still let us try a 600 mm. pipe. From Table No. 14 for Kutter's formula the value of C in the equation $V = C\sqrt{RS}$ is 56·39

$$V = 56{\cdot}39 \times \sqrt{0{\cdot}15 \times \frac{1}{475}} = 1 \text{ m./sec.}$$

which is adequate. Therefore,

$$Q = \frac{\pi}{4} \times 0{\cdot}6^2 \times 1 = 0{\cdot}283 = 0{\cdot}28 \text{ cu. m./sec.}$$

This is slightly in excess of that required. But the next smaller pipe of 550 mm. diam. would be insufficient. Therefore 600 mm. is the correct size.

Example 7 :— Find the velocity and discharge of a fairly old sewer of c. i. 400 mm. diameter laid to a grade of 1 in 100. The length of the sewer is 250 m.

Solution :—In the length of 250 m. the head available is 2·5 m. As the pipe is old, the coefficient of friction, by (5*b*) is,

$$f = 0{\cdot}01\left(1 + \frac{1}{40d}\right) = 0{\cdot}01\left(1 + \frac{1}{40 \times 0{\cdot}4}\right) = 0{\cdot}01063$$

then,

$$2{\cdot}5 = \frac{4flv^2}{2dg} = \frac{4 \times 0{\cdot}01063 \times 250\,v^2}{2 \times 9{\cdot}81 \times 0{\cdot}4} = 1{\cdot}3556\,v^2$$

$$\therefore v^2 = \frac{2{\cdot}5}{1{\cdot}3556} = 1{\cdot}8442$$

$$v = \mathbf{1{\cdot}358 \text{ m./sec.}}$$

$$Q = A \times v = 0{\cdot}1257 \times 1{\cdot}358$$

$$= \mathbf{0{\cdot}171 \text{ cu.m./sec.}} = \mathbf{171 \text{ lit./sec.}}$$

Shapes of Sewers :—Circular sewer pipes are by far the best, and most common in use. For, they offer the following advantages :

(1) They are the easiest to manufacture.

(2) A circular section gives the maximum area for a given perimeter, and thus gives the greatest hydraulic mean depth when running full or half full.

(3) It is the most economical section as far as the quantity of material of construction is concerned.

(4) Being of uniform curvature all round, it offers less opportunities for deposits.

But all these advantages are derived only when it runs at least half full. The circular sewer is, therefore, most suitable when the discharge is more or less constant. When it is very variable as in a combined sewer, it loses its merits, and less the discharge, the poorer is its performance.

When the discharge is subject to great variation, as in a combined sewer, which is over-taxed during the rainy season, and runs with D. W. F. only in summer, when it may not be even 5 per cent of the combined discharge, the egg-shaped sewer, which, for low discharges, maintains the hydraulic depth nearly uniform and gives 25 to 30 per cent higher velocities, when running less than half full, is more suitable. But its disadvantages are : (1) It is more difficult to construct. (2) As the smaller base is to support the weight of the upper broader section, it is less stable. (3) It is expensive, as more material is required and as the cost of construction is also high (4) In the absence of adequate gradient it is not self-cleansing.

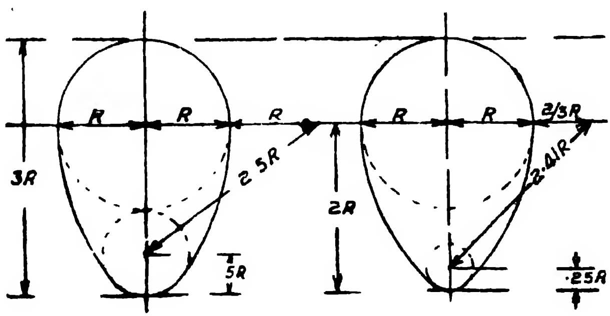


Fig. 189. Egg-shaped sewers. Fig. 190.

Standard or Metropolitan. The new section.

There are several forms of egg-shaped or ovoid sewers in use, but the two illustrated in Figs. 189 and 190 are very common viz. the standard, sometimes called 'metropolitan', and the new. The characteristics of these are as follow :

TABLE NO. 18

	Standard	New
Height ...	3 R ...	3 R
Width ...	2 R ...	2 R
Radius of arch	R ...	R
,, of invert	0·5 R ...	0·25 R
,, of sides	3 R ..	$2\frac{5}{8}$ R

The computations of areas and wetted perimeters of egg-shaped sewers of either form, involve complicated mathematical calculations. Therefore, while designing an egg-shaped sewer it is the usual practice to calculate the approximate diameter of the circular sewer first, which would give the same discharge, when laid at the same gradient, and then to convert it into the dimensions of an egg-shaped section having an equal area. Such sewers, which, though of different shapes, discharge at the same rate, when laid at the same gradient, are called sewers of "equivalent" sections.

For finding an egg-shaped sewer of equivalent section, the diameter of the circular section is multiplied by a constant figure. Thus if d is the diameter of the circular sewer, and d_1 and d_2 those of the old (metropolitan) and new ovoid sewers of equivalent sections, respectively,

$$d = 1{\cdot}209\, d_1 \text{ for old form} \quad \ldots \quad \ldots \quad (10)$$

$$\text{and } d = 1{\cdot}191\, d_2 \text{ for the new form} \quad \ldots \quad \ldots \quad (11)$$

For rough calculations d may be taken as 1·2 times either d_1 or d_2.

The hydraulic mean depth, r, of ovoid sewers of equivalent section is the same as that for circular sewer when running full, though it is higher for smaller depths of flow.

Hence, the discharging capacities of both the egg-shaped and circular sewers, when running full, may be assumed to be equal for practical purposes. Thus,

$$0.7854\,d^2 = 1.147\,d_1^2 \qquad \ldots \qquad \ldots \qquad (12)$$

From this also an egg-shaped section of equivalent area can be designed, as will be clear from the following example.

Example 8:—Design an outfall sewer of an egg-shaped (old) section, for the sewerage on separate system of a city, having a prospective population of 60,000 souls, with a daily quota of water supply per head of 360 lit. neglecting infiltration water.

Solution:—Daily sewage = 60,000 × 360 = 21600000 lit.

$$\text{Average flow} = \frac{21600000}{24 \times 3600} = 250 \text{ lit./sec.}$$
$$= 0.25 \text{ cu. m./sec.}$$

Sewers on separate system are designed for 6 times D. W. F. i. e. for $0.25 \times 6 = 1.50$ cu. m./sec. in this case. Assuming a self-cleansing velocity of 1 m./sec. the sectional area of the sewer must be $\frac{1.5}{1} = 1.5$ sq. m.

If D is the diameter of the proposed egg-shaped sewer

$$1.5 = 1.147\,D^2$$
$$D^2 = 1.308$$
$$D = \mathbf{1.142\ m.} = \mathbf{1150\ mm.}$$

The horizontal diameter of this egg-shaped sewer will be 1150 mm. (42″), its vertical diameter, or height above the invert will be 1725 mm. (63″) and the diameter of the circular portion of the invert = 575 mm. (21 in.)

Egg-shaped Sewer Running Partially Full:— The graphs in Fig. 191 give the hydraulic elements such as the areas, hydraulic mean depths, velocities and discharges, all in proportion to those of the same sewer, when running full, the elements of the latter being assumed as unity. They are similar to those given on page 209 in Fig. 188, for circular sewers running partially full. Their use is indicated in the following example.

Example 9 :– If the sewer in Example 8 runs with peak D. W. F. only, in summer what will be the depth and velocity at that time ?

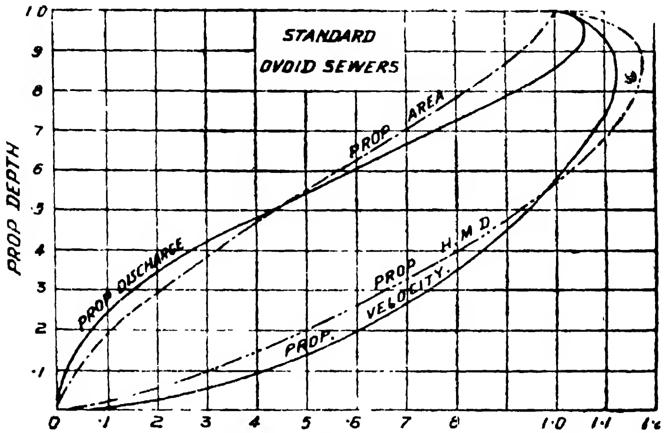


Fig 191.

Graphs of proportional depths, areas and discharges of egg-shaped sewer running partially full by Manning's formula.

Solution :— The peak flow is twice the dry weather flow i. e. $2 \times 0{\cdot}25 = 0{\cdot}5$ cu. m. / sec. This is one-third of the full discharge when the sewer is running full. From the graphs in Fig. 191 for 0·33 discharge, the depth will be 0·44 of the

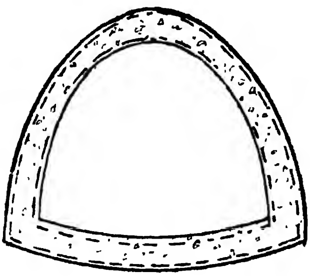


Fig. 192.

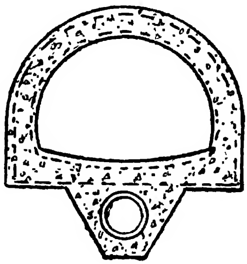


Fig. 193.

Semi-elliptical and horse-shoe sections. Under the horse-shoe section there is a pipe for draining infiltration water.

vertical diameter of the egg-shaped sewer, i. e. $0{\cdot}44 \times 1725 = \mathbf{759}$ **mm**. The velocity will be 0·88 of that when running full. The velocity depends upon the gradient, and if it is 1 m./sec. (3 ft./sec.) as assumed above when running full, for the peak D. W. F. it will be 0·88 of 1 = 0·88 m. which is self-cleansing.

Other forms in common use, viz. semi-elliptical, and horse-shoe are shown in Figs. 192 and 193. These are, in most cases, dictated by the ease, convenience, and economy in construction. For instance, the excavation for a tunnel in earth with the usual timbering made for the heading, takes such a shape that a semi-elliptical section is convenient and economical. On the other hand, if it is in rock, a horse-shoe section would be more logical.

Questions

(1) Find the velocities and dischage per sec. of a 750 mm. (30 in.) diam. sewer laid to 1 in 1000 grade by (a) Chezy formula with Kutter's $n = 0{\cdot}013$. (b) Manning's formula with $n = 0{\cdot}013$.

Ans. (a) 0 81 m./sec., 0·357 m.³/sec. (b) 0·80 m./sec, 0·352 m.³/sec.

(2) What is the velocity and discharge per second of 400 mm. (15 in.) pipe laid to 1 in 100 by Manning's formula ($n = 0{\cdot}013$) ?

Ans. $v =$ 1·66 m./sec., $Q =$ 0·209 cu. m./sec.

(3) A 250 mm. (9-in.) stoneware pipe laid to a gradient of 1 in 125 runs half full. Calculate by Chezy formula with Kutter's coefficient the velocity and discharge per sec.

Ans $v =$ 1·02 m./sec ; $Q =$ 0 05 cu. m./sec.

(4) A 500 mm. (24-in.) diameter pipe of glazed, very smooth stoneware laid to 1 in 1000 runs full. Find the coefficient, velocity, and discharge per sec. ($n = 0{\cdot}010$).

Ans. $c =$ 73·51; $v =$ 0 822 m./sec.; $Q=$ 0·161 cu. m./sec.

(5) Design a Metropolitan egg-shaped sewer which when laid to 1 in 1200 grade will carry 1·5 cu m./sec.

Ans. Horizontal diam = 1150 mm.; vertical ht. = 1725 mm.

CHAPTER VI

FIELD WORK

THE field-work consists of the following main items :—

(1) Reconnaissance survey,

(2) Detailed survey for preparing —

(*a*) A map of the entire area to be sewered with all the roads, lanes, cart-tracks, tram and railway lines, *nallas*, gardens, parks, agricultural land or vacant plots, ponds, boundaries of houses, fountains, public water stands, surface drains, existing sewers, if any, and outfall site.

(*b*) Longitudinal and cross sections of roads and *nallas*.

(*c*) Contoured plan of the whole area.

(3) Investigations in field and collecting information pertinent to the preparation of the project, such as high and low flood levels of streams, quality, quantity and rates of materials available for work, etc., the different strata to be met with while excavating for sewer lines or foundations of masonry works, etc.

(1) **Reconnaissance Survey** :— This is a preliminary survey or rather observation for determining the rough general outline of the sewerage scheme, and is done by an expert with the help of whatever rough data is available, and a general map of the town. It is done by going round all the important parts of the town slowly in a motor car or preferably, riding on horse-back or better still, walking on foot. The first thing to be considered is how the sewage is to be finally disposed of. If by land treatment, to inspect the land, examine its nature, consider its extent available, cost, the levels-for, the land must be fairly above the high flood level (H.F.L.) of the stream, if there is a stream close by, and yet must be easily commanded by the outfall sewer. The wind direction, and the possibility of aerial nuisance to the town

must also be considered. If the disposal is to be done by dilution, the point or points of discharge, the bodies of water such as a lake, river, or tidal sea, the dilution furnished in the hottest part of the year; if it is sea, the depth, direction of wind, and the direction and strength of the tidal currents, must be considered. The possibility of nuisance of smell, formation of sludge banks, especially in proximity of bathing *ghats*, temples, and mosques, etc., so revolting to the eye must be thought out. Whether the water is used for drinking purposes on the downstream side, if it is a river, must also be investigated. If so, it may prove to be a danger to public health, unless other conditions mentioned later under disposal by dilution, are favourable.

If none of the two methods, viz. land treatment, and dilution is feasible, the sewage must be treated, at least partially, before it is discharged into a river or a *nalla*. The sort of treatment suitable for the individual needs and circumstances of the town, and the degree of treatment, must be considered and the probable rough initial and operating costs must be worked out. In most cases a separate, or at the most partially separate system of sewerage may be favoured. The quantity of sewage may be roughly worked out by assuming an increase of 40 to 50 per cent in the quantity of the quota of water-supply allowed per head per day for the present population.

When the question of disposal of sewage and the position of the outfall is determined, the direction in which all the sewage must be conveyed will also be fixed. Then the general lie of the area of the town may be considered, whether the whole area is sloping in one direction, or also in a subsidiary direction in addition, whether there is a main valley or a ridge across the town. A ridge across a town presents a peculiar problem which must be solved on its own individual merits. Then the levels may be considered. Spot levels of a few salient points, if not already available, may be quickly obtained by running a few fly levels. This will show the average gradient available. It would also give an idea as to whether an entirely gravitational scheme is possible, or pumping would have to be partly resorted to. A gravitational scheme is the cheapest in the running cost. If there are a few parts where the gradients are likely to be flat, flushing tanks will have to be provided.

Approximate positions of storm water overflows may also be determined. If any *nallas*, railway line, etc. have to be crossed, the number and positions of the siphons which have to be constructed will be known. In this way a general outline of the scheme, with all its essential features, can be obtained in this reconnaissance survey.

(2) **Instrumental Survey**:— In most cases a map of the town, showing most of the details mentioned above, may be available. If so, it will save a lot of labour and time However, its accuracy must be tested before accepting it. This can be done by taking check measurements at several places. If the error found is within 0·3 per cent, it should still be acceptable. For, this error means an error of 0·9 m. in a distance of 300 m. between two manholes, or an error of 0·0045 m. in a maximum gradient of 1 in 200 if allowed in that distance, which is negligible both for design and construction.

It is possible that the map may be correct, but not revised since it was first prepared. If so, it should be brought up to date. The town-planning office may be consulted, and if they have a map ready for the town, a copy may be obtained. The engineer can then ascertain from it, where the main roads will be located, and can calculate the exact future population of the extension area. For, in the town-planning maps separate zoning is usually shown demarcating the area in which only six or twelve houses per acre will be allowed. Similarly industrial, shopping or business, and residential areas are separately zoned.

If no such map is available, or the one available is incorrect, a traverse survey of the entire town, either by a chain and theodolite, or a chain and prismatic compass, or at least by a plane table is necessary.

Levelling:— The object of levelling is: (1) to enable longitudinal and cross sections of roads, lanes and other surfaces under which a sewer is to run, to be drawn, (2) to enable the contours of the whole area to be drawn. so that one can see at a glance in what direction and at what rate the surface is sloping, and (3) to find at what levels the cellars, depressions and ponds, if any, which, it may be desirable to drain, lie.

Before starting levelling it is necessary to verify and correct, if necessary, the permanent adjustments of the levelling instrument The chain should also be standardised by comparing it with a steel tape almost every day before beginning the survey work. The next operation is to run a series of very accurate fly levels along roads, starting from a G. T. S. bench mark, with a view to fixing permanent bench marks on some important objects, at intervals of about two furlongs. These levels should be checked and rechecked, if necessary, until the error is within permissible limits, viz. 1 cm. per km. in very flat country, like the plains of N. India, and double this, in the parts with steep ground slopes as in the Deccan.

While levelling, staff readings should be taken as shown below:—

(*a*) At every 50 m. (200 ft.) interval if the country is flat, or, at every 25 m. (100 ft.) if undulating, and at every summit and hollow and at every change of gradient, along the centre line of roads, lanes, and at their junctions.

(*b*) Levels of cellars, by taking measurements by a tape below the floor, levels of inverts of inspection chambers.

(*c*) Floor levels of buildings that are at a lower level than the road surface.

(*d*) Spot levels in fields that are lower than the road.

(*e*) Levels for cross sections at every 100 m. (400 ft.) at right angles to the lines, for cross profiles of roads, up to 25 m. (100 ft.) on either side, or whatever distance available between rows of houses, with staff readings at 3 to 8 m. (10 to 25 ft.) so as to obtain a clear idea of the cross profile of the ground on either side and the width of road and side gutters.

(*f*) Levels for longitudinal and cross sections of *nallas* and water courses. These should also be surveyed with a chain and prismatic compass, with staff readings at 10 m. (50 ft.) if the bed is steep, or at 25 m. (100 ft.) if it is flat. The levels of highest floods should be noted.

When all these levels are plotted on Municipal map, they should present a network of levels, but if any blank spaces are left out, anywhere, extra lines should be surveyed with levels across them, or spot levels should be taken, so that accurate contours can be drawn.

(*g*) The site for the outfall and treatment works, if any, should be surveyed and spot levels taken at closer intervals.

Field Notes :—Copious notes should be recorded, supported by neat, dimensioned sketches. Nothing apparently unimportant should be left out. For instance the following: Observe and note down when houses lie far back from the road, or at low levels, and make sure that all properties within a reasonable distance from the public road, and certainly all those that have their boundaries within 100 ft. can be connected.

When a cross drainage work such as an arched culvert, or a slab drain or a piped drain, is met with, a neat sketch should be drawn on the notes page, showing the following details:—the bed levels of the *nalla*, the width and height up to springing if it is arched, or the depth or diameter, if it is a slab or a pipe drain, the road level at the top, the high and low water level marks for fixing positions of siphons, or storm water overflows. The positions of water mains, electric cables and their depths below the road surface, the character of the sub-soil strata, such as earth, gravel, kunker, *muram*, or rock, as seen exposed on the banks of *nallas*, or wells, the nature of the road surface such as metal, concrete, stone paving, asphalt, places liable to be flooded and so on.

The field-work also includes collection of the information such as the sources, quality and quantity available, of engineering materials with their average lead, i. e. the distance from the centre of the town. These materials are: Stone, brick, stone metal, gravel, sand, lime, cement, pipes of stoneware, c. i., concrete, jointing materials, etc. The distance of the nearest railway station, and the condition of the road leading to it, should be recorded, and the possibility of transporting materials like cement, steel, pipes, etc., directly from the nearest commercial town (if the present town is not a big place), by motor vans so as to avoid loading, unloading and the possible breakage in them at the railway station, should be investigated.

Similarly, enquiries should be made of the current daily rates of wages of the skilled and unskilled labour.

The next important item is the underground survey along the lines of sewers, to determine the nature of the strata likely to be met with while excavating for trenches, and foundations of works and the sub-soil water levels. For shallow depth, a steel probing rod, pointed at the bottom and with a driving head at the top, is very serviceable. By applying ear to the head while thrusting it into the ground, one can hear distinct sounds, and tell when the point is passing through earth, sand, etc. It rings when rock or hard *muram* is encountered. For greater depths a posthole auger is very good, in all strata, except those of loose sand, *muram*, or rock. It brings to the surface samples of the materials. For still greater depths, and in sand and *muram*, actual trial pits may be taken. The results of all these should be recorded in a note-book for use while estimating quantities, and preparing estimates of costs.

Rock excavation in particular is a very costly and tedious job, as in the midst of occupied area it has to be done by chiselling and chipping.

Questions

(1) What is reconnaissance survey and why is it important?

(2) Write down full instructions, for the guidance of a surveyor, employed on surveys for project work.

(3) What is the significance of determining the nature of sub-soil strata and levels of sub-soil water?

CHAPTER VII

OFFICE WORK (Collating Data)

THE entire office work includes the following items in their sequential order :—

(1) Plotting the survey, drawing the longitudinal and cross sections, drawing the contours, determining general lay-out, marking the branch and main sewer lines, marking and numbering the manholes, determining the positions of storm water over-flows, and inverted siphons, dividing the area into population districts and drainage districts, and preparing statements of population and surface areas, M. H. to M. H., on each branch and main, etc.

(2) Calculating drainage areas, the number of houses, and from them the population separately on each sub-branch, branch, and main sewer. Calculating the quantity of sanitary sewage including industrial wastes, storm water from roofs and back yards, for design of separate or partially separate system, and storm water from the entire drainage area of each sub-branch, branch, and main for the combined sewerage system.

(3) Designing sewer sections, and noting down the grades, drops, velocities and the invert levels on the longitudinal sections.

(4) If, at certain places sewage requires to be lifted, designing either automatic ejectors, air lifts or pumps, whichever is found economical and convenient, with accessories and buildings for housing them.

(5) Designing the various appurtenant works, such as manholes, lamp-holes, inlets, catch-pits, storm water over-flows, inverted siphons, etc.

(6) Designing outfall works including treatment works according to the method of disposal of sewage contemplated, etc.

(7) Estimating quantities and cost of all the above.

(8) Writing out detailed specifications.

(9) Writing out a report incorporating all the features of the project, different alternative proposals considered, and final recommendations, indicating also the proposals for raising the necessary funds, and suggesting the ways and means of repaying the loan with interest by equal annuities, spread over a certain period.

(10) Submitting drawings, estimates, and the report to the proper authority for technical and administrative approval.

(11) When the scheme is approved and sanction to raise the loan is accorded, arranging finances, calling for tenders, placing orders for machinery and equipment after calling for quotations, and accepting one of the tenders.

These are discussed in the following pages, from a practical point of view, some briefly, and others in detail, according to the requirements of the student preparing for examination.

Preparing a Plan:—Whatever survey is made, either partial for revising a Municipal map, or in the absence of the latter, the entire survey of the town, it should be plotted to a scale of 1 : 2500. It will have to be suitably enlarged with a pantograph later, to prepare large scale plans separately of each sewer district. All the details surveyed, as well as those recorded in the notes, should be shown on the plan. The North direction should also be invariably shown.

General Lay-out of Sewers:—This is the most important and difficult thing in the sewerage project, in which the advice of an expert, who has varied experience in the preparation and execution of sewerage schemes is often very helpful. The position of the outfall, to which all the sewage is ultimately to be taken is the first deciding factor. The next is the topography of the town. If there be a valley traversing across the town, meeting a body of water, such as a river or a lake, at its lower end, with the town situated on both sides of it, the logical arrangement would be to lay the main sewer along the valley at its bottom, with the branches and laterals perpendicular or inclined at an angle to it.

If, instead of a valley, there is a ridge, two separate mains, with their systems of branches, one on each side of the ridge, may be laid ; or, if one of the mains is small, and the ridge not very high, the sewage from the smaller main may be pumped into the larger main, or if high, diverted into it through a cut, or a tunnel across the ridge.

If the outfall be some large body of water on one side of the town, towards which the area is sloping uniformly, it may be found convenient to lay a number of small independent sewers, each serving as an independent main and draining into the body through its own outlet. If this is deemed objectionable from the point of view of possible contamination of water, or foul smell, or unsightly appearance along the water front, used for bathing or religious or recreational purposes, it may be necessary to lay an intercepting sewer, which would collect sewage from all the separate sewers, and discharge it through one or more outlets at a safe place, on the downstream side of the town, into a body of water for dilution.

It may be, as often happens, that the area occupied by the town may be such as could be divided into different zones, such as high, mid-level, and low level zones. In such a case different mains may be laid, to collect the sewage at the end, finally leading to the outfall. Or, the sewage from the higher zones may be allowed to gravitate, and that from the lower ones, pumped into that of the high level.

The best course is to walk over the area with a large scale map in hand. The time and labour spent in this would be amply paid for, later. It would give the engineer first-hand knowledge of the work, and lay before him the practical difficulties in the way, far better than any close study of the map in office.

For determining the most efficient and economical lay-out, it is recommended that a tracing should be made of the

Municipal map showing only the roads, alleys and the contours, and several white prints made therefrom. Different alternative lay-outs may then be tried on the prints, and the one which gives the minimum length of the main sewer should be finally adopted. For, main sewers are only collecting sewers, and the shorter their length is, the more economical would the scheme be, since on account of their large size, they are costly. Sewers serving properties are the real useful sewers. Further, if the length of the main sewer is reduced, it means a steeper grade and higher velocity.

Location of Sewer Lines:—Sewer lines should be located as far as possible in the centre of the street, and they should be in straight and as great lengths as possible. If they are in the centre, the length of house connections on both sides would be equal. However, when a street runs along side-long ground, it is desirable to locate the sewer on the side falling away from the street, so as to command more easily the connections from basements, back yards, etc. The direction of the flow, which, in most cases, follows the ground slope, should be shown by means of arrows. Dead ends should be avoided as far as possible. It is desirable that sewer lines should not cross private properties, and if this is unavoidable, a strip of land should either be acquired, or, a legal agreement should be made with the owner.

The main intercepting sewer, if any, should be located first, then the outfall and main sewers, in say, blue pencil, by a line, then lines in red pencil or ink may be drawn to represent sub-mains and branches. The direction of flow should be shown by arrows.

Large and deep sewers should be kept, as far as possible, out of the business area, bazar, or crowded streets, since, when under inspection or repairs, they seriously interfere with the traffic, which is always heavy in these localities. The streets also are generally narrow at such places in most Indian towns.

Location of Manholes:— The next step is to locate manholes on the sewer lines, and indicate them by small hollow circles. The following points should be noted in this connection :—

(*a*) There should be a manhole at every change of direction, change of grade, and change in the section of the sewer, and at street intersection whether or not there is a branch sewer joining it.

(*b*) The maximum distance apart between two manholes should not exceed 50 m. for Indian conditions unless the diameter of the sewer is 1000 mm. (4 ft.) or more, so as to allow a man to enter it for inspection. In that case the distance may be 150 m. (500 to 600 ft.) or even more.

(*c*) The position should be such that when opened for inspection they should not materially obstruct traffic. If the street is narrow, the entrance should be made on one side with an arched or slabbed passage-way from it leading to the sewer under road.

(*d*) The change in direction should not be at an angle less than 90°.

(*e*) The manholes should be numbered serially. Those on the main or trunk sewer should be numbered first. The numbers should start either from the top downwards or from the bottom upwards. Whatever system is adopted, it should be the same on all drawings. The manhole, say, at the bottom of the main sewer, should be numbered A_1, the next A_2, A_3 and so on. Then those on the branch at the bottom being numbered B_1, B_2, B_3; those on the next branch C_1, C_2, C_3 and so on, so that any manhole can be spotted on the plan at a glance. This should be done in each district separately. Thus the manholes on the main sewer in drainage district No. 6 should be marked by numbers $6/A_1$, $6/A_2$ etc.; those on the lowest branch in the same district as $6/B_1$, $6,B_2$, and so on.

Longitudinal Section :— The L. S. or the profiles of the roads should then be drawn to 1:1000 horizontal, and 1:100 vertical scales. On these should be shown the chainages, surface levels, summit and hollow points, the points at which gradients of roads change, the cellar levels, if any to be drained, rock levels, and sub-soil water levels wherever trial pits or bores are taken, positions of proposed manholes with their numbers, the points at which branch lines or laterals join and datum line. Blanks should be left for velocities and discharges, gradients of sewers, invert levels of the incoming and out-going sewers at each manhole, etc. which can be filled later when the sewer sections are designed.

After this the position of storm water overflows may be marked. These are places where a main or a large branch sewer approaches a *nalla*, so that the sewage in excess of a certain amount can be discharged into it.

Sub-divisions into Districts:— The next step is to divide the area into two sets of districts, one population districts, and the other, drainage districts The former division is for computing the population on each sub-branch and branch and is required for calculating the quantity of sanitary sewage for designing sewers on the separate system. The boundaries of this division should not be inked on the finished map but may be indicated by pencil lines and later rubbed out. The houses served by each branch, or rather the tenements on each branch should be calculated and the population estimated on the basis of 4·5 souls per tenement. For computing the future population of the undeveloped districts, the area should be measured by a planimeter, and population calculated on the basis of the density of population per acre or so many houses per acre, prescribed by the town-planning authorities.

Public institutions, such as schools, colleges, and their hostels, hospitals, hotels, clubs, theatres and other similar social, religious, and charitable institutions, the quantity of sewage from which, is likely to be different from that from residential buildings, should be separately considered, and the quantity of the sewage from them added.

Industrial concerns in each district and the wastes produced by them, should also be taken into account.

For making sub-divisions of drainage areas, ridge lines should be first drawn from the contours, dividing the area into a number of main valleys each bounded by ridge lines, then the areas included in each should be measured by a planimeter, and storm water calculated from them by one of the two methods already described, viz. arbitrary method in which a uniform run-off of 5 to 10 mm. (¼ to ½ inch) intensity of rainfall per hour is assumed over the whole area, or the rational method in which areas of different impervious surfaces are measured and the impervious factor found out, from which the storm water discharge is calculated.

When all the above information is collected, it is a simple matter to tabulate it in the form shown in Table No. 12 and kept handy while designing the sections of sewers.

Example 11 :—A town has a present population of 8,000 and the prospective increase in 30 years is expected to be 25 per cent. If the quota of water supply per capita per day is 360 litres and if no industrial wastes are admitted into sewers, find the average discharge, and design the outfall sewer on separate system for a gradient of 1 in 440 for carrying 6 times the average discharge.

Solution :—Present population = 8000, prospective = 10000

$$\text{Average discharge} = \frac{10{,}000 \times 360}{24 \times 3600} = 41{\cdot}67 \text{ lit./sec.}$$

$$= 0{\cdot}04167 \text{ cu.m./sec.}$$

As the sewers are to be designed to carry 6 times D.W.F.

$$\text{The discharge} = 41{\cdot}67 \times 6 = 250 \text{ lit./sec.}$$

$$= 0{\cdot}25 \text{ cu.m./sec.}$$

If a self-cleansing velocity of 1 m./sec. is assumed, we want a pipe which has a sectional area = 0·25 sq. m. The area of a 600 mm. pipe is 0·2827 sq. m. From Table No. 17, the gradient for a 600 mm. pipe should be 1 in 470 for a velocity of 1 m. Ours is steeper viz. 1 in 440. So, the velocity would be higher. Let us try a 600 mm. pipe.

From Table No. 14 for Chezy and Kutter's formula

$V = C\sqrt{RS}$, C = 56·39 for a 600 mm. pipe.

$$V = 56{\cdot}39 \times \sqrt{0{\cdot}15 \times \frac{1}{440}} = 1{\cdot}04 \text{ m./sec.}$$

$$Q = 0{\cdot}2827 \times 1{\cdot}04 = 0{\cdot}294 \text{ cu. m./sec.}$$

If a 550 mm. pipe is used, from Table No. 14, C=55·33, and A = 0·2376 sq. m. Therefore, $V = 55{\cdot}33\ \sqrt{0{\cdot}1375} \times \sqrt{\frac{1}{440}} = 0{\cdot}977$ m./sec. which is not satisfactory, and $Q = 0{\cdot}2376 \times 0{\cdot}977 = 0{\cdot}232$ cu. m./sec. which is inadequate. Therefore a 600 mm. pipe is required.

Example 12 :— If the town in the above example occupies an area of 150 hectares out of which the area under roof surfaces is 6 hectares and that under paved yards is 3 hectares find the combind discharge and design the outfall pipe if the maximum intensity of rainfall is 50 mm. p. h.

Solution :— Storm discharge = run-off from roofs and paved yards,

$$= \frac{10{,}000 \times 50}{60 \times 60 \times 1000}(6 \times 0{\cdot}82 + 3 \times 0{\cdot}87) = 1{\cdot}046 \text{ cu. m./sec.}$$

in which 0·82 and 0·87 are the impervious factors of roofs and paved yards.

=1·046 cu. m./sec.

Add two times the D. W. F. i. e. 2×0·04167

Combined discharge = 1·129 cu. m. / sec.

For a self-cleansing velocity of 1 m. / sec. we want a pipe having an area $= \frac{1{\cdot}129}{1} = 1{\cdot}129$ sq. m. But as the gradient viz. of 1 in 440 is very steep, a much smaller pipe will suffice. Let us try a 1000 mm. pipe having an area = 0·7854 sq. m. From Table No. 14 for Kutter's formula C = 62·53.

$$\therefore V = C\sqrt{RS} = 62{\cdot}53\sqrt{0{\cdot}25 \times \frac{1}{440}} = 1{\cdot}489 \text{ m./sec.}$$

Q = 0·7854 × 1·489 = 1·169 cu. m./sec. against 1·129 cu. m./sec.

Hence a 1000 mm. pipe would be the correct size.

CHAPTER VIII

OFFICE WORK (Contd.)

(Design of Sewers)

WE are now in possession of all the necessary information to be able to design sewers, viz., the quantity of sewage which can be calculated from the population on each sewer, from manhole to manhole or branch to branch, the quantity of storm water which we can calculate from the areas contributing their run-off to the sewer, branch to branch, the gradients which can be worked from the longitudinal sections, and we know the hydraulic formula, or we can refer to readymade charts and tables.

Standard Practices :— However, before we start actual designing, it is better to discuss certain standard practices which are commonly adhered to. These are :—

(1) The minimum diameter of a sewer should be 150 mm., just as the minimum diameter fixed for a house drain is 100 mm. The American practice is to use 200 mm. (8 in.) minimum.

(2) The minimum depth of a sewer underground should be at least 1·25 m. (4 ft.) under roads, and 1 m. (3 ft.) elsewhere. This is required to protect the pipe from impacts of fast-moving vehicular heavy traffic, and from accidental damage which may result while excavating for repairs to roads, or for foundations, ploughing, etc. and also from frost.

(3) The minimum velocity of flow, called the self-cleansing velocity, should be 1 m. (3 ft.) per sec. for the climatic conditions of this country, when the pipe is running either full or half full. If the grades, however, allow one of 1·25 or even 1·50 m. (4 or 5 ft.) per sec., it is so much the better. Similarly the maximum should be 3 m. (10 ft.) per sec. If it is less than 0·75 to 0·8 (2·5 ft.) per sec., adequate provision of a flushing tank should be made at the head.

(4) When the designed diameter is one, of which commercial sizes are not manufactured, the next larger size available should be used; e. g. a 280 mm (11-in.) pipe is not manufactured, however if the design requires it, a 300 mm. (12 in.) pipe should be used instead.

(5) The outgoing sewer should never be smaller than the incoming one even though the capacity of the smallar sewer may ultimately be greater on account of steeper grade available for it.

(6) If a small branch joins a sub-main or main at a manhole, at the same level, the branch may be subjected to back flow, and may even be clogged by silt deposits, when the main is flowing with greater depth than that of the branch. To avoid this the invert of the branch is placed a little above that of the main, and as a further protection, a steeper gradient is given to the branch in a short length near the junction.

(7) A pipe of a larger diameter than that required by the design should never be used, as a novice is apt to do, on the score that the gradient is flat, or to save excavation. If a smaller pipe is used even on a flatter gradient, it will run full and have a self-cleansing velocity than the larger one, which, on account of insufficient discharge, will flow with a depth less than half the diameter, and will have a sluggish flow. (See page 213.)

(8) If two sewers of different diameters meet at a manhole, the tops of the both are kept at the same level and the difference is met by providing a step or a slope in the invert of the out-going sewer.

(9) There is always same loss of head in overcoming friction at bends or a change in section. To compensate for this, an allowance is usually made of 5 to 10 mm. ($\frac{1}{4}$ to $\frac{1}{2}$ in.) by giving an extra fall in the open channel at the bottom of manholes.

(10) Sewers are designed as open channels even though they may occasionally run full or even under pressure for a few minutes, while carrying storm water.

(11) Design of sewers is made on two principles: (a) that the capacity shall be adequate, but not excessive to accommodate the discharge, and (b) that the size and gradient shall be such as would cause the sewer to run at least half full once a day at peak discharge, with a velocity sufficient to flush the sewer and remove all the deposits if accumulated when the flow was small.

(12) In a separate system of sewerage, carrying sanitary sewage only, the capacity of sewers should be designed to accommodate 3 to 6 times the D.W.F.* In that case no additional allowance for infiltration water need be made, unless in a particular case the excessive flow of infiltration water warrants it. In the combined system sewers are designed to convey a discharge equal to twice the D.W.F. plus the storm water and in both cases over-flow weirs are provided for discharging flows in excess of certain pre-determined quantities to *nallas* at suitable places.

(13) If the bed-fall of some branch is very steep, a drop manhole (see next chapter) should be used. If the difference is only a few cms. (inches) it can be made up by giving a drop in the bed of the manhole. If it is 50 cm. (2 ft.) or less it may be distributed in 2 or 3 upper manholes.

(14) If two sewers intersect each other with a considerable difference between their invert levels, one should either discharge into the other, if the difference is not much, or they should cross each other, one above another.

Sewers are usually designed from the head downwards towards the tail. However, sometimes when the level of the outfall is the controlling factor, it becomes necessary to first fix the level of the outfall, and then adjust the gradients within the head available, above it.

* For Indian conditions, if there is no likelihood of ground water entering sewers, three times D. W. F. is taken for design of sewers. This allows some extra capacity for some rain water entering through street manholes also.

While designing sewers of different diameters for different gradients, nomograms and charts are very convenient to start with, in making the first approximation, which may then be got confirmed, or slightly altered, by the analytical method employing formulæ, or by the use of tables. This arrangement saves considerable time and labour on the part of the designer. Such charts and tables are available for Kutter's and Manning's formulæ both for circular pipes and egg-shaped sewers.

The grades should be tentatively fixed first, and then different sizes of pipes tried for the requisite self-cleansing velocity, and that size which gives the desired discharge should be finally adopted. The calculations need not be very exact. The difference in diameters of pipes manufactured is three inches. Therefore, the nearest or the next larger size should be accepted.

It is convenient to prepare statements of all the information that is required for designing sewers such as the length, grade available, population, discharge, and from it to work out the diameter, capacity, invert levels, etc. and fill in the blanks with these figures in the statement. The two examples worked out in detail in this chapter, one of a hypothetical town with a skeleton plan, and L. section of the main sewer (Figs. 193 & 194) and detailed statement, and another, from Surat Drainage Scheme adopted from the Bombay P. W. D. Report, with L. section (Fig. 195) and a statement, will give a clear idea of the procedure in design, to the students.

Referring to Figs. 193 and 194, it should be noted that the numbering of the manholes is started from the tail end, by the letters A_1, A_2, etc. and that the figure, '5' is prefixed to each letter representing a manhole to indicate the number five district. Further, starting from the bottom, the manholes on the first branch are numbered $5/B_1$, $5/B_2$, etc. then those on the next branch, $5/C_1$, $5/C_2$, and so on. The design of branch sewers is done first starting from the uppermost branch, working down, and the sewers on the main are designed afterwards, each length being designed from the head towards the tail. (See Statement in Table No. 19).

Note also that a ventilating pipe,* is connected to the manhole at the top of both, each branch and the main (see the remarks in the statement and at the top of the longitudinal sections in Figs. 194 and 195).

Fig. 193 – A skeleton plan of the Main and Branch sewers in Dist. 5 of a hypothetical town.

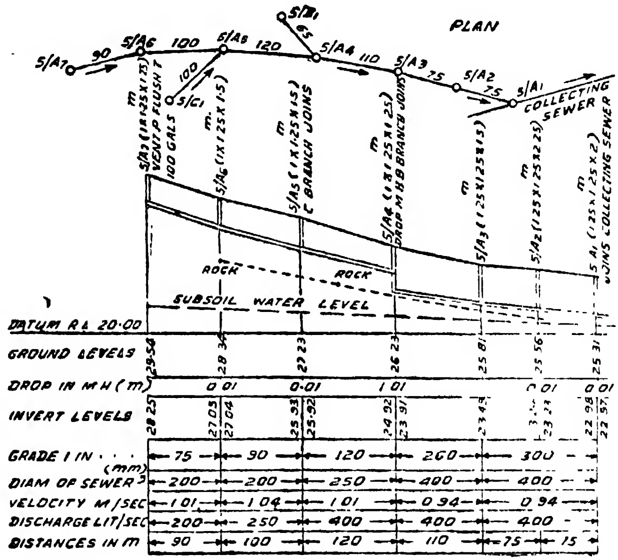


Fig. 194 – L. section of the main sewer. Note the following points :–

(1) A flush tank and a ventilating pipe are provided at the head of the main sewer and branches (See remarks in statement of Table No.19). (2) Almost at every M. H. an extra fall of 10 mm. (⅜ in.) is given in the channel. (3) At M.H. $5/A_4$ a drop of 1·01 m. (3·04 ft) is given by providing a drop manhole.

* These are required at the head of each branch or sub-branch, but are superfluous if disconnecting traps to house drains are dispensed with.

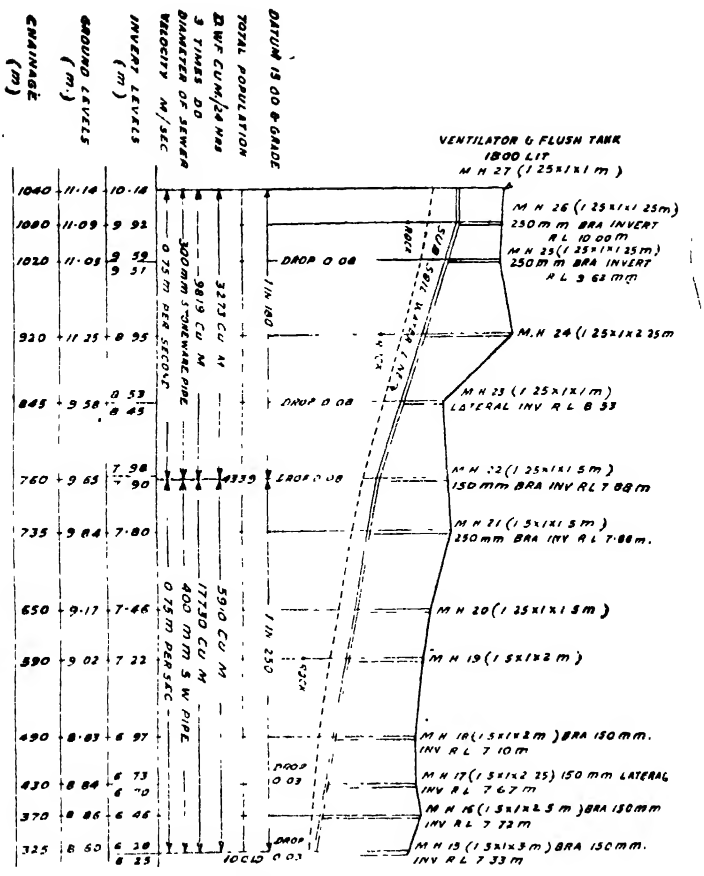


Fig. 195 is part L. section of the main sewer in District No. 14 of a hypothetical town. The points worth noting are that (i) A ventilating shaft and a flush tank have been provided at M. H. 27, which is at the head of the main sewer. (2) All branch sewers meet the main at a level higher than that of the invert of the main. (3) Drops of 0·03 to 0·08 m. (1″ to 3″) have been provided in the M. H channels. (4) A minimum velocity of 0·75 m. (2·5 ft.) per sec. has been provided and (5) Sewers are designed for a capacity to carry three times the D. W. F. which includes provision also for some rain water entering sewers through manhole covers.

TABLE NO. 19

Data for and Design of Branches and Main Sewer of District 5 of a Hypothetical Town

Station or Manhole	Length m.	Population Served: Initial	Population Served: On the Line	Population Served: Total	Discharge at 180 lit. p h. p. d: D W F. lit. per sec.	Discharge at 180 lit. p h. p. d: 6 D W. F lit per sec.	Grade 1 in	Diameter of Sewer mm.	Velocity m. per sec.	Designed Capacity of Sewer litres/sec.	Drop allowed in M. H. m.	Ground Levels R. L.	Invert Levels R. L.	Remarks
$5/C_1$												28·95	26·92	Vent pipe and 450 lit. Flushing Tank.
	100		1200	1200	2·5	15·0	100	200	0 96	30				
$5/A_5$												27·23	25 92	
$5/B_1$												25 71	24·67	Vent pipe and 450 lit. Flush Tank.
	65		288	288	0·60	3·60	100	200	0 96	30				
$5/A_4$												25·20	23·91	
$5/A_7$												29 54	28·25	Vent pipe and 450 lit. Flush Tank.
	90		450	450	0 94	5·63	75	200	1 10	34 7				
$5/A_6$											0·01	28 34	27 04	
	100	450	600	1050	2·19	13·13	90	200	1·01	31·7				
$5/A_5$											0·01	27·23	25·92	Branch C_1 joins,
	120	2250	550	2800	5·83	35·00	120	250	1 04	51·1				
$5/A_4$											1·01		24·92 23 91	Drops of 1 m. in sewer 0·01 m. in channel Branch B_1 joins.
	110	3088	440	3528	7 35	44·10	260	400	1 01	127·0				
$5/A_3$												25·81	23 49	
	75	3528	360	3888	8·10	48·60	300	400	0·94	117·8				
$5/A_2$											0·01	25·56	23·23	
	75	3888	600	4488	9·35	56 10	300	400	0·94	117·8				
$5/A_1$											0·01	25 31	22·97	Joins a collecting sewer.

Example 12 *:—Take the skeleton sewerage plan of District No. 5 of the hypothetical town given in Fig. 194. The detailed data required for design purposes are given in the statement of Table No. 19. Design the first branch sewer, $5/C_1$ to $5/A_5$. Water supply allowed per head per diem is 180 lit. The capacity of sewers to be 6 times the average discharge.*

Solution :—Since a sewer must be at a minimum depth of 1·25 m. below the road surface, the invert level at C_1 is taken at R. L. 26·92 i. e. about 1·3 m. below the ground level of 28·25 at that place. A grade of 1 in 100 is allowed. The minimum diameter of sewer permissible, independent of the discharge, must be 150 mm. The population on the line $5/C_1$ to $5/A_5$ is from the table, 1200 souls.

$$\text{D. W. F.} = \frac{1200 \times 180}{24 \times 3600} = 2{\cdot}5 \text{ lit./sec.}$$

The maximum discharge, for which the sewer is required to be designed is,

$$6 \times \text{D. W. F.} = 6 \times 2{\cdot}5 = 15 \text{ lit. per sec.} \qquad \ldots \quad (a)$$

Let us now see if a 200 mm. pipe laid to 1 in 100 grade provides sufficient capacity to discharge this with a self-cleansing velocity.

From Kutter's Table No. 14,

$$V = C\sqrt{RS} = 42{\cdot}76 \times \sqrt{0{\cdot}05 \times \frac{1}{100}} = 0{\cdot}96 \text{ m./sec.}$$

This is almost the self-cleansing velocity if the sewer runs either full or half full, at least once a day.

$$Q = A \times V = 0{\cdot}03142 \times 0{\cdot}96 = 0{\cdot}03 \text{ cu.m./sec.}$$
$$= {\cdot}30 \text{ lit./sec.} \qquad \ldots \qquad \ldots \quad (b)$$

This is more than (*a*) viz. 15 lit. which is half of the designed capacity, and will therefore give a velocity even slightly more than 0·96 m. per sec. when running half.

But our peak daily flow may be only 2 to 3 times the D. W. F. i. e. 5 to 7·5 lit./sec. This is 16 to 25% of the sewer capacity. From the graph in Fig. 187 and Table No. 16 on page 209 for partially full sewers, these discharges will develop 0·5 to 0·75 of the velocity when the sewer is running full, i. e. 0·5 to 07·5 m. per sec. These are not bad, still, it is advisable to provide a flushing tank at the head and this has been done (see the remark in the remarks column of Table 19). Thus a 200 mm. sewer laid to 1 in 100 grade with a vent pipe and a flushing tank at the head, is the correct design, and this is recorded in the t ble.

Example 13 :—Design the line $5/A_5$ to $5/A_4$ in the above example. (See the plan in Fig. 193).

Solution:—Here the length is 120 m. The population = population on branch $5/C_1$ + that on $5/A_7$ to $5/A_5$ + that on the line $5/A_5$ to $5/A_4$ = 1200 + (600 + 450) + 550 = 2800.

$$\text{D. W. F.} = \frac{2800 \times 180}{24 \times 60 \times 60} \quad 5{\cdot}83 \text{ lit. per sec.}$$

$$6 \times \text{D. W. F.} = 6 \times 5{\cdot}83 = 35 \text{ lit. per sec.} \qquad \dots (a)$$

If a 250 mm. sewer is laid at the available grade of 1 in 120, by Crimp and Bruges' tables,

$$V = C\sqrt{RS} = 45{\cdot}5 \times \sqrt{0{\cdot}0625 \times \frac{1}{125}} = 1{\cdot}04 \text{ m./sec.}$$

This is a very good velocity when the sewer runs full.

$$Q = A \times V = 0{\cdot}0491 \times 1{\cdot}04 = 0{\cdot}0511 \text{ cu. m. / sec.}$$
$$= 51{\cdot}1 \text{ lit./sec.} \qquad \dots (b)$$

This is more than (*a*). Hence 250 mm. is the correct size, and this is recorded in Table No. 19.

The peak daily flow of 2 to 3 times the D. W. F. i. e. 11·66 to 17·50 is 25 to 30 per cent of the full discharge. From the graph in Fig. 187 the velocity will be between 0·65 to 0·75 of that when running full i. e. between 0·66 to 0·75 m. per sec. which is sufficiently self cleansing. Besides, there are two flushing tanks, one at $5/C_1$ and another at $5/A_7$ provided, which will insure sufficient discharge at times to cleanse the sewer. Thus, a 250 mm. sewer laid to 1 in 120 grade is a suitable design.

The student is advised to work out for himself the designs of all the other lines in Fig. 193 and verify the results with those given in Table No. 19.

Questions

(1) A town has a prospective population of 15,000, and water supply available is 150 lit. (32 gallons) p.h p.d. If an addition of 5 % is to be made for the combined discharge of industrial wastes and ground water, design the outfall sewer for the available grade of 1 in 800 for 3 D. W. F. capacity.

(2) The population served by a branch is 7000. The w.s. allowed p h. p. d. is 180 lit. (40 gallons). The available grade is 1 in 260. Design the sewer for a capacity of 3 D.W.F. with a velocity not less than 1 m. (3 ft. per sec.)

Ans.. 400 mm. (12").

(3) Design a sewer with the data: maxi Q = 9820 cu.m. (2·16 mill. gall.) per day, grade 1 in 180, velocity 0·75 m. (2.5 ft.) per sec.

Ans. : 300 mm. (9").

(4) Why are the minimum rain water pipe of 150 mm. (6 in.) and minimum depth 1·25 m. (4 ft.) under road and 1 m. (3 ft.) elsewhere specified for a sewer ?

(5) What are the rules commonly observed while locating manholes on a sewer line on a map ?

CHAPTER IX

SEWER APPURTENANCES

THE principal appurtenances are : (1) Manholes, (2) Lampholes, (3) Inlets, with or without silt-traps, (4) Storm water relief works, and (5) Inverted siphons.

Manholes :— The primary object of a manhole is to afford access to the sewer for facility of inspection and cleansing. Its essential requirements are :

(*a*) It should have an opening wide enough for a man to enter and come out with ease. 550 to 600 mm (22 to 24 in.) diameter is the standard.

(*b*) It should possess easy means of reaching the bottom such as a ladder or steps.

(*c*) The space at the bottom should be wide and long enough for a man to bend in the direction of flow without squeezing his body, and use a brush or a scraper, the standard length of which is 1·25 m. (4 ft.) The minimum should be 1·25 m. (4 ft.) in the direction of the flow and 1 m. (3 ft.) in others.

(*d*) There should be a smooth, open channel with adequate fall, and on its top the floor should be "benched." The slope of the benching should not be so steep as to cause a man standing on it for cleansing, to slip.

(*e*) The frame and cover should be strong enough to withstand the impacts of heavy, fast-moving traffic. The frame should weigh 100 to 225 kg. (200 to 500 lbs.) and the cover 50 to 70 kg. (100 to 150 lbs.) depending on the traffic. A round cover is preferable as there is then the least chance of its slipping down into the manhole.

(*f*) The walls and the floor should be impervious to ground water.

(*g*) The walls should be sufficiently strong to withstand the horizontal thrust of the surrounding earth.

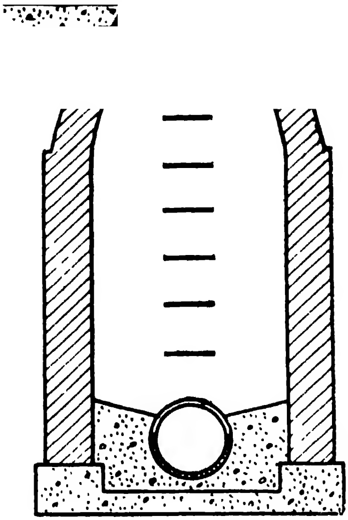
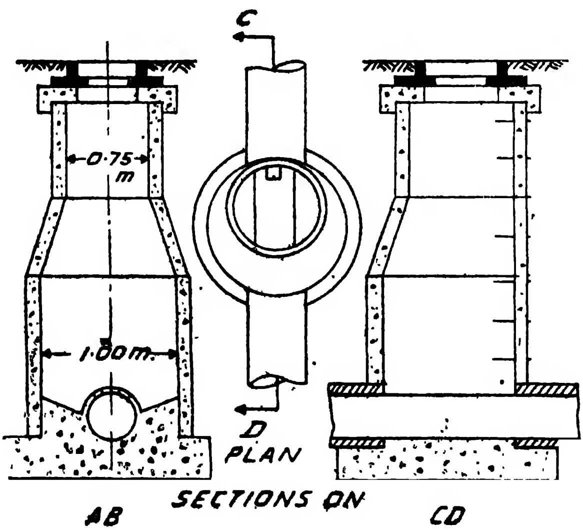


Fig. 196.

A shape, oval in plan at bottom, is suitable where there are no intersecting sewers, and a circular one, where two or more sewers intersect each other. A circular form is stronger than a square or rectangular one by its arch action as in a well.

It is disirable that the walls should be vertical to a height of 1 or 1·25 m. (3 or 4 ft.) above the benched surface, and above that they should be either corbelled out or battered inwards



Figs. 197, 198, 199—Vertical sections and plan at top of a manhole made of three pieces of precast concrete pipes,

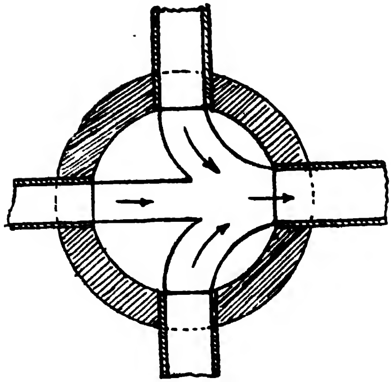


Fig. 200.

all round to leave a small circular opening in the centre as shown in Fig. 196. But when the depth is small this is not possible. In that case the walls should either start with a batter right from the bottom, or may be arched over.

A tapered manhole offers difficulty on the part of the man getting down into it as the steps are on the sloping surface. This is overcome by making one side vertical for fixing the steps as shown in Fig. 199 which illustrates a manhole made of pre-cast concrete spun pipe units. For medium depths this is a form of cheap and satisfactory manholes.

Where two or more sewers of large diameter join at a manhole, the channels should meet in curves of sufficiently long radii, and the bottom of the manhole should be large enough to accommodate the full curves inside it, to streamline the flows of all the intersecting sewers in one direction. The tongues at the junctions of curves should be sharp as shown in Fig. 200 to guide

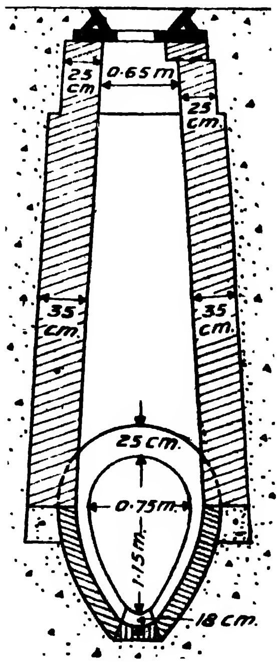


Fig. 201

the flow; otherwise, eddies and other disturbances would be caused.

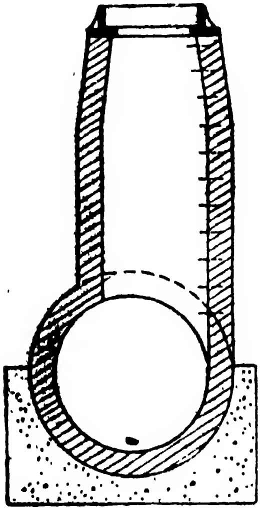


Fig. 202 (Top) :
A manhole built eccentrically on top of a large circular sewer.

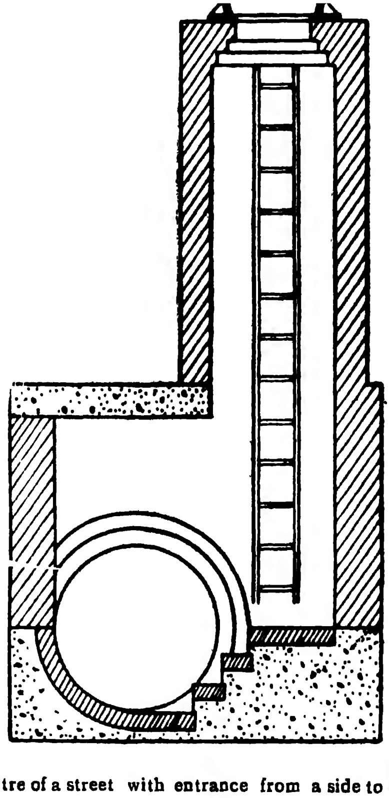


Fig. 203 (Right)
A manhole in the centre of a street with entrance from a side to avoid difficulties of traffic.

A deep manhole built on the top of a comparatively small sewer is shown in Fig. 201 and another built on the top of a large sewer eccentrically, is shown in Fig. 202. Both these have steel steps projecting from a wall for getting down for purposes of inspection and cleansing.

Sometimes when a street is narrow with considerable traffic on it, a manhole placed in the centre is likely to obstruct traffic. To meet the situation, the manhole is built below the centre of a street and a side entrance is provided to it with a covered passage beneath the road. Such a manhole is shown in Fig. 203. This has a ladder for descending to the bottom.

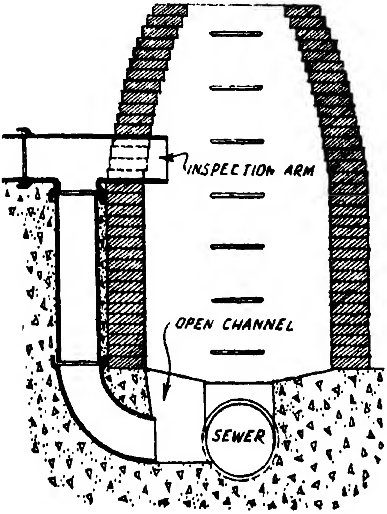


Fig. 204.

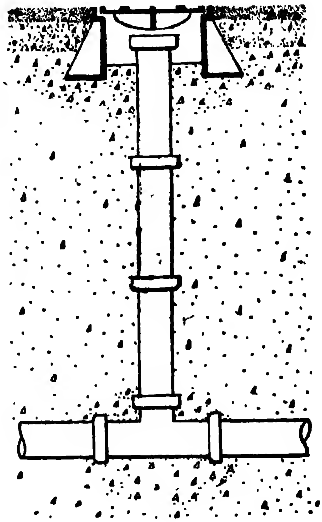


Fig. 205—A lamp-hole.

Sometimes the invert level of a branch sewer is 4 ft. or more above that of the main to which it is to join. In such a case a drop manhole is provided. It consists of a T or Y junction at which the branch sewer ends in a wall of the manhole, and from the stub of T or Y, a vertical pipe (or an inclined one, if it is a Y junction) just outside the wall comes down and discharges its flow into the channel of the main sewer below as shown in Fig. 204. The opening at the top serves for inspection and cleansing.

Lampholes:— When a sewer is straight, but its length between two manholes is more than the usual distance allowed, or sometimes when a very slight change in direction getting stuck into them. The inlet on the face of the curbs need not be very strong, though the spacing of vertical bars cannot be large to prevent twigs and large stones being washed into it.

The area of gratings to be provided for inlets must be calculated by the usual hydraulic formula after making allowance for the thickness of bars.

Horizontal inlets in gutters are preferable to vertical ones at curb faces especially when the road grade is steep, where the water flowing with great velocity is likely to shoot past the inlet, instead of flowing sideways into it. Sometimes a combination of both types of inlets is used.

Catchpits:—Inlets are sometimes combined with catch-pits. The latter are 0·6 m. (2 ft.) or more deep below the invert of the outlet as shown in Fig. 211. Their object is that silt, sand and other coarse and heavy solids, borne by rain water, should settle into them, so that they can be removed from time to time. Otherwise, they may enter sewers and cause deposits. They are best located near street corners. The grit deposited in catch-pits must be removed after each flood. If this is not done in time, the silt would accumulate and when the pit is filled up to the invert level of the outlet, it would cease to function. Besides, organic matter deposited with the silt would decompose and give out foul gases.

In order to prevent sewer gas from entering catchpits, and escaping above ground in the vicinity to cause nuisance to pedestrians some sort of trap with a fairly deep water seal is provided as shown in Fig. 211. But it is likely that water level may go down by evaporation and make the trap useless unless water is frequently replenished into it, particularly, in the hot weather season.

After all, catchpits, if not properly cleaned in time, are rather a nuisance than a convenience, and it is advisable to do without them by designing the sewers for a slightly higher velocity so as to preclude the possibility of depositing silt into sewers. The traps also may be dispensed with since they interfere with free ventilation of sewers.

There are however, places where a silt-trap or a catchpit is necessary, e. g. at the inlets which collect the torrential flow from a steep hillside, or in the vicinity of markets, etc. where a lot of garbage is collected, which, if not removed immediately, is likely to choke the drains. At such places, deep and large catchpits preferably with a screen at top, are required, and special arrangement made to clean them from time to time.

Flush Tanks:—The proper location of a flush tank is at the head of a sewer with a dead end when such sewers are laid to a flat grade. The requirements of a flushing tank are (1) Facility of inspection, (2) No moving parts, (3) Certainty of action, and (4) Rapidity of flow.

Automatic siphonic flushing tanks which have no moving parts are the best. A typical design is shown in Fig. 213. Its action has been already described on page 89, (Fig. 153).

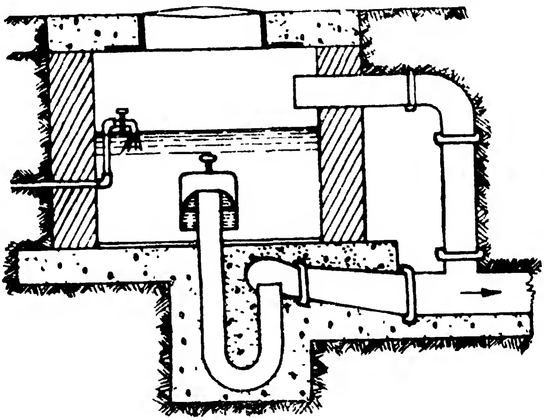
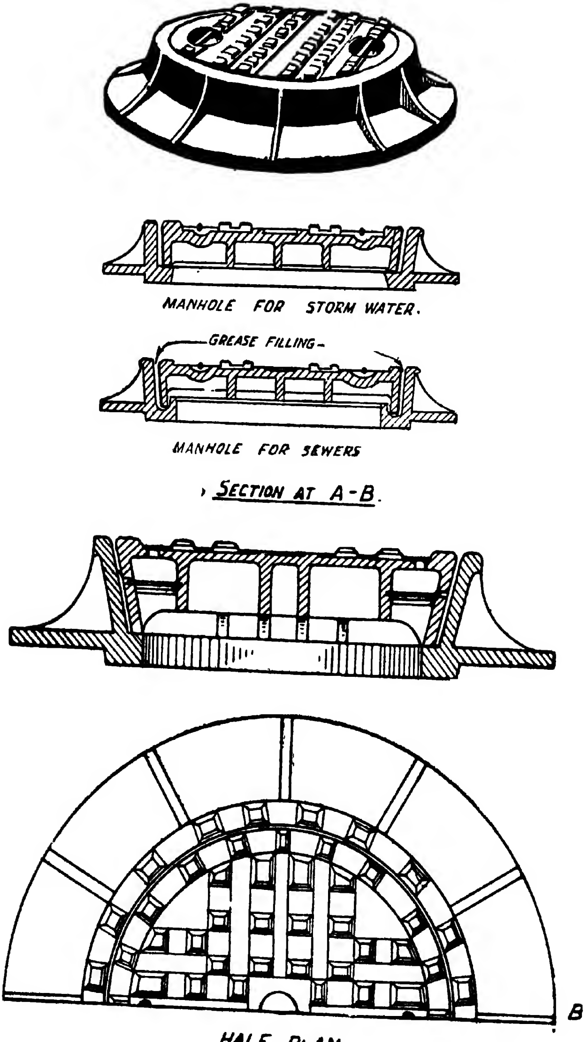


Fig. 213—A siphonic flushing tank.

Sometimes sewage is allowed to accumulate in a manhole and is then suddenly discharged by some means by hand for flushing the sewer below. This is, however, open to several objections, the principal one being that the sewage becomes stale by stagnation and putrefies.



Figs, 214 to 218—Different forms of manhole covers in plan, section and perspective.

Manhole Covers:— The tops of manholes, lampholes, catchpits, flushing tanks, etc., are corbelled out, and a hole sufficiently large for a man to enter with ease for inspection is left, into which a heavy casting of a frame with a water-tight cover closely fitting into it, is provided. It is invariably round so that its cover may not fall down into it, as would happen if it were a rectangular one. The frame and cover must be of substantial section to withstand the heavy vehicular traffic to which it is likely to be subjected. The top should be indented with projections to avoid skidding of motor cars. A few types are shown in Figs. 214 to 218. For making the cover air-tight, a single or double groove is provided all round, which is often filled with grease, or plastic cement as shown in Fig. 216.

Ventilation of Sewers:— Only for a short time, if at all, sewers run full. During the rest of the time the space above the sewage in them, is full of gases, mixed with air, due to the putrefaction of organic matter. These gases include sulphuretted hydrogen and other gases, which are harmful to health. Sulphuretted hydrogen also corrodes pipes of concrete and some metals, used in sanitary works. There are, besides, petrol, which enters sewers from garages and dry-cleaning establishments, and methane, formed as a result of decomposition of putrescible matter. The latter two gases, when mixed with a certain proportion of air, are highly explosive. It is, therefore, necessary to provide means of communication freely between the sewers and the outside air.

The air in sewers is warmer in winter and often cooler in summer than the outside air. Sudden flushing from house connections or laterals drives the air out, and sometimes partial vacuum, or lowering of pressure inside sewers causes outside air to be sucked in. The direction and strength of wind also affect the movement of air in sewers. There is thus a natural movement of air in sewers, and a tendency for mutual exchange between sewer air and the atmospheric air. What is required is the provision of some means for facilitating this exchange.

A few years ago several expedients were used for ventilating sewers, such as providing tall shafts or columns like chimneys, called ventilating shafts, at the head of and along sewers at intervals of 200 to 300 m. (600 to 1000 ft.) on sewer lines, connected to manholes, providing perforated covers over manholes, dispensing with traps in catchpits so that they should serve as ventilators, etc. But they all proved both very expensive and inadequate.

The method now advocated by many sanitary authorities, and which is increasingly gaining favour, is to dispense altogether with intercepting traps, which disconnect house connections from public sewers, and thus remove the barrier. This provides thousands of roof ventilators of private houses as the most efficient ventilating system of public sewers without any cost on the part of the Municipalities.

Questions

(1) What are the requirements of a good manhole? Draw a plan and two vertical sections at right angles to each other, of a manhole 4 m. (12 ft.) deep at the junction of two branch sewers in opposite directions.

(2) What is a drop manhole and what additional purpose does it serve?

(3) What is the object of a catchpit and is it necessary? What precautions must be taken so that it serves its purpose well and does not become a nuisance?

(4) Draw a plan and section of a street inlet in the centre of a road where there is a public stand for horse carriages,

(5) Why is it necessary to ventilate sewers and how is it accomplished? State the pros and cons for providing disconnecting traps to house drains.

CHAPTER X

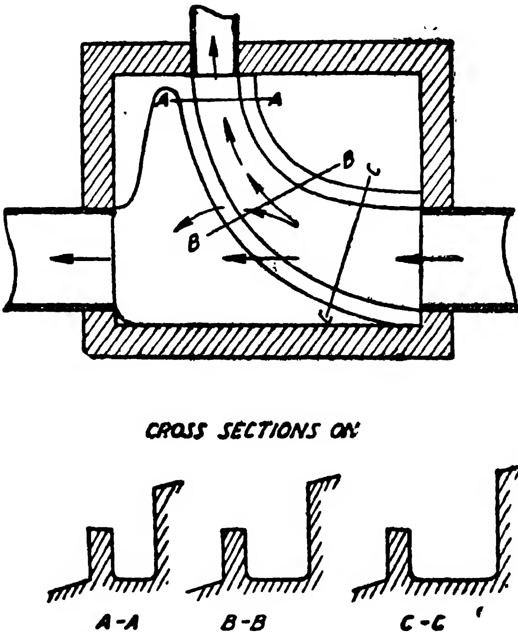
STORM WATER RELIEF WORKS

THE storm water relief works are: (1) Storm water overflows, (2) Jumping weirs and (3) Siphon spill-ways.

Storm Water Overflow Weirs:—This is a very common device and consists of a masonry chamber with an overflow weir built in it at a place where a sewer approaches a natural water course. The object is to keep the discharge of the storm water down to a predetermined maximum and allow the surplus to overflow to the *nalla*. This is done in the interest of economy. For, it reduces the size of the sewer, and by getting rid of the extra flow reduces the cost if the sewage has to be further pumped or treated. This is, however, not allowed if the flow consists of only crude sewage as in the separate system. In the case of storm water there is no harm and in the case of the combined sewage, the sewage already diluted by the rain water is further diluted by the flow of the *nalla*, and the chances of contamination are very much reduced.

The maximum discharge normally allowed to flow to the outfall, that is, the discharge above which the overflow should commence, depends upon the body of the water into which the storm water is to be discharged. If it is into tidal waters, the entire flow may be discharged under favourable circumstances, if it is not likely to cause nuisance of any sort. Elsewhere, if the stream flow is sufficient, all the sewage in excess of 6 times D. W. F. may be allowed to overflow.

Usually the overflow is made by diverting the flow and allowing it to drop vertically over the top of a side weir. This is illustrated in Figs. 219, 220. A curved masonry channel with a weir on the outer side is constructed inside a chamber. The top of the weir is set at such a level that the predetermined flow (usually 6 D. W. F.) flows through it, and is deflected by the weir wall into the sewer of reduced size. When the discharge increases by the addition of run-off from catchment, the level rises and the excess flow drops over the



Figs. 219, 220 – Storm overflow with a side weir, and three cross sections.

weir and is carried to a *nalla*. The length of the weir required is determined by the following formula of Engels.

$$Q = \frac{2}{3}\mu\sqrt{2g} \times \sqrt[3]{l^{2\cdot5}h^{5}}$$

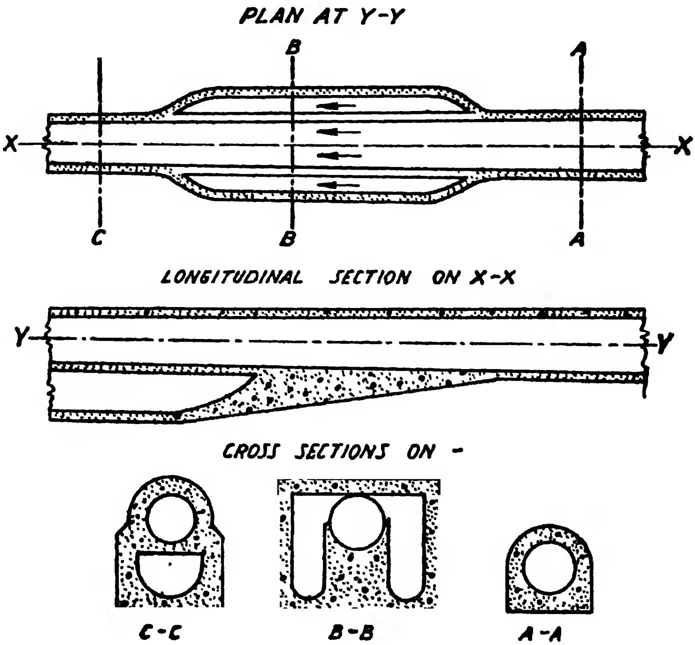
where Q = the discharge over the weir in cu. m./sec.

μ = co-efficient of discharge (0·65 – 0·85).

g = acceleration due to gravity (m./sec.^{2}).

l = length of the weir in m.

h = the outgoing head over the crest in m, The above type of overflow requires considerable length even for ordinary floods. If a double acting overflow with weirs on both sides is adopted as illustrated below in Figs. 221 to 223, the length can be halved.



Figs. 221, 222, 223 — A weir with overflow on both sides.

In the double acting type, inside a covered chamber a channel is constructed joining the incoming and outgoing sewers, capable of carrying 6 × D.W.F. when running full to the brim. When the flow is increased on account of rainfall, it overflows on both the sides into two channels, one on each side provided at a lower level (See C. S. on B B in Fig. 223) underneath the covered channel. These channels join together a little lower down below the main channel

(C. S. on C. C.) and carry the surplus flow ultimately to either a storm sewer or a natural water course as the case may be.

In the above figure, the whole thing is compact under a concrete cover. But very often it is enclosed in a masonry chamber, with one or two manhole covers on the top for inspection.

Sometimes the upper main channel is formed by long pieces of thick steel plates laid horizontally on edge bolted to vertical angle irons embedded in concrete. These are called *dip plates*. Their object is to prevent floating matter from being swept over the weirs and also to regulate the flow. Dip plates are fixed in such a way as to leave a clearance of 3 to 4 in. on sides and at the bottom, through which storm water runs and falls over the crests. Dip plates cause some obstruction which can be compensated by increasing the length of the weir by about 10 per cent.

A better arrangement is to set the overflow at 0·82 diameter of the pipe sewer by cutting its top at that level in the length required by the calculations, so as to form an open channel out of the pipe. This will automatically result in an overflow of all the discharge above that level, on *both sides* of the open channel. If the sewer is designed for carrying 6 D. W. F. when running full, the open sewer will also carry the same as we have already seen (page 210) that the discharge of a pipe running 0·82 full is the same as when it runs full. When the head increases, the discharge also will increase, until when the sewer, downstream of the weir flowing 0·94 full, the discharge will increase to 7·5 per cent above that when full. (See the curve of hydraulic elements in Fig. 188 page 209). Any further increase in head will not increase the discharge of the sewer below, unless it runs under pressure in excess of that necessary to produce a discharge of 7·5 per cent above that, when running full, and this will occur when the hydraulic gradient will be correspondingly increased.

To illustrate this by an example, suppose the sewer below the weir is of 600 mm. (2 ft.) diam. and 125 m. (400 ft.) long laid to a gradient of 1 in 400. The discharge will be 0·31 cu. m./sec. (11·23 cusecs.) (Table No. 14 for Kutter's coefficients). The gradient required to produce an increase of 7·5 per cent or a total discharge of 0·33 cu. m./sec. (12·12 cusecs) is 1 in 340 (approx.) and this hydraulic gradient would give, in a length of 125 m. (400 ft.), a pressure head of 0·05 m. (0·18 ft.). Thus the depth of flow would be 0·65 m. (2·18 ft. above the invert, while the crest of the weir is at $0{\cdot}82 \times 0{\cdot}6 = 0{\cdot}492$ m. (1·64 ft.) above the invert. The depth of the overflow above the crest of the weir will therefore be 0·16 m. or 16 cm. (0·54 ft. or about 6·5 in.)

A diverting weir, even of the double-acting type, i. e. with overflow on both the sides requires a considerable length.

Jumping Weir·—This is another device for allowing excess storm water to escape to a water course, allowing only the maximum discharge, for which the sewer is designed, to flow to the outfall This device is commonly employed in paved yards of buildings to admit small flows into sanitary sewers and increased discharge due to rain water to be carried

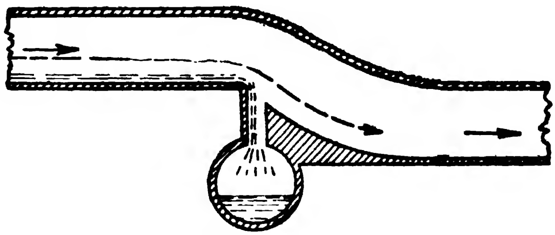


Fig. 224—Jumping weir.

to the storm sewers. The principle is, that when the discharge is small, it falls vertically down directly into the sanitary sewer, and is carried to the treatment works. However, during storms, when it increases in volume, it gains momentum and shoots in a jump across the gap and flows straight to storm water sewer.

Siphon Spill-way:—The one great disadvantage of side overflow weirs, even of those dropping surplus contents on both sides of the sewer, as already mentioned, is that to be effective, a considerable length of the weir is required, and as it has to be enclosed in a masonry chamber, the cost becomes very high. A siphon spill-way is free from this objection, and is a very effective means of controlling storm water, as its capacity is considerably larger, for the same

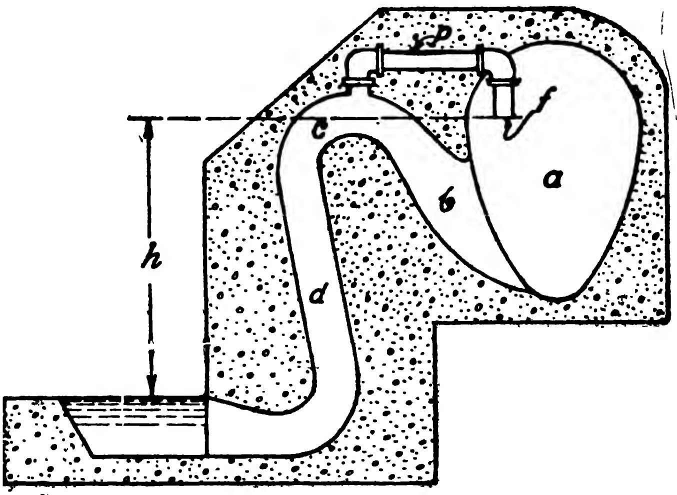


Fig. 225 — A section of siphon spill-way.

cross sectional area of the conduit. Further, it is automatic and very sensitive in its action. There are no moving parts. It is illustrated in Fig. 225. *a* is the combined sewer, to which is attached a siphon consisting of three parts, viz. *b*, the rising leg, with a large entrance, *c*, the throat and *d*, the descending leg ending in a bell-mouth. There is an air pipe *p*, called the "priming pipe", as it primes or starts the siphonic action. This pipe connects the throat of the siphon with the combined sewer. The level *f* of the entrance to the priming pipe inside the combined sewer, is set slightly above that of the crest inside the throat *c*. When normally, the combined sewer flows with the maximum discharge, for which the section of the sewer below the siphon is designed, (usually 6 D. W. F.) the level just touches the crest. As soon as the level rises due to storm water, it seals the entrance to the air pipe, and self-priming commences. The level rises simultaneously both in the combined sewer and above the crest of the siphon, the sewage falls down across the crest and impinges against the walls of the siphon and drives some of the air in front of it, which escapes with the flow through the bell-mouth, and as the flow increases, all the air from the siphon and also from the air pipe is dispelled. The siphonic action sets in full swing till the level in the sewer falls down slightly below that of *f*, the entrance to the air pipe. At this time, air enters the siphon through the air pipe, and the flow of the siphon ceases.

If there is a pond of water in front of the bell mouth to seal the latter as shown in the figure, there is no possibility of air entering the siphon through the bell mouth end at the tail.

Questions

(1) Why is a storm water overflow necessary? Why is it not allowed in the case of sewerage on the separate system?

(2) What are the advantages of a siphon spill-way over the ordinary single and double acting side weirs for discharging surplus sewage into a water course?

CHAPTER XI

INVERTED SIPHONS

INVERTED siphon is the name given to a sewer, which runs full-bore underground, under pressure in a short distance and rises again to the surface.

When a sewer has to cross a *nalla*, river, another sewer, rail road or some such obstacle as a railway or road cutting, the possible courses open are : (1) pumping the sewage, (2) carrying it overhead by means of a trough on top of trestles like an aqueduct, if the levels permit, (3) making a short detour if the depression is local, and (4) carrying it in a sewer underground in a siphon in the short distance of the crossing. In most cases the last named method is the only economical and practical way.

The name siphon is a misnomer, as there is no siphonic action involved.

The Points to be Considered in Design :—(1) The capacity of the siphon must be sufficient to accommodate the maximum discharge, and at the same time the siphon must convey the minimum flow with self-cleansing velocity.

(2) The total length of the siphon, for purposes of calculating the head lost in friction, is not the horizontal distance of the crossing, but the distance along the centre line of the sewer including the slopes and bends.

(3) The pipe or pipes laid underground run under pressure. So, they should be of cast iron or reinforced concrete.

(4) Out of the total head available, allowance must be made for (*a*) the head lost in friction in the length of the pipes, (*b*) head lost in bends, and (*c*) head lost at the entry. Further, as the pipes are liable to be silted, the coefficient of friction must be taken as that for old incrusted pipes. In order to reduce friction, the bends should be easy, and there should be a bell-mouth provided at entry,

(5) It is desirable to arrest coarse matter, both heavy and floating, in a catch-pit a little above the siphon.

(6) Adequate facilities should be provided for inspection and cleansing such as manholes at either ends, penstocks or sluice valves on each pipe, at both the inlet and outlet ends, to isolate any pipe for flushing and rodding. Sometimes a stout chain is provided through the siphon from end to end for being pulled backwards and forwards to loosen the silt deposit.

(7) In the rising leg of the siphon there is an upward gradient, against which the heavier particles in the sewage are to be carried. Therefore, the velocity should be at least 1·25 m. (4 ft.) per sec., though 1·5 or even 2 m. (5 ft. or 6) is desirable.

(8) Long siphons, such as under rivers, should have hatch boxes at about 100 m. (350 ft.) intervals for facility of rodding. There should be a vent pipe in the hatch box to prevent the siphon from becoming air-locked.

Design of Siphons:—This will be clear from the following two solved examples.

Example 14:—Calculate the size of pipe with the following data:

R. L. of invert at inlet	...	45·25 m.
R. L. of invert at outlet	...	43·86 m.
Maximum discharge	...	170 lit./sec.
Minimum discharge	...	40 lit./sec.
Total length with bends, etc	...	75 m.

Solution:—The maximum head available is 45·25 – 43·86 = 1·39 m. Assuming a velocity of 1·5 m./sec. a pipe is required whose cross sectional area is = 0·113 sq. m. A pipe of 400 mm. diam. gives 0·1257 sq. m. Out of the total head of 1·39 m. some head will be lost in (1) friction in the length of the pipe, the coefficient of which for old incrusted pipes, (see formula No. 5*b* on page 211) is,

$$f = 0{\cdot}01\left(1 + \frac{1}{40d}\right) = 0{\cdot}01\left(1 + \frac{1}{40 \times 0{\cdot}4}\right)$$
$$= 0{\cdot}01063$$

(2) head lost in four easy bends, and (3) head lost in entry. Therefore,

$$1{\cdot}39 = \frac{4flv^2}{2dg} + \frac{4 \times 0{\cdot}3\,v^2}{2g} + \frac{0{\cdot}5\,v^2}{2g}$$

$$= \frac{4 \times 0{\cdot}01063 \times 75 \times v^2}{2 \times 0{\cdot}4 \times 9{\cdot}81} + \frac{4 \times 0{\cdot}3\,v^2}{2 \times 9{\cdot}81} + \frac{0{\cdot}5\,v^2}{2 \times 9{\cdot}81}$$

$$= \frac{7{\cdot}973\,v^2}{2 \times 9{\cdot}81} + \frac{1{\cdot}2\,v^2}{2 \times 9{\cdot}81} + \frac{0{\cdot}5\,v^2}{2 \times 9{\cdot}81}$$

$$= \frac{9{\cdot}673\,v^2}{19{\cdot}62}$$

$$\frac{1{\cdot}39}{4 \times 32{\cdot}2} = v^2 \left\{ \frac{0{\cdot}01066 \times 250}{2{\cdot}5} + \frac{0{\cdot}425}{2} \right\}$$

$$v^2 = 2{\cdot}819$$

$$\therefore v = \sqrt{2{\cdot}819} = 1{\cdot}679 \text{ m./sec.}$$

This is a very good velocity.

$Q = 0{\cdot}1257 \times 1{\cdot}679 = 0{\cdot}211$ cu.m./sec.

$= 211$ lit./sec. against 170 lit. we want.

The proportion of the minimum discharge to that when the pipe is running full is $40 \div 211 = 0{\cdot}19$. From the graph for circular pipes in Fig. 188 page 209, the proportional velocity, will be nearly 0·60 of the full i. e. $0{\cdot}6 \times 1{\cdot}679 = 1$ m./sec. which in itself is self-cleansing and at the times of peak daily flow, which will be double the minimum, the velocity will be full 1·5 m./sec. Hence a **400 mm.** sewer for the siphon is the correct size.

Example 15 :—A 600 mm. combined sewer has to cross a railway line, the total distance of which including the bends, etc. is 60 m. The invert of the inlet is at R. L. 35·14 m. and that of the outlet at 34·35 m. The minimum flow is 50 lit./sec. the daily peak flow is 150 lit./sec. and the maximum is 400 lit./sec. If the loss in head due to friction is 0·18 m. calculate the sizes of 3 separate pipes to be provided.

Solution :—The net available head is $35{\cdot}14 - 34{\cdot}35 - 0{\cdot}18 = 0{\cdot}61$ m. This gives a gradient of 1 in 100. For the first approximation a reference to Table No. 17, page 210 shows that for 1 m./sec. velocity, a 250 mm. pipe is required at a gradient of 1 in 150. Our gradient is 1 in 100. It seems therefore likely that if we adopt a 250 mm. pipe it will give a velocity much higher than 1 m./sec. at the grade of 1 in 100. Its cross sectional area is 0·05 sq. m. By Kutter's formula (Table No. 14, page 207).

$$V = C\sqrt{RS} = 45{\cdot}5\sqrt{0{\cdot}0625 \times \frac{1}{100}}$$

$$= 1{\cdot}138 \text{ m./sec.}$$

$$Q = 1{\cdot}138 \times 0{\cdot}05$$

$$= \mathbf{57} \text{ lit./sec. against 50 lit./sec. required.}$$

Hence a **250 mm.** pipe will be provided to take care of the minimum discharge. The peak daily flow is 150 lit./sec. out of which 57 will be handled by the above 250 mm. pipe. The balance is 93 lit. If a velocity of 1·5 m./sec. is assumed, the cross sectional area required is $\frac{0{\cdot}093}{1{\cdot}5} = 0{\cdot}062$ approx. A 300 mm. pipe gives an area of 0·071 sq. m. From Kutter's Table No. 14,

$$V = C\sqrt{RS} = \frac{47{\cdot}76 \times 0{\cdot}274}{10}$$

$$= 1{\cdot}309 \text{ m./sec. which is good.}$$

$$Q = 0{\cdot}071 \times 1{\cdot}309 = 0{\cdot}093 = \mathbf{93} \text{ lit./sec.}$$

This shows that a **300 mm.** pipe is the correct size. The combined discharge of these two pipes is 57 + 93 = 150 lit. We have to provide a third pipe to handle 400 − 150 = 250 lit. A 450 mm. pipe giving a sectional area of 0·159 sq. m. will give, by Table No. 14.

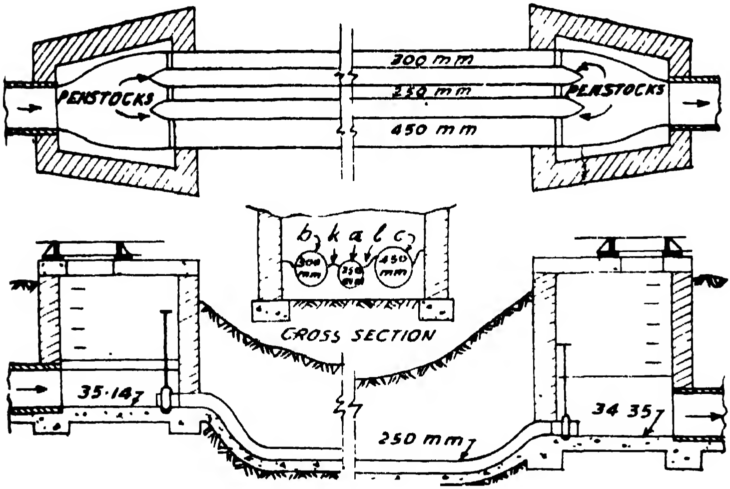
$$V \quad C\sqrt{RS} = 52{\cdot}84\sqrt{0{\cdot}1125 \times \frac{1}{100}}$$

$$= 1{\cdot}772 \text{ m./sec. which is very good.}$$

$$Q = 1{\cdot}772 \times 0{\cdot}159 = 0{\cdot}282 \text{ cu. m./sec.}$$

$$= \mathbf{282} \text{ lit./sec. against 250 lit./sec.}$$

Both the velocity and the discharge are satisfactory. Thus three pipes viz. 250, 300 and 450 mm. will be provided at the same invert level viz. R. L. 35·14 m. at the bottom of the manhole on the upstream side, but the channels leading to them will have ridges between them of different heights as shown on C. S. across the inlet M. H. in Fig. 228 so that when the volume is minimum, it will run into the smallest pipe *a*, in the centre, (see cross section Fig. 228) and as soon as its depth will rise, it will overflow the ridge, *k*, on the left hand side and the excess volume will run in the channel leading to the pipe *b*, i. e. 300 mm. siphon. The ridge *l*, between the channels leading to pipes *a* and *c*, is so high that normally the pipe *c* will run empty and will discharge only when the capacities of pipes *a* and *b* are satisfied and the excess volume will overflow the ridge *l*, between *a* and *c*. A plan, cross



Figs. 226, 227, 228 – Plan, C. section and L. S. of the siphon designed in Example 15.

section and longitudinal section are shown in Figs. 226, 227 and 228 respectively.

Questions

(1) What is the function of an inverted siphon ?

(2) The length of a siphon as measured along the centre line including slopes is 45 m. (140 ft.). The invert levels at the inlet and outlet ends are R. L. 40·24 and R. L. 39·82 respectively. If the minimum, average, and maximum discharges to be carried are 70, 180, 500 lit./sec. respectively, what should be the sizes if three pipes are to be provided in the manner shown in Figs. 226-228?

Ans. : 300 mm., 400 mm., 550 mm.

(3) What should be the minimum velocity inside a siphon and why? What other provisions are commonly made in order to prevent and remedy the blockage of a siphon ?

CHAPTER XII

PUMPING SEWAGE

THE necessity for lifting sewage either by pumps or ejectors arises under the following circumstances:

(1) When a portion of a town is so low-lying that it cannot be drained by gravity to discharge into a sub-main or main unless the entire sewerage system in the other parts is installed at a correspondingly lower level. In such a case it is more economical to pump the sewage from the low-lying portion into the upper branch or main.

(2) When the land is flat and adequate gradients to ensure self-cleansing velocities are not possible. In this case sewage is lifted and is allowed to flow by gravity with self-cleansing gradients.

(3) When the outfall is at a lower level than the body of water into which it is to be discharged.

(4) When a ridge intervenes the town dividing it into two parts. The possible alternatives are: (*a*) To provide two separate mains with separate outfalls, one for each, on two sides of the ridge, with two separate treatment works if the sewage is to be treated. (*b*) To carry the sewage by gravity across the ridge either through a cutting or a tunnel, or (*c*) To pump the sewage over the ridge. In most cases the last method is found to be more economical.

(5) When the sewage is to be treated, and the head available between the level of the outfall and the H. F. L. of the stream is too inadequate for passing the flow by gravity through treatment works.

Site for Pumping Station:—If a very large quantity of sewage is to be pumped, the site should be near a stream, or, a *nalla*, or, a storm water drain, into which the sewage could be discharged during emergencies, such as a breakdown of the pumping plant, failure of power, etc. If this precaution is not taken, the station may be flooded with possible damage to machinery, especially to the electric equipment.

As the pumps are installed usually in a pit underground, it is essential to investigate if the area is likely to be flooded either directly by river water, or seepage from the bottom and sides, in times of heavy storms.

The next thing is to provide a grit chamber for excluding sand, gravel, stones, etc., as much as possible, as they are likely to cause wear of pumping machinery and delivery pipe. The coarse floating matter which is likely to get entangled in the blades of centrifugal pumps, must also be removed by means of screens.

In the event of break-down of the pumping machinery or stoppage of power supply, of which there is every possibility, some arrangement must be made to bye-pass the incoming sewage and allow it to overflow into the nearest *nalla* for fear of flooding the station. A non-return or reflux valve at the beginning of the rising main and one or two more, at intermediate places, if the pipe is long, is also a necessity. There should be valves provided in the rising main to empty the latter into the nearest manhole, or *nalla*, so as to facilitate isolation of the main for inspection of pumps when necessary.

Power for Lifting Sewage:—This may consist of either: (1) Steam for driving pumps, or impulse or reaction turbines, (2) Internal combustion engines working on either gas, light oils like petrol or kerosene, or heavy oils, or Diesel engines, or (3) Electric motors.

(1) **Steam engines** are not much in favour at present for pumping sewage for the reasons viz. (*a*) They are not economical unless on a large scale, or the place is near a coal mine or a forest area. (*b*) There are innumerable moving parts, which are liable to wear out and have to be replaced at great recurring expense. (*c*) Two separate establishments, one for generating steam, and the other for running the engines,

are required to be maintained for twentyfour hours in three shifts, and (*d*) the initial cost of land, buildings, and plant is high.

(2) **Internal Combustion Engines** are more economical and have less parts, but they too require constant attendance of a skilled mechanic for all twenty-four hours.

(3) **Electric Motors**, unless electricity is generated solely for the pumping station, are very convenient, and free from most of the above objections. They are moreover, compact, silent in working, free from the nuisance of smoke, automatic in action and occupy less building space. No constant attention also on the part of a highly skilled mechanic is required.

Types of Pumps:—Those in common use are: (1) Centrifugal, (2) Reciprocating, either of plunger or diaphragm type, (3) Axial flow, and (4) (a) Ejectors, (b) Air lifts.

(1) **Centrifugal Pumps**:—The volute type of centrifugal pumps have a special chamber which receives the liquid from the impeller and delivers it to the discharge main. Impellers are either open or closed. The open type from which solids and rags and other fibrous matter, which is always found in sewage, can be more easily disentangled are more suited to handling sewage than the closed types. One type of this pump has fixed cutting blades which come in contact with a rotating conical impeller with sharp-edged grooves on its surface. When the cone is fast rotating, the solids in the sewage are caught between the edges of grooves and the fixed blades and are shredded to pieces and then pumped along with sewage.

Recently a single suction volute pump with impeller having only two vanes is specially developed for pumping sewage. As there are only two vanes it provides large waterways, and allows whole solids up to 3 or 4 in. diam. to pass freely into the discharge pipe. There is a clean-out provided on the suction side, which can be easily opened, if required, to remove obstruction, if any, which may have choked the impeller.

(2) **Reciprocating Pumps**:—These are not suitable for pumping sewage as they are liable to be clogged by solids or fibrous material, even though the sewage may have been passed through coarse screens. Again, their initial cost is higher and efficiency lower than those of a centrifugal pump.

(3) **Axial Flow Pump**:—This is sometimes called a propeller pump as its impeller resembles the propeller of a ship. It consists of a number of blades fixed like screw threads on a shaft, and there are vanes both on the inlet and outlet sides. When the propeller rotates, these vanes guide the flow axially along the shaft. This pump is very suitable for pumping large volumes of sewage against low head.

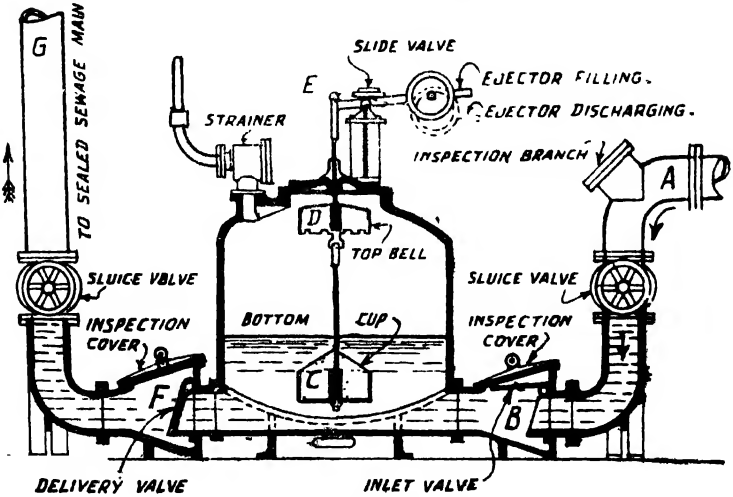


Fig 229—A section of Shone's pneumatic ejector.

(4) **Automatic Pneumatic Ejectors**:—These work on compressed air, which can be supplied from a central station. Their efficiency is low, but they are very convenient when small quantities are to be lifted to a high level, for which a separate pumping station is not justified. They have the advantage that there are no parts likely to be clogged, they are silent in action and that they do not require any attention. There are several types, but all of them work on the same

principles. Shone's patent ejector illustrated in Fig. 229 is typical of this class. It consists of a closed air-tight iron receiver with inlet pipe, *A*, controlled by a sluice valve. Sewage enters the receiver through the check valve, *B*, and as the level rises, it lifts the inverted top bell, *D*, by the floatation effect of the air entrapped in it. This closes the exhaust valve, and opens the compressed air valve by the movement of the levers. The compressed air, which then rushes into the receiver, closes the check valve, *B*, and forces the sewage through the other check valve, *F*, into the sealed rising main, *G*. This goes on until the level of the liquid falls to such a point that the weight of the bottom cup, *C*, with the liquid in it, causes it to drop. This reverses the action, i. e. closes the air valve and opens the check valve, *B*. The operation is then repeated. Fig. 229 shows the ejector being filled.

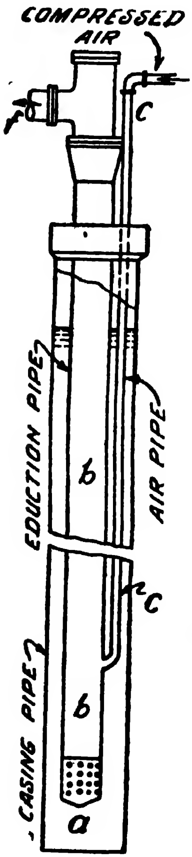


Fig. 230.

While the ejector is discharging, the incoming sewage is either retained in the inlet pipe, *A*, or, is automatically diverted to another similar unit, if installed. Usually ejectors are installed in a pair, so that while one is being filled the other is emptied, and thus a uniform rate of flow is maintained. This arrangement permits a smaller rising pipe being used.

(4*b*) **Air-lift Pumps**:–Just like ejectors these also work on compressed air, and have no moving parts. Consequently, they are admirably suited to pumping strongly acid or alkaline or gritty matter like sewage, which is otherwise likely to damage the moving parts of other types of pumps by corrosion or abrasion. The efficiency of air-lift pumps is low. The principle is explained in Fig. 230.

The pipe *a*, is the casing or lining pipe, say, of 15 cm. (6 in.) diam. inside which there is another pipe, *b*, called *eduction pipe*, say of 8 cm. (3 in) diam. with perforations at bottom and reaching almost the bottom of the pipe *a*. *c* is a small tube, say 2 cm. (1 in.) diam. carrying compressed air, connected to an air-compressor and joined to the eduction pipe, *a* near the bottom. In the beginning the water level in pipes *a* and *b* is the same, but when compressed air is introduced through the pipe *c*, it moves with the sewage in pipe *b*, and as the mixture of sewage with water is lighter, the pressure inside *b* is reduced and the level rises. Ultimately, when sufficient air enters it, water or sewage mixed with air is forced out through the outlet *f*.

Example 16:—Design the capacity, air-pipe diameter, and sealed main diameter of an ejector, to be installed for lifting the sewage of a district, having a population of 10,000, and the quota of water supply 160 lit. per day per capita. Assume a velocity of 7·5 m./sec. of the compressed air in pipe and 1 m./sec. that of sewage in the sealed main.

Solution :—The average flow of sewage per minute

$$= \frac{10{,}000 \times 160}{24 \times 3600} = 18{\cdot}52 \text{ lit./sec.}$$

Peak flow $= 2 \times 18{\cdot}52 = 37{\cdot}04$ say 40 lit./sec.
$= 0{\cdot}04$ cu. m./sec.

(*a*) **Design of Air-pipe** :—$Q = A \times V$; $V = 7{\cdot}5$ m./sec.

$$A = \frac{0{\cdot}04}{7{\cdot}5} = 0{\cdot}005332 \text{ sq. m.}$$

$$0{\cdot}005332 = 0{\cdot}7854 d^2$$

$$\text{Diameter of air pipe } d = \sqrt{\frac{0{\cdot}005332}{0{\cdot}7854}} = 0{\cdot}0824 \text{ m.}$$

$$= 82{\cdot}4 \text{ mm. say 100 mm.} \quad (a)$$

(*b*) **Design of the Sealed Main** :—

Peak discharge $= 40$ lit./sec. $= 0{\cdot}04$ cu. m./sec.
Velocity $= 1$ m./sec.

$$\text{Area} = \frac{0{\cdot}04}{1} = 0{\cdot}04 \text{ sq. m.}$$

$$0{\cdot}04 = 0{\cdot}7854\, d^2$$

$$d^2 = 0{\cdot}05093$$

$$d = 0{\cdot}224 \text{ m.} = 224 \text{ mm. say } 225 \text{ mm.} \quad (b)$$

(c) **Design of Capacity of Ejector**:— Assuming the ejector is filled and emptied every 5 minutes, it will work 12 times per hour.

$$\text{Capacity of ejector} = \frac{\text{daily quantity of sewage}}{12 \times 24 \text{ hours}}$$

$$= \frac{160 \times 10{,}000}{12 \times 24} = 5556 \text{ lit.}$$

$$= 5{\cdot}556 \text{ cu. m.} = 5{\cdot}6 \text{ cu. m. say}$$

At time of peak flow = 11·2 cu. m.

Assuming a height of 2·5 m.

$$\text{Area of barrel} = \frac{11{\cdot}2}{2{\cdot}5} = 4{\cdot}48 \text{ sq. m.}$$

$$\text{Diameter} = \sqrt{\frac{4{\cdot}48}{0{\cdot}7854}} = \sqrt{5{\cdot}704} = 2{\cdot}388 \text{ m.}$$

$$\text{say} = 2{\cdot}5 \text{ m.} \quad \ldots \quad (c)$$

Thus **diameter of ejector D = 2·5 m., diam. of air pipe = 100 mm, diam. of sealed main = 225 mm.**

Calling for Tenders for Pumps:—While inviting tenders for supply of pumps from manufacturing firms, full information with detailed description of works should be given. The important points in it are:

(1) As far as possible a minimum of three pumps should be ordered, any two of which should be capable of handling the maximum flow, and one should stand as a lay-by.

(2) The quantity of sewage to be pumped—the maximum, average, and minimum flow per hour, and the head to which it is to be lifted.

(3) The kind of power to be employed, whether electric supply, steam, or oil engine. If electricity, the voltage, and whether it is an A.C. or D.C. If A. C., the number of cycles and phases. If oil or steam engine, the H. P.

(4) The preliminary treatment, in addition to passing the sewage through detritus tanks, should be stated. If screening is to be done, the mesh of the screens. If no screening is to be done, it should be clearly stated to that effect.

(5) If electric power is to be used, the type of the motor, whether (*a*) *squirrel cage*, which is cheap, simple to operate and easy to control, but difficult to start; (*b*) *slip ring*, which is easy to start and control, but is costly and requires renewal of brushes from time to time; (*c*) *synchronous*, which is economic in operating costs, but difficult to start, and expensive initially, if automatic.

(6) The type of control—whether by float or hand.

(7) The type of switch-gear. There is a variety of them on the market, each having its special merits. It is advisable to consult an electrical engineer before selecting a type. In fact an electrical engineer would be very helpful in specifying all the electric equipment.

(8) A site plan showing the entire lay-out, with a plan and sections of the pump-house should be supplied.

(9) All the different pipes and valves used, or proposed to be used, should be described.

(10) Whether the erection of the pumps on site is to be entrusted to the firm, or to be done independently should also be clearly stated.

Questions.

(1) Describe the advantages of a centrifugal pump over other pumps for pumping sewage.

(2) Why is electrical power the most suitable?

(3) Describe the action of an automatic ejector with a neat sketch.

(4) An ejector has to lift 2250 lit. (500 gallons) per minute; if the velocity of air in the air-pipe is 6 m. (20 ft.) per sec. and that of sewage in the sealed main 0·75 (2·5 ft.) per sec. find the diams. of pipes and the capacity of the ejector, supposing it is filled and emptied 10 times an hour.

Ans.. Air main, 100 mm. (4-in.); sewage main, 300 mm. (10 in.); ejector, 13·5 cu. m. (450 c. ft.)

CHAPTER XIII

WRITING A REPORT

THE descriptive report accompanying the drawings and estimates should be brief, but at the same time, should embody all the salient features of the scheme, so that even a layman, upon its perusal, can have a fairly clear idea of the scheme, without going through the technical details of the drawings and the labyrinth of numerical figures in the statements.

The following is adopted, after a slight abridgement, from the actual report on Surat Drainage Scheme* submitted by the Public Health Engineer to the Government of Bombay, Public Works Department, and it is hoped that it would serve as a good example for the guidance of the student.

GENERAL REPORT (1947)

Situation and Importance of the Town :—The city of Surat is situated on the left bank of the Tapti river, and lies at East Longitude 72° 52' and North Latitude 22° 12'. It is 20 km. (12 miles) from the coastal health resort, Dumas, and 265 km. (165 miles) from Bombay on the broad gauge section of the Western Rly. As the first British Trade Settlement in India, it is of historical importance and is an industrial centre even today, owing to its local gold and silver lace industries and fine cloth mills.

Configuration :—The city is enclosed by a wall round it and a moat beyond, the latter serving as a storm water channel, which discharges its contents into the Kankra Creek branch of the river. The town lies on a flat area lying between contours R. L. 15 m. (49) and R. L. 3 m. (10) and is divided into flat valleys by several water courses, called "Khadis." The wall on the river side serves as a protection from floods.

The Present Condition of Drainage :—(a) The contents of the baskets in the latrines are deposited in trenches outside the city and the wash water from them is let into "cutcha" soak-away pits.

* By courtesy of the P. W. D., Government of Bombay, who have kindly given permission to print the report together with whatever drawings, statements and estimates required for this volume.

(*b*) *Sullage* : – The waste-water from houses is also admitted into the soak-away pits in all the seasons except the rainy season. Thus the sullage and ablution water and urine from latrines is expected to be absorbed by the soil and sub-soil, but, when the pits are full and overflowing, they are emptied and cleaned by the Municipality, at the owner's expense. In the rainy season both sullage and liquid contents of latrines are allowed to be discharged into street gutters, and these being not laid to proper grade, the sewage and sullage stagnate and putrefy in them leading to insanitary conditions dangerous to public health.

(*c*) *Storm Water* : – The city has been provided with a few storm water drains which discharge into the water courses, or "khadis," and from these into the moat. The flood is controlled by means of penstocks across the water courses underneath the wall on the river side. These penstocks are kept closed during high floods and are opened as the floods subside. As a result, the low-lying area of the city is flooded at times.

Water Supply .—The water supply is derived from infiltration through porous pipes buried in the sandy beds of the Tapti river about 5·25 km. (3¼ miles) away. It is collected there in jack wells, and is pumped from the latter to elevated reservoirs for distribution by gravity. The supply is found to be more than sufficient, even for the prospective population at the rate of 45 gallons per head per day.

Quantity of Sewage :—Though the rate of water supply is assumed to be 200 lit. (45 gallons) per capita per diem, about 75 to 80 per cent of this i. e. about 150 to 160 lit. (35 gallons) is expected to reach sewers.

Rainfall : – The average rainfall is 1150 mm. (45·52 inches). The maximum and minimum figures on record are 1650 and 740 mm. (65·21 and 29·10 inches) which occurred in 1937 and 1923 respectively.

Population :—The present population is 2,09,700 as per food ration cards. The rate of annual increase since 1921 has been steady and the same has been assumed during the design period of 30 years and calculations are made by arithmetical progression. The prospective population at the end of this period is taken at 3,00,000 souls.

Sewer Design :—The subsoil water level varies from R. L. 3 m. (10) to R. L. 4·5 m. (15), the average being R.L. 3·75 m. (13). As the sewers are proposed to be laid in almost all cases above this level, no allowance for ground water in sewer design is found necessary. The sewers are designed for a capacity of three times the dry weather flow, which includes some allowance for the surface water which may enter them during the rainy season.

The entire area of the city is divided into 20 drainage districts spread over three sections – two low-lying, and one high level. The sewage from districts 10 and 11, flows through a 24-in. main to the Low Level Pumping Station at Syedpura, and that from districts 12, 13 and 14 through a 600 mm. (24-in.)

sewer, to the Low Level Pumping Station at Salabatpura. From these stations the sewage is discharged into the main of district No. 9 which leads it to the Central Pumping Station at Sagrampura. From the latter place, the entire sewage is pumped and led it to the sewage disposal works through 1400-1150 mm. (54"-45") R. C. outfall sewer.

If a detention tank were provided at Sagrampura Central Pumping Station to serve as a balancing tank, the cost of pumping would have been reduced as it would have been possible to pump sewage at a uniform maximum rate. But, this would have caused septicity in the sewage; besides the cost of the balancing reservoir would have been prohibitive. Hence sufficient number of pumping sets have been provided which will come into operation automatically according to the quantity of incoming sewage.

Tractive Power :—Electric tractive power, which is most suitable for driving pumps automatically, has been proposed. For project purposes the present tariff for large consumers of the Surat Electric Co. Ltd. have been adopted. Later, it is proposed to generate electricity sufficient for running the disposal works, and a few installations of the Central Pumping Station, by means of sewage gas, which will be produced in sludge digestion tanks. Provision for a duplicate set of oil cum-gas engines has been made in the estimates, so that when sewage gas becomes available, the plant will be run on gas. However, provision has been made for some oil storage for use during emergencies.

The Main Features of the Scheme:

(1) Main sewers of the drainage districts.

(2) Branch and lateral sewers.

(3) Syedpura and Salabatpura Main collecting sewers.

(4) Low level pumping station at Syedpura.

(5) Low level pumping station at Salabatpura.

(6) Central pumping station at Sagrampura.

(7) 1400 mm. (54") and 1150 mm. (45") rising mains from central pumping station.

(8) Sewage disposal works consisting of (a) a stilling chamber, (b) a detritus tank, (c) two clari-flocculators, (d) sludge digestion tanks.

(9) Sewage farm for broad irrigation.

These are briefly described below :—

(1) **Main Sewers** :—The main collecting sewers for each of the 20 drainage districts vary from 150 mm. (6") to 1100 mm. (42") in diameter. Stoneware pipes are proposed up to 400 mm. (15 in.) diameter, and R. C. pipes for larger ones, the latter being cheaper. All the sewers are designed to carry three times the D. W. F. with a minimum self-cleansing velocity of 0·75 m. (2½ ft.) per sec. Overflows and flushing tanks have been provided wherever necessary.

Index Plan of Surat Drainage Scheme

Scale : 1 : 63360

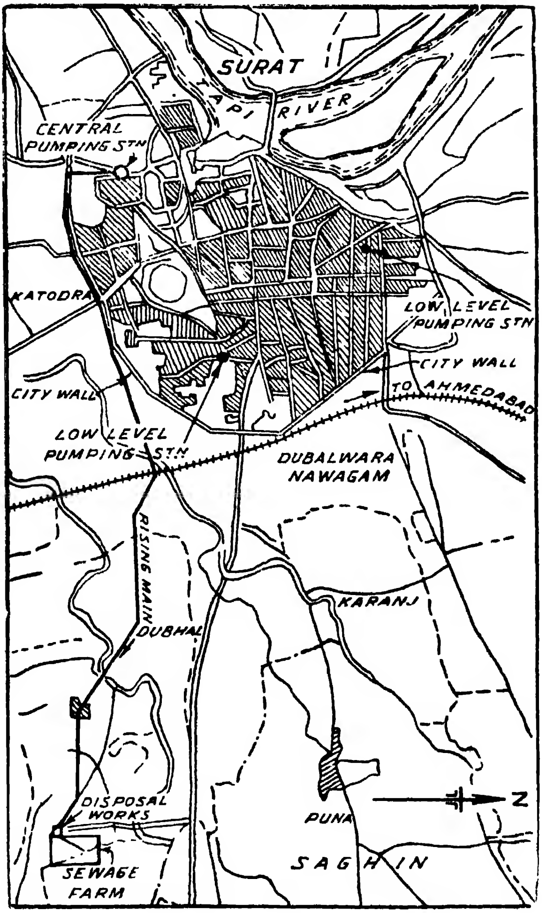


Fig. 231.

(2) **Branch Sewers and Laterals** :—These vary from 150 to 550 mm. (6″ to 21″) and are designed on the same principles as the main sewers. Ventilators and flushing tanks have been provided wherever necessary.

(3) **Main Collecting Sewers** :—The Sagramapura main collecting sewer is aligned from the central pumping station to the end of the

main sewer of district No. 9. It is 1450 to 1200 mm. (57 to 48 in.) in diameter and 1375 m. (4500 ft.) long. This sewer will carry the sewage from all the 20 districts to the disposal works.

(4) **Low Level Pumping Station at Syedpura** :—The quantity of sewage to be pumped at this station varies from 17730 (3.9) in fair weather to 26600 cu. m. (5·85 mill. gall.) per day in rainy season, against a head of 15 m. (51 ft.) The total power required is 65 B. H. P. (metric). The units of different capacities to provide this power are proposed as follows :

(i) 3 units of 32 B. H. P. (metric) each to pump 77 lit./sec. (1016 gallons) per minute.

(ii) 2 units of 16 B. H. P. (metric) each of 39 lit./sec. (508 g. p. m.) capacity.

The rising main is of 600 mm. (24″) dia., 775 m. (2530 ft.) long and discharges into the main sewer of district No. 9 at M. H. 65. The overflow takes place into a water course at a level sufficiently high above the H. F. L.

The outlet to the river will remain closed during floods. There is a storage space of sufficient capacity up to the top of banks until it is discharged into the river when the floods subside.

The capacity of the sump is equivalent to 20 minutes D. W. F. Elevators for removing grit from the sump have been provided.

(5) **Low Level Pumping Station at Salabatpura** :—At this the quantity of sewage to be pumped varies from 13375 to 20000 cu. m. (2·94 to 4·41 mill. galls.) per day. The lift is 9 m. (30 ft.) The power required is 38 B. H. P. (metric) for which the following units have been proposed :—

(i) 2 units to pump 102 lit./sec. (1355 g. p. m.) 25 B H. P. (metric) each.

(ii) 2 units to pump at the rate of 51 lit./sec. (678 g. p. m.) — 12·5 B. H. P. (metric) each.

The rising main is of 600 mm. (24 in.) diam. and 260 m. (850 ft.) long and discharges into the branch sewer of district No. 9 at M. H. 16—B. The overflow takes place high above the floods, for which sufficient storage capacity is available during floods.

(6) **Central Pumping Station at Sagrampura** :—The quantity to be pumped is about 95500 cu. m. (21 mill. gall.) per day against a head of 26·5 m. (87 ft.). The total B. H. P. required is 560, and is proposed to be supplied by the following units :—

(i) 4 units, each to pump at the rate of 320 lit./sec. (4240 g. p. m.) —227 B. H. P. (metric) each.

(ii) 2 units to pump at the rate 160 lit./sec. (2120 g. p. m.) — 114 B. H. P. (metric) each.

The sump is designed to hold 20 minutes D. W. F.

Residential and other accommodation provided is for one Electrical Superintendent, 3 oilmen, 4 sweepers, 2 cleaners, 1 office room and 1 store room.

This area will be wire-fenced, and facilities of water supply and drainage for the staff provided.

(7) **The Rising Main to Sewage Disposal Works**:—This is proposed to be an R. C. C. pipe 1400 mm. (54") diam. up to chainage 21600 and 1150 mm. (45") diam. up to 21060 ch. beyond. All the accessories such as air, sluice, scour valves, 'khadi' crossings, etc. have been provided.

(8) **Sewage Disposal Works**:—The sewage from the rising main will flow into stilling chambers 3 × 1·25 × 2·25 m. (10′ × 4′ × 7·5′) up to F. S. L., then through an influent channel 1·25 × 1·25 m (4′ × 4′) into a detritus tank 7·5 × 7·5 × 1·25 m. (25′ × 25′ × 3·75′) up to F. S. L. The latter is designed for one minute's detention period. The influent and effluent channels have been arranged at corners diagonally opposite to each other of the detritus tank to increase the travel of the sewage. The detritus tank has been provided with all the necessary mechanism for removing grit, and washing and raking the tank.

The clarifying tank is 30 m. (100 ft.) in diam. and 3·25 m. (10·5 ft.) deep at sides and 5·5 m. (18·5 ft.) at the centre. The feed enters centrally through a 750 mm. (30 in.) vertical pipe, round which there is a circular baffle 3 m. (9·5 ft.) deep. The flocculator mechanism is installed in the central compartment and the flocculated solids pass into the outer zone beyond the baffle wall peripherally over a continuous circular weir, and settle on the floor of the outer annular space.

There are two flocculating tanks provided, the combined capacity of which will be 1125 cu. m. (247,350 galls.) equivalent to 33 minutes detention period for the ultimate D. W. F. of 47750 cu. m. (10·5 mill. galls.) per day, and that of the two annular compartments will be 5375 cu. m. (11,82,500 galls.) equivalent to $2\frac{3}{4}$ hours detention period.

Sludge Pumps:— The sludge from clari flocculation tanks must be removed before it starts putrefaction. But, too quick removal also is not good, as it does not get sufficient time to become compact. Hence plunger pumps driven by a duplicate set of 355 B. H. P. (metric) oil-cum-gas engines with generating sets are proposed.

Sludge Digestion Tanks:—The sludge from flocculating tank will be pumped into sludge digestion tank 30 m. (100 ft.) diam. and 8·9 m. (29 ft.) deep. It consists of two circular tanks, a primary, and another secondary, connected by a central chamber containing a mechanism to agitate the sludge. There is a dome-shaped gas-holder on the top, the capacity of which will be 2200 cu. m. (77,500 c. ft.) and this gas will be used for running oil-cum-gas engines coupled directly to generators. The electricity generated will be used for running the equipment of the treatment works and the central pumping station.

Engine House :—An engine house 15 × 11 m. (50′ × 36′) is proposed for housing the above duplicate set of engines. A travelling crane mounted on a trolley to run on rails on top of side walls of the engine house, is provided for lifting heavy machinery during erection and repairs.

Effluent Main :—This is proposed to be a 1150 mm. (45″) R. C. C. pipe from the flocculation tank to the sewage farm.

(9) **Sewage Farm** : – 20 hectares (50 acres) of land is proposed to be acquired to demonstrate to local cultivators, the advantages of irrigation with effluent for increasing the out-turn of agricultural produce. There will be sufficient effluent to irrigate in 1960, 600 hectares (1500 acres).

The Cost of the Scheme : – The details are given below : –

			Rs.
(1)	Preliminary surveys	...	15,800
(2)	Providing Ruderpura and Sagrampura main collecting sewers	...	2,97,300
(3)	Main sewers of 20 drainage districts	..	9,62,300
(4)	Branch sewers and laterals	...	34,33,000
(5)	Low level pumping station at Syedpura	...	4,12,840
(6)	Low level pumping station at Salabatpura	...	2,72,960
(7)	Central pumping station at Sagrampura	...	6,23,670
(8)	54″ and 45″ rising main from central pumping station to disposal works	...	10,08,100
(9)	Sewage Disposal Works	...	16,73,700
(10)	Sewage Farm, channels, incinerators etc.	...	5,40,000
(11)	Land Compensation	...	7,30,400
		Total	99,70,070
		Say	99,70,000
	Add 28% establishment and tools and plant charges on 92,39,600 i. e. excluding land compensation	...	25,87,108
		Total	1,25,57,108
	Deduct rebate at 13% on 92,39,600	...	12,01,157
	Gross estimate with 15% establishment and tools and Plant charges	...	1,13,55,951
		Say	1,13,56,000

Annual Maintenance and Repairs Charges and Working Expenses: –

		Rs.
Maintenance and Repairs of collecting sewers in all the 20 districts	...	44,000

(2)	M. and R. and running expenses of the central Pumping Station ...	1,30,400
(3)	M. and R. Low level P. S. at Syedpura ...	27,500
(4)	,, Low level P. S. at Salabatpura ...	20,000
(5)	,, of rising main from Central P. Stn. to Disposal works ...	10,100
(6)	M. and running cost of disposal works ...	1,06,780
	Total	3,38,780
	Say	3,38,800

Annual Receipts from the Scheme :—

(1)	Value of 1,80,000 c. ft. of gas from the sludge digestion tank per annum ...	69,500
(2)	Revenue from effluent sold for irrigation of 1500 acres by 1960 at Rs. 60/- per acre ...	90,000
(3)	Saving out of the total present expenditure of Rs. 250,000 per annum on (a) sanitary up-keep, (b) basket system of latrines, (c) trenching night soil, and staff for emptying trenches for obtaining manure ...	1,50,000
	Total	3,09,500

Depreciation :—Annual depreciation of works as worked out in a separate statement* assuming life of works 36 years. ... 2,95,000

As this period is more than the loan period of 30 years, it is not necessary to instal depreciation fund. However, some items of the scheme have shorter life than the loan period, and for their replacement, a fund called "special repairs fund" will be installed. Its annual instalment is assumed to be Rs. 80,000.

Annual Burden on Local Body : – As the Local Body is entitled to get $33\frac{1}{3}\%$ by way of grant-in-aid from Government, the capital to be considered for purposes of annual burden by way of interest and repayment will be $\frac{2}{3}$ of 1,12,93,000 = 75,29,000.

Annual Burden on the Municipality : –

		Rs.
(1)	Interest at $3\frac{1}{2}\%$ on loan of 75,29,000 ..	2,63,515
(2)	Sinking fund at $2\frac{1}{4}\%$ compound interest on Rs. 75,29,000 after 30 years (factor = 0·0237) ...	1,78,437
(3)	Annual M. and R. charges and working expenses ...	3,37,000
(4)	Special repairs fund ...	80,000
	Total	8,58,952

* Not printed.

Deduct	(1)	Electric energy produced	...	69,000
	(2)	Revenue from sale of effluent	...	90,000
	(3)	Saving in existing expenditure	...	1,50,000
			Total	3,09,000
		Net annual burden on Municipality	...	5,49,952
			Say	5,50,000

Hence the Municipality will have to find out ways and means to meet this fresh annual burden due to sewerage scheme.

The increase in incidence of taxation of the prospective population of 2,50,000 in 1960, works out at Rs. 2·25 per annum per head only.

Questions

(1) State the main general features of the Surat Drainage Scheme.

(2) What is the capacity for which the sewers are designed ?

(3) How is the sewage proposed to be disposed ?

(4) What is the percentage charge assumed in the estimate for tools and plant and establishment ? Why is a rebate of 13% deducted ?

(5) What share of the cost do Government usually bear as in this case ?

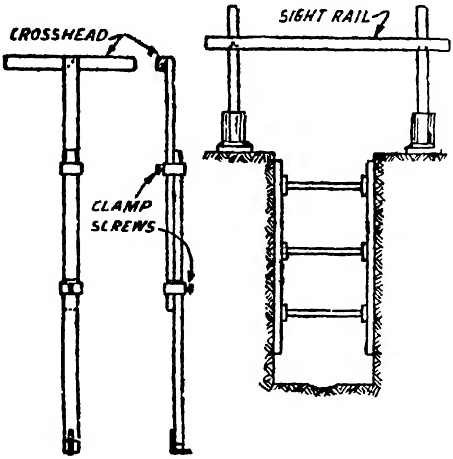
CHAPTER XIV

EXECUTION OF WORK

Setting-out Sewer Lines:—When the project is sanctioned for construction and funds are allotted, the first thing to be done is to mark the centre lines of sewers on the streets, starting from the lowest i. e. the outfall end of the main sewer, proceeding upwards. Next, branch lines should be set out from the points of their junctions with the main, working towards the head. This work is done best and very quickly by means of a transit instrument, but even a prismatic compass, if used very carefully gives sufficiently accurate work. The lines should be chained and the measurements should be recorded in a field book. Square-headed wooden pegs should be driven flush with the road surface at intervals of say, 25 ft. not along the centre line, but on one, parallel to it, called an offset line, at a distance of about 2 ft. greater than one-half the width of the proposed trench, on that side which is not likely to be disturbed, nor covered under excavated stuff. The centre line is to be avoided as it is within the portion to be excavated. If the road surface is hard, like that of asphalt, an iron spike should be used instead of a wooden peg. On concrete road surfaces a square mark should be made by means of a chisel, instead. All this is required for subsequent checking of the centre line after the trench is excavated. On both sides of the centre-line parallel lines should be marked by means of a chord dipped in lime in the usual way.

Levelling:—If considerable time has elapsed, say, more than a year since the first survey for preparing the project was done, most of the permanent bench marks previously located along the road sides, will have been disturbed by this time, and if any be still left, they cannot be taken as reliable. The next step would therefore be to run fly levels from the nearest G. T. S. bench mark, and establish bench marks on permanent objects such as plinths of *pucca* buildings along road-side, at intervals of about two furlongs after checking and rechecking their values. Then staff readings should be taken on the top of each peg driven on the offset line parallel to the centre line, and at all points where a change, either in direction such as on a bend, or a junction with a road, or a change in grade, occurs. At all the latter places there will be manholes.

Giving Line and Grade:—This means giving the alignment and the levels of invert of the sewers. This is usually done first at the ground surface and then they are later transferred to the bottom of the trench. There are several methods, but the one described below is found by experience to be the simplest. In this method sight rails are erected, first at the lowest end of the sewer, and then proceeding upwards, at all changes in direction and grade, and also at intermediate points, such as, manholes, if the straight sewer line is of considerable length, and finally at the head of the sewer line. A sight rail erected across an excavated trench is illustrated in Fig. 232. It consists of straight wooden poles planted vertically in say, 9 in. stoneware pipes, placed firmly on either side of a trench, on the ground, with their sockets at the bottom. The poles are firmly planted inside them, by packing sand or earth around. Cross pieces of wooden boards are nailed to them, on one face, as shown in the figure, so that the upper edges of the boards are perfectly horizontal, and their levels are so adjusted by a levelling instrument that



Figs. 233, 234. Fig. 232.

the imaginary line, set out in the air by the upper edges of any two adjacent sight rails, would be parallel to the designed invert level of the sewer between them as marked on the longitudinal section. A thin chord may be tied to the sight rails and stretched to represent the centre line of the proposed sewer line. The depth of excavation at any point in the trench can be determined by holding an adjustable boning rod, or *traveller*, shown in Figs. 233, 234, with its height from the bottom of the iron shoe to the top surface, made equal to the vertical distance between the line of sight rail and the invert line. If the top of the boning rod is above the line of sight rails, some excavation is needed at the bottom; on the other hand, if it is below the line, some filling by packing concrete or other hard material is necessary. The exact level of the invert is obtained when the projecting horizontal shoe at the bottom of the boning rod is resting on

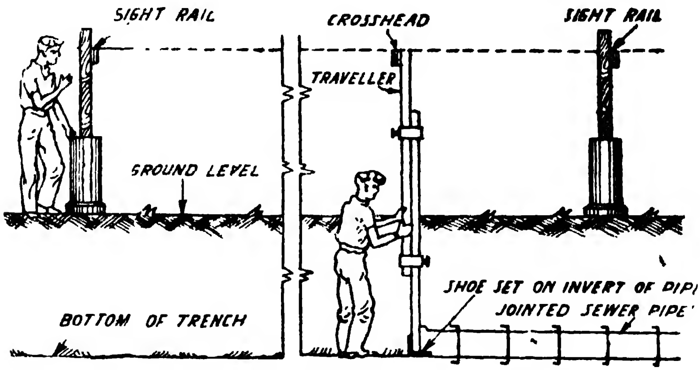
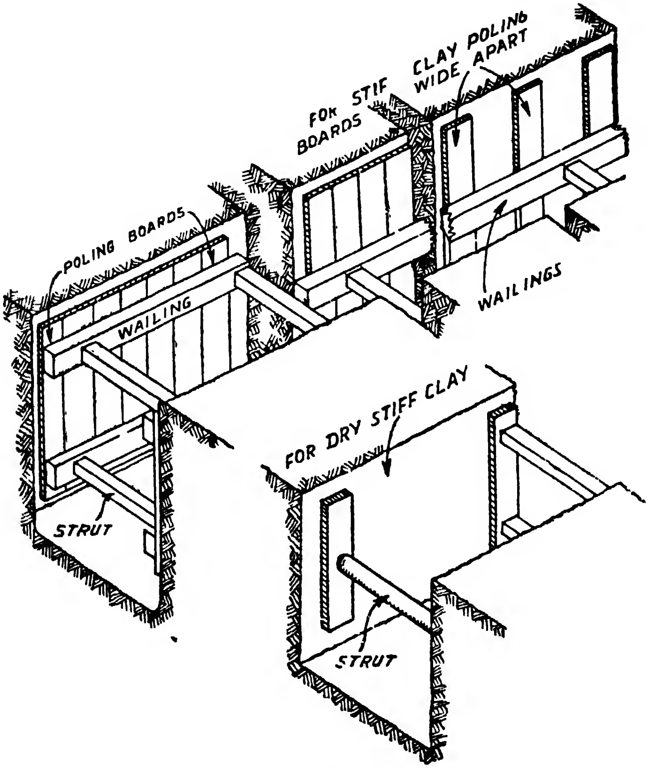


Fig. 235 —Showing how alignment and invert levels of sewers are given.

the invert of the pipe, and the top of the same is just touching the line of sight rail at the top. This is illustrated in Fig. 235.

Excavation of Trenches :—Both excavation and laying of pipes is started from the lower end of the sewer, proceeding upwards. The excavation is usually done in this country by manual labour with the help of picks and phaorahs. The excavated material should be stacked on one side of the trench, leaving at least one foot space between the edge of the trench and toe of the spoil bank. If the soil is firm, the sides may remain vertical, particularly if the depth is shallow. But, even when the trench is deep it is desirable to keep the sides vertical and protect them by means of shoring. For,



Figs. 236—239.

this is cheaper than filling and remaking the road surface on the wider gap. If it is running sand, marsh, or morass, shoring must necessarily be done from the ground surface. Shoring in different soils is shown in Figs. 236 to 239.

When the depth of a trench exceeds 2·5 m. (8 ft.) one or more platforms should be made by nailing boards on top of timbers for facility of lifting material and also of lowering pipes for being laid later.

Excavation in rock in the midst of occupied areas by means of blasting is dangerous and therefore, is mostly done by picks, crowbars and chisels. Harder rock may be excavated by drilling holes close together in rows and splitting it by driving plugs and feathers. At any rate, rock excavation increases the cost but it is unavoidable.

The width of a trench depends upon the diameter of the pipe, and also upon the depth of the excavation. Still, it should not be less than 55 cm. (21 in.) even for a shallow trench, as it is the minimum width required for a man to bend and excavate, and fill the stuff into a basket. As a general rule, for a pipe sewer a width not more than 15 cm. (6 in) greater than the diameter of the sewer, subject to the minimum of 55 cm.(21 in.) is required. If it is a brick or concrete sewer to be constructed *in situ*, no side space should be left, the excavation on the bottom and sides being made to conform to the exact shape and size of the sewer to be built.

Before allowing the contractor to lay pipes, the bottom of the trench must be dressed correct to the grade conforming to the size and shape of the sewer at least 7·5 m. (25 ft.) ahead of the pipe being laid. Sufficient earth should be removed from below the main body of the pipe so that the latter rests solidly in its length on the ground with its invert at the correct level. To accommodate the spigot end or the collar and make room for the facility of caulking at the bottom of the pipe with hands, a recess sufficient for the purpose should be excavated in the bottom below the socket ends.

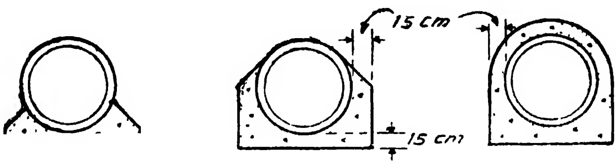
For small depths of trench, say, about 2·5 to 3 m. (8 to 10 ft.) if a stiff material, not likely to settle down, such as soft *murum*, or stiff, hard clay is met with, there is no need of putting concrete for bedding of pipes. But beyond that depth sewers require to be protected and made stable against both tilting and settling by providing a concrete cradle, with a broad base as shown in Fig. 240. The British Ministry of Health require the following :—

(1) In trenches with 4·25 m. (14 ft.) of cover, pipes to be bedded and haunched with at least 15 cm. (6 in.) of concrete.

(2) In trenches with 6 m. (20 ft.) or more cover, pipes to be surrounded by at least 15 cm. (6 in.) of concrete.

(3) All pipes with less than 1·25 m. (4 ft.) of cover under roads, and 1 m. (3 ft.) not under roads, to be surrounded by at least 15 cm. (6 in.) concrete.

The requirements mentioned in (1) and (2) above are shown in Figs. 241 and 242.



Figs. 240, 241, 242 : Showing concrete cradles and haunches to pipes.

If the bottom of a trench consists of hard *muram* or rock, it is necessary to spread a layer of concrete or fine sand just to make the bed even.

If water is encountered, it should be drained to a sump, from which it should be pumped to keep the trench dry during and till two hours after laying pipes. It may then be allowed to flow through the pipes very slowly. In such circumstances quick-setting cement should be profitably used for making the joints.

Laying Pipes :—The process of laying and jointing stoneware, concrete, and cast iron pipes has been described under Plumbing and Jointing. It is necessary that soon after a joint has been finished, the inside of the pipe should be cleaned of all cement or other jointing material that may have been forced into the pipe through the joint, by pulling through the pipe a rubber disc which fits it well or a bag stuffed with straw, or some such device.

If there is a break in the line, on account of the intervention of a manhole, etc., the last pipe before reaching the break, and the first after leaving it should be omitted, or left uncemented, so that the line already laid need not later be disturbed.

It is important to provide *Y* or *T* junction pieces for house connections at their proper places, in time, while the pipe line is being laid. A neat sketch should be recorded in the field book of all such provisions by taking three offset measurements from the nearest permanent objects so as to locate them easily later at any time. Those which are not to be connected to houses immediately should be plugged with stoppers in clay.

Very often it is not possible to know the exact positions of future house connections. In that case it is not difficult to cut a hole on the top of the sewer, and fix a saddle piece for making a new connection.

Testing of Sewers :— After allowing a week's period for the cement in joints to set, sewers should be tested before the trenches are filled. The hydraulic test is usually applied as it is very simple.

To apply this test, the lower end of the sewer, in the length to be tested, is first plugged. The test is started from the head of the sewer proceeding downwards, and usually the length between two manholes is tested, so that after

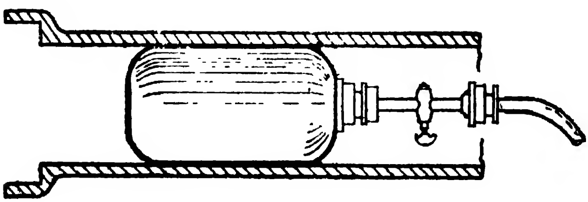


Fig. 243 — A rubber bag with a cover of canvas, to serve as a plug.

a length is tested, the water filled in it can be run to fill the next length to be tested.

There are two types of plugs. Both these are shown in Figs. 243 and 244. The one in Fig. 243 consists of a cylindrical rubber bag covered with canvas. It is placed inside a sewer at the lower end of its length, and is inflated by pumping air into it through a rubber tube with a tap attached to it, so that, it exerts pressure against the inner surface of the sewer all round and prevents leakage of water from it. If there are any branch connections, they must also be all securely plugged by means of gunny cloth and hard wet clay. Another plug of the type shown in Fig. 244 is similarly fixed at the upper end. It has two metal discs D D, which hold a rubber ring R, between them at the circumference. A wing nut, N, mounted on the tubular axle, when screwed in, presses the discs, causing the ring to expand and making the plug fit tightly. To the tubular axle is attached a rubber tube, with a 15 cm. (6 in.) funnel at its other end.

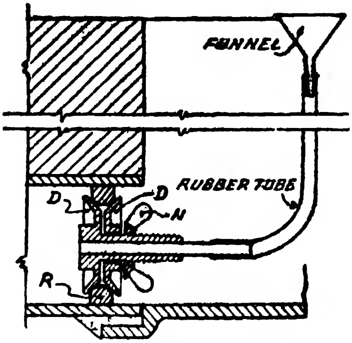


Fig. 244.

The funnel is raised to the required height and water is poured into it up to the top slowly, taking care to drive out all the air bubbles. Then the level of water in the funnel is watched for an hour. If at the end of the period the level does not fall below the permissible limits, the work may be regarded as satisfactory. These limits vary from 1 cm. (½ in.) for a 150 mm. (6 in.) pipe to 20 cm. (8 in.) for a 750 mm. (30 in.) sewer. If the fall is excessive, it indicates a leak, for which each joint should be examined from the exterior and the underside felt with hands for traces of moisture. Any defective joints should be marked with chalk, opened by means of a chisel and rectified.

The test is rather very rigid. Practical experience shows that not only the cement joint, but the pipes themselves, whether of stoneware or cast iron, are bound to be slightly porous, and to absorb moisture to a small extent. Further, much will depend upon the season and the time of the day when the test is made. The high temperature, at noon time in summer, is bound to cause loss of water by absorption and evaporation to a considerable extent.

Instead of watching the fall in the level of water, each joint should be examined. A slight seepage, or a little 'weeping' at the joint should be allowed. There should not be any spray or visible drops of water coming out.

Filling Trenches·—When the tests are made and all defects have been remedied, the trenches may be allowed to be filled. In the first 2 ft. depth only fine clay, from which stones and lumps of greater than 2·5 cm. (1 in.) size are excluded, should be carefully packed round the sewers, in layers not exceeding 23 cm (9 in.). The upper portion may be filled with stones, or any other material in 30 cm. (1 ft.) layers, and consolidated, making due allowance for the shrinkage. The permanent surfacing of the road, such as with asphalt, or concrete, should be delayed till the material has well settled down.

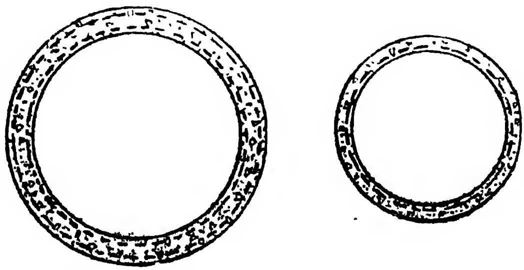
Built-up Sewers :—These may be classified according to (1) the shape, such as circular, horse-shoe, semi-elliptical, or egg-shaped, etc. (2) the material used such as brick or concrete; the concrete may be, further, either plain or reinforced; (3) the situation whether in open trench or tunnel. When the depth of a sewer below ground surface is considerable, say, more than 10 m. (30 ft.) a tunnel is more economical.

As a general rule, the excavation for built-up sewers of any shape should be just wide enough to suit the outside dimensions of the sewers with the necessary thickness of walls and as far as possible it should conform to the shape of the sewer to be built, so that no material is wasted and thus economy is effected.

In respect of the shape, circular sewers are by far very common for the reasons already stated on page 214. Pre-cast concrete pipes are manufactured at present in this country up to 1750 mm. (6 ft.) diam. by spinning moulds and compacting concrete by centrifugal force and these are much cheaper than any built-up sewer. For this reason circular sewers only of diameter above 6 ft. are required to be built up.

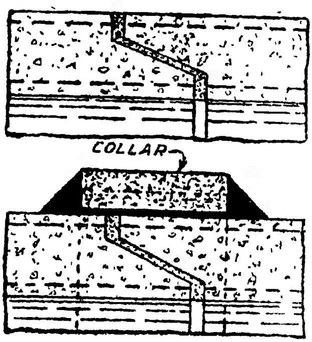
For building a circular sewer a rectangular base covering the entire width of the trench is first made of concrete, on top of which a curved surface is made and on this is placed either an all iron collapsible centering or a wooden centering consisting of ribs, and tongued and grooved, close lagging on their top. If the trench at bottom is not much wider, than the outside diameter of the sewer, there is no necessity of outer form. A round shape is given on the top by trowelling.

Sewers of Concrete:—These may be of concrete, either plain or reinforced with steel. Sewers of small diameter, say, up to about 2 ft. are made of plain concrete. Sewers seldom run full, and therefore, the internal pressure may be nil or negligible, but they are heavy and likely to break while being handled. Besides they have to bear the superincumbent load of material and traffic on their top and are often subject to bending moment. That is why they need to be reinforced except those of small diameter. The main reinforcement consists of circumferential rings of either high tension steel, or m. s. rounds, kept at particular distance apart by longitudinal binders of ¼ in. bars tied by pieces of wires. The rings are placed in moulds at 1 to 2 cm. (½ to ¾ in.) from the inner surface, while being cast. Pipes of larger diameter, especially those laid at the bottom of deep trenches have two sets of rings, each located about 1 to 2 cm. (½ to ¾ in.) from both the surfaces. Both these are shown in Figs.



Figs. 245, 246: Singly reinforced and doubly reinforced pipes.

245, 246. Sewers of plain concrete and sometimes small reinforced concrete pipes also, are provided with a socket at one end and a corresponding spigot at the other. These are jointed in the usual way like stoneware pipes with a gasket and paste of neat cement. Large size R. C. C. sewers have a mortise at one and a tenon to suit at the other, and are jointed with cement or asphalt to form what is known as the OG (ogee) joint. This is, however, not satisfactory. It is therefore sometimes further strengthened by means of a concrete collar sufficiently wide to cover the overlap of the joint. Both these joints are shown in Figs 247, 248



Figs. 247, 248.

Sometimes wage-shaped blocks of concrete like voussoirs of an arch, with joggles cast on one side to interlock with each other, are moulded. Both the top and bottom surfaces being segments of circles, the joints are thin, and radiate towards the centre. Such sewers can withstand the stresses they are ordinarily subject to even without enforcement The construction also is easy.

Brick Sewers.–The construction of brick sewers is not now much favoured on account of the high cost and difficulty of construction especially in non-circular shapes. In older practice, a specially moulded and baked stoneware block subtending an angle of 120° at the centre was used to form the invert of an egg-shaped section as shown in Fig. 249 as that part is subject to the scouring action of sand and gravel rolling with sewage flow at the bottom. But it was found to be very costly.

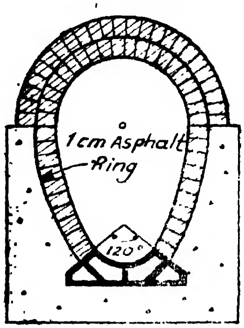


Fig. 249:

A brick sewer with terra cotta invert block.

of urea, proteins (both animal and vegetable) and hydrocarbons. It undergoes decomposition by the action of the anærobic bacteria which is the first stage towards purification. This process of putrefaction goes on up to B giving off on the way, ammonia (NH_3), CO_2, and the foul-smelling hydrogen sulphide, (H_2S). At B the second stage in purification, viz. that of oxidation begins by the action of the ærobic bacteria and continues till C is reached, forming nitrites on the way at *b* as a result of partial oxidation. At C complete oxidation takes place and the stable compounds of nitrates and sulphates are produced. By absorbing these as food, the vegetable life grows from C onwards up to D. During this period plant tissues, plant proteins (seeds), and free oxygen are produced by the vegetable life. The latter is produced by absorbing CO_2 from the air with the aid of chlorophyll of plants, and giving out oxygen in the presence of sunlight. This process of growth of plant life is completed at D from where the animal life grows, consuming the products produced by the plants and producing animal proteins (meat, milk, etc.) up to E. From E to A there is animal waste in the form of urine and other excretions, dead bodies, etc. From A onwards the cycle is repeated.

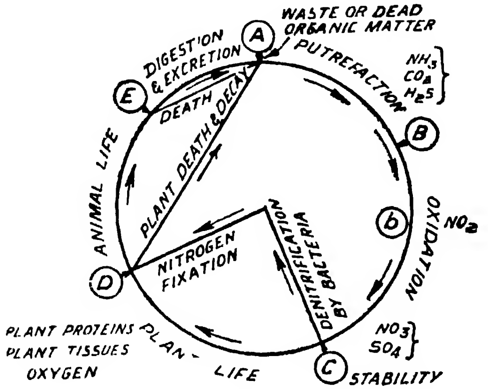


Fig. 257 : Nitrogen cycle connecting life and decay of animals and plants.

We have assumed above that all the products of plant life are eaten by animals and that through the channel of animal life they reach A as wastes. But this is not strictly correct.

Often there may be a short circuit from C somewhere between C and D, to A as shown by a straight line DA, indicating that plants may go to waste directly as happens e. g. in forests, where leaves, flowers, etc. of vegetable life lie in layers on ground surface to decay.

Similarly, out of the nitrates formed as a result of oxidation at C, some are denitrified i. e. reduced to nitrogen by anærobic bacteria. But it is not lost to plants, as another species of bacteria convert this nitrogen into nitrates (Nitrogen fixation), and then it is again made available to plants. This is shown by the lines CF and FD (F at centre of circle).

Analysis and Tests of Sewage:—An engineer is not expected to do the analysis or the various tests of sewage, but he must be in a position to interprete the results. While in charge of disposal works he has to constantly watch to what extent the sewage has been purified, and whether the prescribed standard has been attained. If not, he must immediately take steps to exercise the necessary control to improve matters. The following table gives typical analysis of average sewage at Purification Works at Dadar, Bombay.

TABLE NO. 20

Typical Analysis of Sewage at Purification Works, Dadar, Bombay.

Constituents	Parts per 100,000	Constituents	Parts per 100,000
Solids dissolved :		Oxygen consumed in 4 hrs. (Permanganate test)	9·5
Volatile	23·4		
Fixed	69·0	Oxygen dissolved	...
Total	92·4		
		Nitrogen organic	
Solids suspended :		,, Free ammonia	1·68
Volatile	35·6	,, Albuminoid Amm.	0·33
Fixed	13·0	,, Nitrites	nil
Total	48·6	,, Nitrates	nil
Solids settleable	43·6		
B. O. D. 5-day at 37° C.	31·0	Chlorides	18·0
		Alkalinity	28·0
Relative stability	Not determined	pH	6·90
		Fats	...

Sampling of Average Sewage :–The strength and character of sewage depends upon several factors, dilution being an important one amongst them. It varies not only with different parts of the same town, but also with different hours in the same part. Hence, tests are made on "average" sewage, which must be a truly representative sample. It is made up of the mixtures of different samples collected at 30 minutes, intervals over 24 hours period, proportioned in volume to the rate of the flow at the time of the collection. During this period it should be kept at a low temperature. The sample should be not less than 250 c. c , preferably one litre, and collected from the mid-depth of the sewer or channel It should be well mixed and should be analysed within 2 or 3 hours; and if this is not possible, it should be either kept at a temperature between 5° to 10° C (40° to 50° F.) to inhibit bacterial action, or treated with a preservative. It must be stored in a wide-mouthed bottle provided with a glass stopper. The date and hour of collection with the name of the preservative, if any used, should be noted on the lable pasted on the bottle.

The preservatives commonly used are chloroform, formalin, and sulphuric acid. The test for dissolved oxygen, if necessary, should be done immediately after the sample is collected, and that for bacteriological analysis, as soon after that as possible.

Sulphuric acid should not be used as a preservative in the sample intended for determining the organic solids, and the acidity or alkalinity. Similarly chloroform should not be used in the sample to be used for determining the organic matter and grease. In the same manner, the sample for making the B. O. D. test should be without any preservative.

TESTS

(1) **Tests for Solids**:—A rough test for *settleable* solids is made by pouring the sample in an Imhoff cone illustrated in Fig 258 up to the litre mark, and allowing it to rest for two hours. The amount of the sediment collected at the bottom is read on the scale at the bottom of the cone.

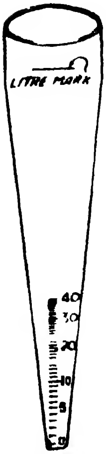


Fig. 258 : Imhoff cone.

Total Solids :—An accurate test for these is made by taking a measured volume of sewage from the average sample, and heating it slowly until all the water is evaporated, leaving a residue, the weight of which is that of the *total solids*. This residue is then heated sufficiently to burn off all the volatile matter, cooled and weighed again. The loss in weight is due to the *volatile* or *organic* solids, and the residue left after ignition is recorded under the *fixed* or *mineral* solids. The volatile solids are classed as organic matter.

Example No. 17 :—A sample of 100 grams of sewage of a certain town was tested. The solids left upon evaporation weighed 0·0725 gm. The residue left after they were ignited weighed 0·0340 gm. Find (1) the total solids p. p. m. (parts per mill.) (2) the fixed or inorganic solids p. p. m. and (3) the volatile solids p. p. m.

Solution :—

$$\text{Dry solids} = \frac{0{\cdot}0725 \times 1{,}000{,}000}{100} = \mathbf{725}\ \text{p. p. m.} \quad \ldots \quad (1)$$

$$\text{Fixed solids} = \frac{0{\cdot}0340 \times 1{,}000{,}000}{100} = \mathbf{340}\ \text{p. p. m.} \quad \ldots \quad (2)$$

$$\text{Volatile solids} = \text{loss on ignition}$$

$$= \frac{(0{\cdot}0725 - 0{\cdot}0340) \times 1{,}000{,}000}{100}$$

$$\text{or } 725 - 340 = \mathbf{3{\cdot}85}\ \text{p. p. m.} \quad \ldots \quad \ldots \quad (3)$$

Example No. 18 :—If the sample in the above example is from a town having a population of 40,000, and the quota of water supply allowed per capita per day is 350 lit. what will be the weight of the total solids contained in the daily flow of sewage if there is no industrial waste water admitted into sewers.

Solution :—Daily flow $= 40{,}000 \times 300 = 12 \times 10^6$ lit.

$= 12 \times 10^6$ kg.

Solid contents $= 12 \times 725 = 8700$ kg. $= 8{\cdot}7$ tonnes, *Suspended Solids* :—For finding out the quantity of suspended solids, two equal samples of sewage are taken. From one of them the quantity of total solids is determined and the other is passed through an asbestos filter, and the total solids of the effluent of the latter are determined. The difference between the two amounts is taken as the *suspended solids*.

The solids obtained from the effluent of the above are the *dissolved solids*. From these, again, volatile and fixed dissolved solids are found out just as those from the total solids, as shown above.

(2) **B. O. D. (Biological Oxygen Demand) Test**.—This is a very important test for determining the strength of sewage, and is done as a standard test in America. In Britain and also in this country a test for noting oxygen absorbed from potassium permanganate in either four hours or 30 minutes is made instead. Though the latter is very convenient and can be quickly made, the result obtained is not so positive and valuable as in the B. O. D. test. It is described later.

We have already seen that the small amount of dissolved oxygen which may be present in a fresh sewage is readily consumed by the bacterial action of decomposition of the most easily decomposable organic matter in the sewage, and that as soon as all the oxygen is depleted, septic or anærobic action starts. This shows that if oxygen is supplied in the beginning to the sewage containing bacteria, ærobic condition will prevail until the biochemical oxygen demand is satisfied. This affinity of sewage for oxygen is therefore, a measure of the amount of organic matter present in the sample. Thus the B. O. D. of a sewage, or as a matter of fact of any putrefying liquid, is the quantity of oxygen required for the biochemical oxidation of the decomposable matter present in it at a given temperature and within a given time. For obtaining complete oxidation of all the organic matter, the test will have to be continued for 2 or 3 months as the rate of depletion of oxygen is very slow after the first 8 or 10 days, during which period, most of the oxygen demand is satisfied. Such refinement is not required in practice. Hence it has been the standard practice to make the test for 5 days only at 20°C. in America.* This is equivalent to about 68 per cent of the total demend; a 10-day B. O. D. is about 90 per cent of the total.

For conducting this test the sample of the sewage which is free from any preservative is diluted with clean, slightly alkaline water (pH value about 7·4), the dissolved oxygen contents of which, are predetermined. It is then kept in a glass-stoppered bottle at the average room temperature for incubation for five days. The dissolved oxygen still remaining in the sample at the end of this period is measured, and is subtracted from that at the beginning. The difference gives the amount of oxygen utilised by the sewage.

It is assumed in this test that the rate of depletion of oxygen is directly proportional to the amount of organic matter present.

The test requires very careful manipulation on the part of the chemist.

The B. O. D. of normal sewage is about 300 to 400 parts per million.

(3) **Relative Stability**:—This is another test on the same lines as above, based on the further assumption that the time required for satisfying the biological oxygen demand varies as the amount of organic matter present in the sewage. In this test a small quantity of methylene blue is added to the sample, which is kept at room temperature. As soon as the dissolved oxygen is consumed, anærobic or septic condition is set up, giving rise to the formation of hydrogen sulphide, the sulphur in which, bleaches the blue colour. The time in days for the disappearance of the blue colour is noted and the relative stability is calculated by the following equation:

$$S = 100\,(1 - 0{\cdot}794t)$$

where S = per cent relative stability; and t = time in days.

*If this test is conducted in this country, it is done at 37°C. (98·6°F.)

The following table gives the relative stability in percentage of the demand satisfied.

TABLE NO. 21

Days required for decolourising at 20°C	Per cent Rel. stability	Days required for decolourising at 20°C.	Per cent Rel. stability
0 5	11	4·0	60
1·0	21	5·0	68
1·5	30	6·0	75
2·0	37	7·0	80
2·5	44	8·0	84
3·0	50	9·0	87
3·5	55	10·0	90

Relative stability above 60 per cent, which is reached in 4 to 5 days is deemed sufficient for discharging the effluent safely into a stream. This test is not done in this country.

(4) **Oxygen Consumed**:–This test is made in this country and in Britain for determining the relative strength of sewage, whether strong, medium or weak, instead of the B O.D. test. In this test a known quantity of 10 per cent of acid solution of potassium permaganate is added to the sample of sewage, which is then boiled for 30 minutes or four hours at room temperature of 26°C. (80° F.) The potassium permanganate liberates oxygen which is consumed by the sewage.

The test is easy to perform and can be done in a short time as compared with the period of 5 days required for the B. O D. test. However, it does not give the total oxygen needed for the biological oxidation of all or the bulk of the organic matter.

(5) **Dissolved Oxygen**:—Normal sewage, when fresh, has some oxygen dissolved in it gathered from the diluting water. But in a few hours it is all consumed by the biological action. Most sewage samples, therefore, do not contain any oxygen by the time they are tested. If the effluent from sewage treatment works contains some oxygen dissolved in it, it is an indication that the treatment has been very satisfactory, and that the effluent can be safely discharged into a stream.

(6) **Nitrogen**:—Nitrogen appears in five different forms in sewage, viz., (i) Ammonia nitrogen, or free ammonia, (ii) Organic nitrogen, (iii) Albuminoid nitrogen, (iv) Nitrites, and (v) Nitrates.

Ammonia nitrogen and organic nitrogen together, constitute the total organic nitrogen in the sewage. Albuminoid ammonia does not actually exist in sewage, but it is produced by decomposing part of the organic nitrogen for the purpose of a test as we shall see later. Nitrites and nitrates are different forms of the organic nitrogen formed at a later stage of purification

(i) *Ammonia Nitrogen*:—For measuring the free ammonia which is given off when sewage decomposes, it is distilled and collected in the distillate.

(ii) *Organic Nitrogen*:—For this test, after the free ammonia is first distilled off the sample, strong sulphuric acid is added to it, which is then boiled until all the organic nitrogen is converted into ammonia, and from the latter the quantity of nitrogen is calculated.

(iii) *Albuminoid Ammonia*:—Unlike free ammonia this does not really exist in sewage. For producing it, the sample is first freed of all free ammonia; it is then treated with alkaline solution of potassium permanganate. The ammonia given out as a result of the chemical reaction is called *albuminoid* ammonia to distinguish it from free ammonia. Albuminoid ammonia is taken as a measure of the easily decomposable organic nitrogen present in sewage. The test, however, is unreliable, and is seldom made.

(iv) *Nitrites* (XNO_2) and (v) *Nitrates*, (XNO_3):—These rarely exist in raw sewage, and therefore, there is no occasion for testing raw sewage for these. They are formed at a later stage of purification by the oxidation of free ammonia or organic nitrogenous matter. The presence of nitrites in effluent indicates that oxidation is in progress. Nitrites are not stable; therefore, they are further oxidised to form nitrates, which are stable and are absorbed by plants as food.

(7) **Hydrogen-ion Concentration:**—When a substance is dissolved in water, the solution formed "ionises", i. e. splits into electrically charged positive H-ions and negatively charged OH-ions. In other words, the positively charged H-ions and the negatively charged OH-ions dissociate from each other. Acidity is caused in the solution if the positively charged ions exceed in number the negatively charged OH-ions, and alkalinity is caused if the reverse takes place, and the greater the number of H-ions, the stronger is the acidity of the solution, and vice versa. In neutral solutions their number is equal.

It has also been found that

Concentration of H-ions $\times$ *concentration of OH-ions = a constant.*

This constant has been measured and found to be 10^{-14}. Since the mention of H-ion concetration implies also that of the OH-ion concentration from the above equation, it is sufficient to refer to one of them and it has been the practice to speak of H-ion concentration though the solution may be alkaline with OH-ions predominating in number. From the above equation, the concentration of H-ions in a neutral solution, i. e. pure water is 10^{-7}.

For the sake of convenience, scientists are agreed to express the H-ion concentration in terms of the logarithm of its reciprocal and call this "pH" value. Thus the H-ion concentration or pH value of a neutral solution is 7 and when it is 6, 5, 4, etc. i. e. less than 7, it is progressively a stronger acid, until when pH is 1, it is the strongest acid. Similarly when pH exceeds 7, it is alkaline, the alkalinity progressively increasing until pH = 14 when it is the strongest alkaline solution. This is shown in the following table.

TABLE NO. 22.

pH value	Acidity or Alkalinity
1	Strongest acid
2 } acid	
3	
:	
7	Neutral solut
8	
9	
: } alkali	
14	Strongest alkali

Laboratories are equipped with a set of sealed tubes filled with standard colours each indicating its pH value. For testing the pH value of a solution a certain chemical reagent is added to it. Such reagents produce different colour effects on different pH values of solutions. The shade produced by the reagent in the sample is matched with that of one of the tubes in the set to determine its pH value.

As has been already mentioned, fresh sewage is slightly alkaline (pH value 7·3 to 7·5), but as it becomes septic it turns acid. But after oxidation when it is relatively stable, it becomes alkaline again. We shall see later that the control of pH value is very important in the treatment of sewage or sludge. Sometimes lime is added for creating alkaline condition. A high concentration of either an acid or alkali in sewage is indicative of industrial wastes.

Hydrogen Sulphide:—The source of sulphur in sewage is the organic proteins. Calcium and magnesium sulphates present either in the original water supply, or introduced later through the infiltration of ground water into sewers, may also be responsible. Anærobic decomposition of organic protein is invariably accompanied by evolution of H_2S. The latter is a colourless foul-smelling gas heavier than air; it corrodes some metals and has a destructive effect on cement and its products, such as concrete, used for conduits. It is therefore of utmost importance to keep down the percentage of this gas in sewage and the best method of doing it is to check septicity by whatever means possible. We shall revert to this later.

(8) **Chlorides and Chlorine**:–Chlorides are mineral salts, and therefore, are not affected by the biological action of sewage. Sodium chloride, (common salt), is the main source of chlorides introduced from kitchens or industrial plants like ice-cream manufacture. The presence of chlorides above a certain minimum is taken as indicative of the pollution with industrial wastes, but it is unreliable.

Chlorine should not be confused with chlorides. Free chlorine is the residual chlorine left afer the chlorine demand is satisfied. Its presence indicates that all bacterial life has been destroyed except perhaps some spores. Chlorine demand is sometimes taken as the measure of the organic matter present. It may be between 10 and 55 p. p. m. in normal sewage.

(9) **Fats and Greases**:—These float on the top of sedimention tanks, often choke pipes in the winter, and clog filters. If collected and chemically purified they may have a market. The fat contents of a sewage are determined by first treating the sample with dilute hydrochloric acid, which liberates fatty acids. The latter are evaporated and the residue is dissolved in ether. When the ether is driven off, the ether-soluble matter which remains behind, is weighed.

Industrial Wastes:—If the liquid wastes from industrial plants do not form a large quantity, they do not materially affect the strength of the sewage, nor the expense of sewage treatment works. But often very large quantities are discharged and it is also possible that the discharge from industries like tanneries, corn products, food manufactures, etc. may contribute a very large load of organic matter. Similarly certain industries such as dyeing, bleaching, galvanising, copper working, paint manufactures, etc., may introduce chemicals which are detrimental to bacterial life. In such cases the waste discharges seriously interfere with the treatment works. The special problem presented by them must be studied. In most such cases it would be desirable to treat such wastes separately before the effluent is discharged into sewers.

Population Equivalent:—As the total solids and organic matter contributed per head of population by its sewage must be fairly constant, particularly in non-industrial towns, where the sewage consists of mostly pure domestic wastes, it is possible to calculate the B. O. D. chlorine demand, and total solids per capita, with some degree of accuracy. Investigations made in several cities of U. S. A. have shown the following average figures of population equivalent for strictly domestic sewage per capita per day.

5-day B. O. D. at 20° C. kg.	Chlorine Demand kg.	Total solids kg.
0·078 to 0·082	0·0021	0·18

From the above, if the B. O. D. of the wastes from a certain industry is calculated it is possible to compute the population equivalent, which is, as we have seen above, the estimated number of people contributing sewage equal in strength to that produced by the particular industry. For example, if the 5-day B. O. D. at 20°C. of a certain industrial waste is 95 kg. per day, it is equivalent to a population of

$$\frac{95}{0{\cdot}078} = 1218$$

It is thus possible to find out the B.O.D. separately of the liquid wastes from each manufacturing plant, to calculate its population equivalent, and on this basis tax it for the treatment of its wastes.

Questions.

(1) The weight of an evaporation dish is 141·6452 gms. with 100 grams of a sample of sewage in it. After evaporating the latter it weighed 41·7224 gms Find the amount of total solids in the sewage p. p. m.

Answer : 772 p. p. m.

(2) The dry solids in the above problem upon ignition weighed with the dish 41·6684 gms. Find the fixed and volatile solids in p. p. m.

Answer : Fixed = 232 p. p. m ; volatile = 540 p. p. m.

(3) The total daily flow of sewage of a certain town is 4·5 mill. gallons If the solid contents (dry) are 1375 p. p. m., find the total daily weight of the dry solids.

Answer : 61875 lb. or 27·62 tons.

(4) Explain in detail the processes of biochemical action in sewage purification.

(5) What does the presence of the following in sewage analysis indicate ?

(a) *p*H value = 6·5; (b) H_2S ; (c) 0·5 p. p. m. of dissolved oxygen ; (d) NO_2 , (e) NO_3 ; (f) excess of chlorides.

(6) What is the B. O. D. test ? What is meant by (a) strong sewage, (b) weak sewage and how is the relative strength or weakness ascertained ?

CHAPTER XVII

CONSIDERATIONS OF OUTFALL

THE outfall, or the place of disposal of sewage is of primary importance, and very often it governs the entire sewerage scheme. For example, if the town or city is situated on the bank of a large, perennial river or the shore of the sea, or a large body of water like a lake, disposal of sewage by dilution either with or without previous treatment is the obvious and economical method. If there is a large area of sandy soil easily under command, land-filtration or irrigation may offer a satisfactory solution, and so on.

Though the choice of site for the outfall, and the extent of the area required depend upon the method of treatment to be adopted, there are a few common factors applicable to every case, since the effluent must ultimately be discharged into a stream. The ideal conditions of a good site are that,

(1) It should be within a safe and economic distance from the outskirts of the inhabited area.

(2) It should be situated below the level of all the surrounding properties.

(3) It should be preferably on the leeward side of the town.

(4) The land available for treatment works should be ample not only for the present needs, but also for future extension, and should be cheap.

(5) It should afford stable foundations at a reasonable depth below the ground.

(6) The sub-soil water level should be low even during the wet season.

(7) It should afford sufficient head for the working of all the components of treatment works one above the other

to enable the sewage to flow from one unit to another by gravitation in the process of purification and ultimately to be discharged well above the H. F. L. of the stream.

Such ideal conditions are not always met with, and therefore in most cases a compromise has to be made. If a good site just below the town is not available, very often the sewage is collected in an intercepting sewer, which conveys it to a suitable site away from the town, where it is suitably disposed. Sometimes, instead of one outlet several outlets at different places are found convenient and advantageous under certain circumstances. For instance, in the method either of dilution or land-filtration, small quantities are better manageable, or in sewage farming and land-filtration, the several multiple outlets together easily command the necessary area required than if all the discharge were to be carried to one place only.

Though the method of disposal of sewage by dilution presents the simplest and most economical means, if it is not carried out on strictly scientific lines, it is likely to cause nuisance by the formation of small unsightly islands of half-digested floating sewage solids, or heavier particles of organic matter settling at the bottom near the water-front giving out objectionable foul-smelling gases, and of oily sleek covering considerable area of the surface of water. To prevent these a very careful thought based on observations extended over a long period must be given to the selection of the final site for discharge of sewage into the tidal currents of the sea or the perennial stream of a river.

If it is a sea-outfall, the site should have a rocky promontory, or a long arm of land extending into the sea, from the extreme end of which, the sewage may be discharged below low-water level of the lowest tides. In its absence, a pipe line of the necessary size will have to be laid on top of trestles to a place where the depth of water is sufficient.

The tidal currents should be strong enough to disperse the sewage solids and mix them with sea water thoroughly, before the latter have time to settle down. To ensure this most important condition, float observations should be made at all the possible sites, at the ebb and flow tides, and continued over a year to cover all the seasons, and all the possible combinations of the most adverse conditions.

Roughly speaking, if there is no material deposited on the fore shore, but on the contrary, there is a tendency of a scour being caused, it is an indication of a very good site. If there is a deposit of gravel and coarse sand, the site may be good, but if there are deposits of fine sand or mud, it may at once be pronounced as unsuitable.

The site should be as far away as possible from bathing *ghats*, sea-beaches and other religious and recreational places, and from the neighbourhood of shell fish.

The channel into which the effluent, whether crude or partially treated, is discharged should be free from debris, which might collect solids. Similarly, channels forming standing pools of water which may become septic or breed mosquitoes, should be avoided.

Though a sea-outfall is apparently a simple and most economical method one can adopt, particularly when the tidal currents are sufficiently large and strong, and favourable in direction, the construction is very expensive and often fraught with hazards. For, in most cases the sewers are to be laid during tides, and very often at a level below that of low tides and they are then likely to be washed away, distorted, or damaged unless great care is taken in the first instance.

In sea water, cast iron pipes are liable to rust, besides being heavy and therefore difficult to be laid and jointed. Steel pipes, which are stronger and lighter are more advantageous, and further they can be plugged at both ends and easily floated and rolled into position.

Storage tanks of R.C.C. or brick masonry are often built of a capacity to hold the volume of sewage during periods of high tides, with control gates, so that they can be emptied into the sea when the tides are low again. Then they may be designed and constructed to serve the double purpose of storage and sedimentation. In any case, they should be long and narrow, leading the discharge from one into the other and designed to a grade to give a slightly higher self-cleansing velocity while being emptied. They should also be covered at the top by means of an R. C. C. flat slab, and provided with chimney vents, so that the contents will remain hidden from the public gaze, causing the least nuisance either to the sight or smell The R. C. C. slab may be used as the bottom of a light garden of flower-beds for public use.

The outlet of sewage into a river should be placed below the water line and the deeper it is the better; for it gets a good chance of being mixed with a diluent before it reaches the surface.

The site for land filtration should be of land with at least five feet deep porous soil, and the land for the sewage farming should have at least 0 60 m. (2 ft.) of fertile soil at top overlying 1 m. (3 ft.) or more of sandy or gravelly sub-stratum. For both these the surface should be level and the sub-soil water table should be low even during the wet season.

For sewage farming with intensive garden cultivation such as under sugarcane, 0 03 cu.m (1c. ft)per sec. can irrigate about 20 to 25 hecs (50 to 60 acres) depending upon the nature of the soil. Expressed differently this means that 0 4 hec. (1 ac.) can take care of 45500 lit. (10,000 gallons) per day If it is a fodder crop, double the area calculated as above would be required. For land filtration approximately half of the above area will suffice. But at least three times these areas should be acquired both for filtration or irrigation. For, while one part is under perennial irrigation, another will be under eight-months crops and the third will be either under seasonal crop, or lie fallow to rest if the soil is not very good.

The site for intermittent land filtration should be extensive and there should be ample river sand in close proximity.

For Imhoff tanks a much greater depth of soil—6 to 10 m. (20 to 35 ft.) is required. If there is rock, the cost of excavation will be great.

The site for activated sludge process should be flat or gently sloping. If all the components are economically grouped together, about 0·08 hec. ($\frac{1}{5}$ acre) may suffice for treating 45500 lit. (100,000 gallons) per day.

The area of land for percolating filters should be about 0·1 hectare ($\frac{1}{4}$ acre) per 45500 lit. (100,000 gallons) per day. For normal percolating filters 2·5 to 3·75 m. (8 to 12 ft.) of head is required between the invert level of the influent sewer and the H. F. L. of the stream into which the final effluent is to be discharged.

The above figures of areas, do not include land which may be required for future extensions, sludge storage, gas tanks and other ancillary works.

Questions

(1) What precautions must be taken before effluent is discharged into a river and why?

(2) What are the requirements of an ideal site for a sea outfall?

(3) If there is neither sea nor a river but there is plenty of low-lying land beyond a town, but of a deep clayey soil, what alternatives would you seek for the disposal of the sewage?

(4) Why are multi-outlets instead of a single large one often advantageous for broad irrigation?

(5) The total sewage of a town is 91000 cu. m. (2 mill. gallons). How many hectares (acres) of land of suitable type would be required to be acquired for broad irrigation of sugar-cane?

CHAPTER XVIII

METHODS OF DISPOSAL OF SEWAGE (GENERAL)

THE methods of disposal of sewage may be classified under two main categories: (1) *Natural*, and (2) *Artificial*.

(1) The **natural methods** comprise (a) Land Treatment, and (b) Dilution.

(a) In *land treatment* sewage is evenly spread on the surface of land either for pure filtration through the porous soil, or for irrigation, when crops are grown. In land treatment the water in the sewage is absorbed by the soil and the organic solids left behind on the surface are oxidised partly by exposure to air, light and heat of the sun, and partly by the biological action of the bacteria present in the top layer of the soil.

(b) *Dilution*:— This consists of discharging the sewage into sea, river, or other large body of water such as a lake.

The theory underlying dilution is thatwater exposed to open air contains a large amount of oxygen dissolved in it. When sewage is discharged into it the bacterial organisms present in it use this oxygen. But if the diluting water is not sufficient to supply the biological oxygen demand to oxidise the entire organic matter, not only a nuisance of foul odour, and unsightly islands of half-digested floating, putrefying matter at the surface would be created, but the depletion of oxygen would kill aquatic life, and if the water is used for domestic consumption a little downstream, as often happens, it is likely to be a danger to public health.

To avoid these evils, in most cases some primary treatment is given to the sewage before discharging it into the water. This treatment consists of removing the floating and suspended matter which contains a large amount of organic particles, by means of screens. Very often the sewage after passing through screens is allowed to pass through a detritus tank where the heavier particles such as of sand, gravel, etc. settle. If the dilution is not sufficient or the currents not favourable, the influent from detritus tank may require to be settled in sedimentation tanks, for separation of settleable solids, before the effluent is discharged into the sea or river. In the latter case the screenings are buried under-ground, the sand and gravel from detritus tanks are used as a filler material and the sludge from the sedimentation tank is further treated to remove its objectionable qualities or buried in trenches.

(2) **Artificial Methods**:— The treatment of sewage by these methods is effected in two stages: (a) primary, and (b) secondary.

(a) The *primary stage* seeks to separate the solid matter from the liquid, mostly by mechanical means. It consists firstly of screening by which the floating matter is separated; secondly, grit removal in grit chambers or detritus tanks, and thirdly the settlement of suspended solids in sedimentation tanks, or settlement and partial digestion in Imhoff tanks. In the final process of the primary treatment the suspended solids precipitate at the bottom of sedimentation tanks in the form of sludge. Sometimes certain chemicals are used as coagulants to hasten precipitation in sedimentation tanks.

(b) *Secondary stage*:—The effluent passing out of the primary stage of treatment as described above, has considerable organic matter still left in it, which must be removed or rendered innocuous by oxidation. This is done by one of the following means:—

(a) Land treatment, to which we have referred above.
(b) Filtration by one of the different methods, such as intermittent sand filters, contact beds, trickling filters, etc.
(c) Activated sludge process, usually followed by a further treatment.

All this does not finish the job. We have still to dispose of (i) the screenings, (ii) the grit, and (iii) the sludge, all of which contain some organic matter which is likely to prove a danger to public health.

The screenings are buried underground or burnt.

The grit which consists mostly of sand and gravel mixed with some organic matter, though washed, is not useful even as an engineering material in roads, much less for mortar or concrete. It is used for filling depressions.

The sludge which contains 90 to 95 per cent of water is first dewatered, and the solids left behind are either buried under-ground, or dried into cakes to be used as a fertiliser.

The various methods of disposal are tabulated below for a ready reference.

I. Natural Methods

- Dilution with or without preliminary treatment.
- Land Treatment
  - Filtration
  - Sewage Farming

II. Artificial Methods

Primary Treatment

A. Removal of coarse, heavy solids such as sand, gravel, etc. by detritus tanks.

B. Removal of coarse, floating, bulky solids such as rags, tins, coal, paper, etc. by coarse screens.

C. Sedimentation of fine organic solids by:
   (i) Plain sedimentation in settling tanks with or without mechanical appliances.
   (ii) Chemical precipitation.

D. Separation and partial digestion of fine organic solids by:
   (i) Septic tanks.
   (ii) Imhoff tanks.

Secondary Treatment (Oxidation) by:

A. Filtration by means of
   (i) Intermittent sand filters.
   (ii) Contact filters.
   (iii) Trickling filters.

B. Aeration by means of
   (i) Activated sludge process.

CHAPTER XIX

LAND TREATMENT

LAND treatment comprises (1) Filtration on the surface of open porous land, and (2) Irrigation, or sewage farming. This is called broad irrigation to distinguish it from sub-surface or subsoil irrigation with under-ground porous drain pipes with open joints for irrigating the sub-soil stratum. As on account of practical difficulties and high cost, sub-soil irrigation is mostly confined to small private installations, it is not considered here.

The process by which the purification of sewage takes place in both the above methods is the same, viz. mechanical straining, or filtering through the particles of soil, and bio-chemical action, by which the complex compounds in sewage are converted into harmless mineral salts with the aid of bacteria. The difference is that whereas in filtration all the surfaces of the innumerable particles of soil to a certain depth below the surface are brought into play, both for the mechanical and biological actions, in irrigation the sewage does not penetrate beyond 5 to 8 cm. (2 to 3 in) into the ground, and mostly the exposed surfaces of the latter can be utilised. Secondly, in irrigation the end products, viz. the stabilised mineral salts such as the nitrates, sulphates and phosphates are utilised then and there by the root system of the crops grown. Really speaking the value of water which forms 99·9 per cent sewage is the most important. The quantity of nitrogen supplied by the sewage is very small, and it takes a long time before it is available in the form of assimilable nitrates for plant use.

Both the above forms of land treatment are suitable where

(1) Rivers run dry, or have a small flow during summer, and therefore, discharging sewage into them is out of the question.

(2) Climate is arid, and favourable for land treatment.

(3) Plentiful land with sandy, loamy, or alluvial soil overlying soft *murum*, sand or gravel is available. Porous soil which allows filtration and æration freely is the best. Black cotton soil, *chopan*, or even heavy red or yellow soil is unsuitable. Too porous land like sand bed is also unsuitable even for filtration since the water in the sewage will pass down very quickly, leaving a colloidal slime at the surface, which would clog the pores of the soil, and would itself continue to putrefy giving off foul odours till it dries up.

(4) The sub-soil water table is low even during the wet season.

(5) The rainfall is low and there is an acute demand for irrigation water.

(6) There is a good market for crops such as vegetables, with a promise of good returns.

There are a large number of towns in Europe and America notably Berlin and Paris where broad irrigation has been and is being practised with profits. But the places where land filtration is resorted to for disposal of sewage are few.

Application:—The land should be first ploughed deep (at least 30 cm. or 12 in.), levelled and divided into plots and subplots, of areas depending upon the surface slope. Each subplot should be enclosed by low embankments. This treatment, viz. of ploughing, levelling, etc. should be done every 6 to 12 months. The crops should be grown on ridges between two furrows 1 to 1·25 m. (3 to 4 ft) wide. Vegetables which are not eaten raw, maize, jwar, lucerne, and other fodder crops, fruit trees, sugarcane, etc. have been tried with success in this country. About 5 to 10 cm. (2 to 4 in.) of sewage should be applied at a time at 8 to 10 days intervals, depending upon the nature of the soil, and the requirements of the crops. In this way, about 32 to 75 cu.m. (7,000 to 16,000 gallons) of sewage per day per hectare (acre) can be used depending upon the nature of land and the crop. If only land filtration is adopted, double this quantity can be applied. If screening, sedimentation or both is done or if the farm is under-drained, this quantity can still further be increased. If the soil is poor, under-drainage is necessary, but it increases the cost. The system of underdrains should consist of subdrains of agricultural pipes 75 mm. (3 in.) diam. laid at right angles to the surface slope of ground, with butt joints. To discharge into main drains 150 to 300 mm. (6 to 12 in.) diam. of stoneware laid with open joints 5 to 10 m. (20 to 30 ft.) apart with manholes for inspection. The under-drain system is about 1 to 1·5 m. (3 to 5 ft.) below the surface of ground.

As a rough rule sewage should not be applied in quantities at a time, greater than those absorbed within 30 minutes. Excessive dose would cause offensive odours.

Sewage-sickness.— After continuous application of sewage on land the soil often gets *sewage-sick*, when its pores get clogged, preventing oxidation and causing noxious smells. The remedy is to break up the surface, and give the land rest. For this 2 to 3 times the land actually under irrigation, should be acquired in the first instance. Frequent ploughing and rotation of crops are preventive measures.

It is important to note that the primary object of sewage farming should be to dispose of sewage without nuisance. Crop-growing should be the secondary consideration. One should not expect profits out of it. The expenditure incurred should be regarded as the cost of purification, part of which may be met from the sale of produce.

Example No. 19 : —A town with a population of 45,000 is provided with 180 lit. (40 gallons) of water per head per diem. If there is no ground water likely to enter sewers, and 80 per cent of the water supply is available after sedimentation, how much land including 50 per cent reserve, will be required for broad irrigation, if it is of such a nature as would consume 160 cu. m. per day per hectare ?

Solution :—Quantity of daily sewage $= 45000 \times 180 \times 0{\cdot}8$
$= 6480{,}000$ lit./day $= 6480$ cu. m./day.

$$\text{Land required} = \frac{6480}{160} \times 1{\cdot}5 = 60{\cdot}75 \text{ hectares.}$$

Lagooning : —Lagoons or sewage ponds are a cheap and efficient means of sewage disposal requiring little attention, in which sewage purifies itself by natural processes. It is suitable where a large natural depression is available or a cheap artificial tank can be constructed in a depression in a place away from human habitation on the leeward side, as aerial nuisance is bound to arise. The factors affecting its satisfactory working are :—

(1) Adequate preliminary treatment to prevent formation of sludge banks.

(2) Sufficient surface area for oxygenation by encouraging growth of algæ on the surface, which absorbs sun's rays and gives off oxygen, preventing septicity. Sun-light and wind are the important factors.

(3) The depth should be about 1·25 m. (4 ft.) to discourage weeds protruding above the surface.

(4) Dilution is helpful, but is not quite necessary

(5) Turbidity prevents the sun's rays from penetrating the surface.

(6) Partially treated sewage should enter the pond at one end and the purified effluent should pass out from the outlet at the opposite end. The detention period should be at least 24 days.

(7) Breeding of mosquitoes should be prevented by keeping the surrounding area free of grass, weeds, and other vegetation.

Pisciculture :—Fish ponds for the culture of fish is another natural method of sewage purification. It has been in use at Munich and Strassbourg in Germany on a large scale and the results are very promising. At Munich the sewage of 7 lakhs of population is purified by this method with both economic and sanitary success. The ponds occupy one-tenth of the area normally required for irrigation to treat the same quantity. The method is briefly described below :—

A series of six shallow tanks 0·6 to 1 25 m. (2 to 4 ft.) deep, one overflowing into the next, are constructed. Sewage previously screened and settled, and diluted with 2 to 5 times its volume with river water is filled, and special varieties of fish, "carp" and "tench," and ducks are introduced in them. The purification is effected by the innumerable small organisms such as plankton which multiply in the sewage, and form the food for the fish and ducks.

Care must be taken to maintain a minimum of 4 to 5 p. p. m. of dissolved oxygen in order to avoid sludge deposits, and discourage accumulation of scum at the surface which prevents æration. It is also necessary to exclude toxic substances such as hydrogen sulphide, oily wastes, and materials which might clog fish gills. If a positive balance of dissolved oxygen is maintained, the sewage will remain free from H_2S and other offensive gases. The ponds and drains are cleaned every year. In the plant at Strassbourg about 200 to 250 kg. (400 to 500 lbs.) of fish and 100 to 125 kg. (200 to 250 lbs.) of duck meat are realised annually per acre. The plant removes 88 per cent of organic matter and 80 per cent of nitrogen from the sewage in the last pond.

Questions

(1) Under what specific conditions is land treatment indicated as preferable to other methods of sewage treatment?

(2) What is the difference between land filtration and broad irrigation as far as purification of sewage is concerned?

(3) What is sewage sickness and how can it be prevented and remedied?

(4) One million gallons of sewage per day is to be treated by culturing fish in tanks. Calculate the area required and also the water required for dilution, provided it contains normal quantity of dissolved oxygen in it.

(5) What are the drawbacks of disposal by lagooning?

CHAPTER XX

DILUTION

DILUTION is one of the principal methods of disposal of sewage. Still a special importance attaches to it since, with any method of sewage treatment, except land treatment, the final disposál is by dilution.

Though there are several agencies at work such as the aquatic flora and fauna, sun's rays, etc. in purifying sewage when the method of dilution is resorted to at least 95 per cent or perhaps more of the purification is effected by the oxygen dissolved in the diluting water.

Normal river water contains about 8 parts per million (p.p.m.) and sea water about 6·5 p. p. m. of dissolved oxygen at 25°C (80°F) and, as a general rule, sea water holds about 20 per cent less oxygen in solution at the same temperature. The main source of oxygen is the atmosphere or air in contact with water surface.

The quantity of dissolved oxygen varies inversely as the temperature. Thus,

Temperature	River water Dissolved Oxygen p. p. m.
5°C (40°F.)	13
25°C (80°F.)	8·0
35°C (90°F.)	6·5

Movements in the surface of water caused by ripples, waves, falls, rapids, etc. increase the absorption of oxygen to the limit of saturation.

Conditions Favourable for the Adoption of Dilution :—

(1) Proximity of a sea or river.

(2) Fresh, non-septic sewage.

(3) Large volume of diluting water, high in dissolved oxygen.

(4) Strong forward current to prevent deposition near the outfall site.

(5) Adequate depth of water at the point of discharge.

(6) Absence of back currents, pools, favourable to sedimentation, and absence also of rocky projections on banks, and weeds, which are liable to catch and collect solids.

Conditions to be Guarded Against:—Offensive odours due to putrefying deposits at the bottom, and sludge banks at the top, unsightly floating matter and discoloured surface due to oil sleek, deposits on banks or shores, excessive depletion of oxygen, contamination of shell fish, and destruction of aquatic life, are to be guarded against.

Self-purification of Streams:—It is observed that sewage-polluted water of a stream gets progressively purified in the course of its flow downstream. This is due to (1) Physical, (2) Chemical, and (3) Biological processes going on inside the stream.

(1) *Physically*:—The dissolved organic matter is diluted and is immediately oxidised by the dissolved oxygen. If the current is strong, both the lighter and heavier suspended solids are dispersed and carried away. If the current is sluggish, the heavier particles are deposited, encouraging the growth of bacteria and algæ. Where sedimentation takes place, the water tends to become clear.

(2) *Chemically*:—The dissolved oxygen in the original stream, and also that added through the water of tributaries and through æration in the course of its flow over falls, etc. and wind action, combines with the organic matter. The ultra-violet and actinic rays of the sun which penetrate the water deep, if it is clear, have a bactericidal effect both directly, and indirectly through the process of photo-synthesis, by which the green leaves of aquatic plants absorb CO_2, and give off oxygen.

(3) *Biologically*:—The bacteria adhering to the organic solids, feed on the latter and multiply, resolving the complex compounds into simpler elements, and ultimately creating stable conditions. The other micro-organisms called plankton, both plants and animals, help purification. The plants (algæ) contain green chlorophyll which under sun's light

produces oxygen, and the animal plankton feed upon dead organic matter and some kinds of bacteria. Worms and insects also help the process of purification by feeding upon organic matter.

Sea Water *versus* **River Water for Dilution**:—River water is better for dilution for the following reasons:—

(1) As we have already seen river water absorbs and holds 20 per cent more oxygen in solution, at the same temperature.

(2) The sp.gr. of sea water being greater it holds solids in suspension more than river water in which they readily settle.

(3) The higher sp. gr. and lower temperature of sea water cause the lighter and warmer sewage to rise to the top in sea water and tend to form sludge banks.

(4) Sun's rays penetrate deeper in river water as it is generally clear than in sea water, and exercise a greater purifying effect.

(5) Organic solids have a greater tendency to form hydrogen sulphide gas and give off foul odour in sea water than in river water.

Although the direct discharge of sewage from sea-side or river-side towns into adjoining sea or river waters was once regarded as a simple, efficient and most economical method of sewage disposal, in very few amongst the hundreds of towns in which it is adopted in Europe and America, it has been found to be satisfactory and also economical in the long run, when public health and amenities are at stake. The modern trends, therefore, are definitely towards subjecting the sewage to some form of secondary treatment in addition to screening and detritus to reduce the pollution load before it is discharged into diluting waters.

This applies with still greater force to our country, where (1) on account of the tropical heat the percentage of dissolved oxygen is low, (2) there are very few coastal towns which have strong tidal currents in the forward direction, and the necessary depth of water at the point of discharge, (3) most of the rivers run dry, or have a very meagre flow during summer, and those which have a good flow are, in most cases, the only source of water to the several villages situated on or close to their banks, and, (4) excepting a few large cities which have ample water supply, the sewage of most towns is concentrated as the available quota of water per capita hardly exceeds 45 to 75 lit. (10 to 15 gallons) per day, and on account of the high temperature the sewage gets septic very soon.

Standard of Purification:—This necessarily varies according to the degree and nature of protection required to be given to the water into which the final effluent is to be discharged. The usual yard-sticks by which the degree of purification is measured are:

(1) The percentage removal of suspended solids.
(2) The extent to which the B. O. D. is satisfied.
(3) The removal of bacteria.

The percentage removal of suspended solids give a measure of the removal of the organic matter and turbidity. As a general rule the water into which the effluent is discharged is tested. It should be free from any nuisance, and be safe for the purpose for which it is to be used. In order to prevent nuisance there should be a balance of free oxygen dissolved in it after meeting the B. O. D. of the sewage impurities. Some authorities have suggested that this balance of oxygen should be a minimum of 30 per cent of the saturation.

For the preservation of aquatic life which draw their oxygen requirements from the source of the dissolved oxygen in the water a minimum of 3 to 4 p. p. m. of dissolved oxygen is necessary.

If edible shell fish, particularly, oysters, which are eaten raw, are cultivated, special care must be taken to see that not only the necessary quantity of the dissolved oxygen is present but in addition, that the water is not contaminated by pathogenic bacteria which are introduced by the sewage. The standard adopted in this respect in America is that the *B. coli* index should not exceed 50 per 100 c. c.

For river water, which is used as a source of drinking water supply, chemical standards alone are not sufficient in determining whether the water is safe for drinking. A bacteriological test is necessary and is of greater importance than those for suspended solids and B. O. D. The following standard bacteriological test is adopted in this country :—

(i)	*B. coli* when present in 20 c. c. or more	Safe
(ii)	,, ,, ,, ,, 5 c.c. ,, ,,	Suspicious
(iii)	,, ,, ,, ,, 1 c.c. ,, ,,	Dangerous

The standard recommended by the Royal Commission on Sewage Disposal in their Report No. 8 is as follows :—

"An effluent, in order to comply with the general standard must not contain as discharged, more than 3 parts per 100,000 of suspended matter, and with its suspended matter included, must not take up more than 2 parts per 100,000 of dissolved oxygen at 5 days.

If the dilution is between 150 and 300 volumes, the dissolved oxygen test may be omitted, and the standard for suspended solids fixed at 6 parts per 100,000.

If the dilution be between 300 and 500 volumes the standard for suspended solids also may be further relaxed to 15 parts per 100,000.

With dilution exceeding 500 volumes, all tests may be dispensed with and crude sewage discharged, subject to such conditions as the provision of screens, and detritus tanks, as might appear necessary to the Central Authority."

Questions

(1) What are the conditions favourable for dilution ?

(2) What standards of purification are prescribed by the Royal Commission ?

(3) What are the most important factors which bring about purification of river streams ?

(4) Compare sea-water and river-water as far as their purifying property is concerned.

CHAPTER XXI

PRELIMINARY TREATMENT

We have already seen that sewage contains (1) Coarse heavy solids like sand, gravel, (2) Coarse, floating matter like rags, pieces of wood, coal, etc. (3) Settleable suspended solids, (4) Very fine, suspended solids, and colloidal matter, and (5) Solids in solution.

An attempt is made to remove as much as possible out of the first three sorts, by pure mechanical means, viz. precipitation in tanks and screening. This process is called the preliminary treatment. The purpose of this treatment is to reduce the load on the secondary treatment of oxidation, which seeks to remove the solids in the last two categories.

Grit Chamber:—The terms, grit chamber and detritus tank, are synonymous. The purpose of a grit chamber is to separate heavy mineral matter like sand, gravel, large pieces and dust of brick, road scrapings, ashes, etc. Some of these substances, if not removed from the sewage, are likely to damage pumps and other mechanical appliances employed, and interfere also with purification by the secondary treatment. The amount of silt or grit varies with sewages, and also with the system of sewerage adopted. That from sewage on the combined system will be much more than the amount of grit from sewage from separate system. For exact determination of the quantity, which is required for a proper design, actual experiments must be made on average samples collected at different times in different seasons.

The principle of design of grit chambers is the same as that of all sedimentation tanks, viz. reduction of velocity by increasing the cross-sectional area of flow. The only difference is that as grit is heavy, a very small detention period is required. The velocity, however, cannot be very low. It should be such as would cause the heavy inorganic solids to settle, allowing the light, suspended solids to be carried away. If the velocity is very low, the organic matter also will settle and get entangled in the mineral matter causing septicity, and require labour and expense to remove it. However, some organic matter, adhering to the surface of mineral particles, is bound to settle. If it is less than 12 per cent, it is unlikely to become offensive.

0·25 to 0·3 m. (0·8 to 1 ft.) per sec. is found to be a suitable velocity for Indian conditions. But it is very difficult to maintain it uniform throughout as the discharge, and with it, the depth are very variable.

The remedy is to provide one chamber sufficient to take care of the minimum discharge, and one or more in addition for use according as the discharge increases.

A detention period of $\frac{1}{2}$ to $\frac{3}{4}$ minute is deemed sufficient. The former figure is for coarser grit and the latter for slightly finer.

The tank is usually in the form of a long and narrow channel with sides vertical at top, and steeply sloping below about $\frac{1}{3}$ depth to form an extended trough at the bottom for collection of grit. The angles should be rounded The inlet and outlet ends should be flared, (gradually widened), to prevent eddies due to sudden change of section. Tanks, rectangular in plan with hopper bottoms, are unsuitable for this country as they are difficult to clean.

The British Ministry of Health have recommended the capacity of grit chambers to be 1 per cent of the daily quantity. But this has been found excessive. About 0·7 to 0·8 per cent should suffice for this country, according to sanitary authorities.

Grit may be removed either by hand or mechanical grit removers. If by hand, two tanks are necessarily required, so that while one is being cleaned, the other will be in operation. Hand removal is not quite satisfactory, but is economical on small works. The grit is first stirred, so that any particles of organic matter sticking to the grains may be dislodged and come to the surface, and be carried away. Then the grit is shovelled into buckets, and heaped on the top of a perforated trough to drain.

The mechanical grit removers are patented and of various designs. Most of them are automatic in action. In one, there are buckets attached to an endless chain, which, while rotating, scrape and collect the grit and deliver it to a trough at the top. During the travel of the bucket all the water is drained. In the Dorr "Detritor" the grit is scraped from a sump, washed and at the same time pushed up an incline, outside the tank, with the result that a very small proportion of organic matter is claimed to be retained in it.

Disposal of Grit :—For Indian conditions the only use for the grit is as a filler material in an embankment. The grit from even the most efficient detritus tanks contains too much organic matter to be used in concrete, unless it is washed again, the expense of which is more than the value of new material.

The procedure of design of detritus tanks will be clear from the following example :—

Example No. 20 :—The dry weather flow from the separate system of sewerage of a certain town is 200 lit./sec. Assuming the maximum flow to be three times the average, design a detritus tank.

Solution:—Assuming a velocity of 0·3 m. per sec. and detention period of ¾ minute or 45 seconds, the length of the tank,

$l = 45 \times 0{\cdot}3 = 13{\cdot}5$ m.; if depth is 1 m.

$$\text{Width for average flow} = \frac{0{\cdot}2 \times 60}{13{\cdot}5 \times 1} = \frac{12}{13{\cdot}5} = 0{\cdot}89 \text{ m.}$$

say 1 m.

$$\text{Actual velocity, } v = \frac{0{\cdot}2}{1 \times 1} = 0{\cdot}2 \text{ m./sec. which is good.}$$

Thus the detritus tank or rather channel, will be 13·5 m. long, 1 m. wide and 1 m. deep. But this depth will be the depth of actual flow; we must provide at least 0·5 m. depth for the storage of grit and 0·25 m freeboard at top. The tank will therefore be 1 m. wide from top up to 1·25 m. depth, below the top, then the sides will steeply slope down inwards to form an elongated trough 13·5 m. long and 0·6 m. wide at the bottom with rounded corners. The total depth will be 1·75 m.

Three such tanks will be required for handling the maximum flow, so that one tank will be normally in operation when the discharge is minimum, and the others will come in use as it increases.

Screening:—This is another mechanical device which seeks to remove coarse, bulky, floating matter from sewage. The objects of screening are:—

(1) To separate coarse matter which would otherwise clog sewers, block channels, and by getting entangled in the vanes or blades of centrifugal pumps may injure or even break them. (2) If disposal is done by discharging the crude sewage into a stream, screens, which are in this case usually finer, arrest the coarse and some of the fine suspended solids, which would otherwise act as a nucleus for the formation of unsightly sludge banks, or floating islands, and, (3) Incidentally screens remove a small percentage of organic matter sticking to the coarse floating matter.

Classification of Screens:—Screens are classified as (1) *coarse* having bars or racks 40 to 100 mm. ($1\frac{1}{2}''$ to $4''$) apart, (2) *medium*, with spacing of bars or widths of mesh of 10 to 25 mm. ($\frac{1}{2}$ to $1\frac{1}{8}$ in) and are used where reciprocating pumps are employed, and (3) *fine*, which are generally in the form of elongated slots, 5 to 1 mm. ($\frac{1}{4}$ to $\frac{1}{16}$ in.) wide and 5 to 50 mm. ($\frac{1}{4}$ to 2 in.) long, and are used for removing fine suspended solids. As they remove at the most not more than 10 per cent of suspended solids, they are not much used at present as they get clogged and have to be cleaned frequently by hand, even in automatic mechanical devices. Sedimentation tanks are found to be more economical and efficient, hence fine screens are no longer used on recent installations.

Types of Screens:—Screens may be vertical, inclined, or horizontal though screens at an inclination of 45° to 60° are more easily cleaned and offer greater exposed area; they may further be fixed or moveable. Then there are screens named according to their construction, such as rack screens, bar screens, slot screens, wire mesh screens, etc ; also according to their shapes, e.g. band screens, drum screens, cage screens, etc. each being used for a specific purpose. The bars, bands, or plates are of mild steel in all cases. In an improved type the bars are wedge-shaped in a horizontal section, and measure about 10 mm. (½″) on the front, 5 mm. (¼″) on the back side and are about 50 mm. (2 in.) deep between the front and rear surfaces. This prevents solids being wedged in between the bars.

Screens require to be cleaned frequently. This is done either by hand or machine. The latter is more satisfactory. Mechanically worked screens are patented. Attached to these are automatic rakers, which, in some devices like that of M/s Dorr and Co., push the screenings into a pit where they are washed and picked up by an elevator.

The submerged area of screens when cleaned by hand should be 300 per cent of the cross sectional area of the approach sewer, and that of the mechanised one, half this.

Comminutor:—This is a mechanical appliance used in U. S. A , which combines a screen and a disintegrater in a single mechanism. It is claimed that, since both these operations are done in a closed chamber, the whole thing is quite clean, sanitary, and free from any nuisance.

The comminutor comprises a revolving slotted cylinder open at bottom, with cutters of special steel, mounted on its surface in the form of small projections The cylinder is placed in a sewage channel, and rotates about its vertical axis. Outside the cylinder is fixed to the frame, a vertical comb of sharp edges of special hardened steel. As the cylinder rotates, any solid material in the sewage is caught between the teeth of the comb and the steel projections, and is sheared into particles small enough to pass through the slots along with sewage, and thence through the bottom opening as shown in Fig. 259.

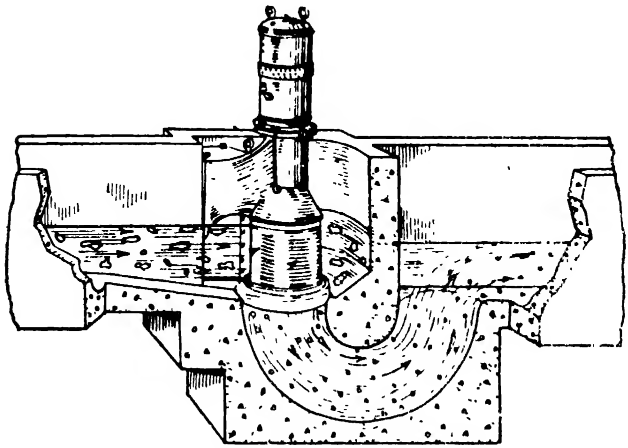


Fig. 259—A comminutor in vertical section

Quantity of Screenings :—The total quantity of screenings varies very much, from ·025 to ·700 cu. m. (1 to 25 c. ft.) per 5000 cu. m. (1,000,000 gallons) of sewage, depending upon the character of the sewage, and mesh of screen. Coarse screenings are the least—·025 to ·050 cu. m. (1 to 2 c. ft.) per 5000 cu. m. (m. g.) and contain only a small proportion of organic matter. The quantity of medium screenings is more and that of fine screenings up to even 1 cu. m. (30 c. ft.) containing 80% of water and lot of organic matter.

With recent advance made in the process of sedimentation giving a higher efficiency, screens have lost their former importance for removing suspended solids. The modern tendency is to employ bar screens with 25 mm. (1 in.) spacings which will arrest only floating bodies, and on smaller plants hand cleaning is resorted to,

Disposal of Screenings:—(1) Burial in shallow trenches, with depth not exceeding 1 m. (3 ft.), when reasonable degree of isolation of plant and adequate land are available, is the principal method of disposal. The trenches should be covered with earth to exclude flies and offensive smells. (2) Screenings removed by fine screens are often mixed with house refuse and composted. (3) Dewatering in centrifuges, and incinerating with the help of gas from sludge digestion tanks. (4) Disintegrating by means of special disintegraters worked by power which chop and grind the screenings so as to pass 5 to 8 mm. ($\frac{1}{4}$ to $\frac{3}{8}$ in.) wide slots. They may then be dumped into sea, or buried in trenches. (5) Comminuting as described above.

Skimming Tanks:—Sewage usually contains some fatty oils and grease, which, if not removed in time, are likely to accumulate at the surface of sedimentation tanks, or may clog filters and interfere with oxidation in æration tanks. However, Indian sewage, perhaps on account of the fact that the majority of people are vegetarians and do not use animal fats, contains these in a negligible quantity, and even then on account of the hot climate they do not congeal. It is not therefore necessary to provide special skimming tanks. However, it is desirable to insist on the provision of grease traps on the part of large hotels and other similar establishments in their plumbing systems. This precaution is perhaps very useful during winter months in North India and on hill stations where the temperature often goes sufficiently low to congeal fats and grease.

Questions

(1) What is preliminary treatment and what are its objects?

(2) The D. W. F. and maximum discharge of sewage of a town are 125 and 325 lit/sec. (4 5 and 11·7 cusecs). With detention period of 45 secs. and velocity 0·25 m. (0·8 ft.) per sec., design a detritus tank.

(3) How are grit and screenings disposed of?

CHAPTER XXII

SEDIMENTATION

ALTHOUGH sedimentation means precipitation or settling out whether it is heavy sand and gravel, or suspended solids, slightly heavier than water, the term is technically used to denote the settlement of suspended solids only.

Theory of Sedimentation :— All solid particles heavier than water tend to settle by the force of gravity. However, there are three opposing forces in nature : (1) the velocity of flow which transports them away horizontally. The transporting power varies as the sixth power of the velocity ; (2) the viscosity of the liquid which offers frictional resistance. This varies inversely as the temperature, and (3) the shape and size of the particles. In respect of the latter though the weight and volume vary as the cube of the diameter, the area of surfaces, on which the frictional resistance depends, varies as the square of the diameter. This means that very small particles settle very slowly. These facts are expressed by Stokes in the following formula :

$$v = 418\,(s - s')d^2\,\frac{0{\cdot}3t + 7}{10}$$

where v = velocity of settlement in mm. per sec., s = sp.gr. of the particle, s' = sp. gr. of water, d = diameter of the particle in mm., and t = temperature in degrees C.

However, Hazen later proved that this law does not apply to particles of d = less than 0·10 mm. which settle down at a velocity which varies as the first power of d and not as d^2 as in Stokes' formula. His formula for these particles is :

$$v = 418(s - s')\,d\,\frac{0{\cdot}3t + 7}{10}$$

Out of these three opposing forces, an attempt is made to reduce the velocity of flow by increasing the area of cross section of the flow. In fact, this is the basic principle of practical design of all settling tanks. Temperature which governs viscosity cannot be controlled for practical and economical reasons. When the sewage is strong i. e. concentrated, there is a tendency on the part of smaller particles to 'floc' i. e. to combine or gather together and form larger particles, which then according to the 3rd law mentioned above, more readily settle. This can also be done artificially and very often is attempted in normal or even weak sewages by adding certain chemicals, as coagulants, which accomplish the same thing.

Even if the liquid is made more or less quiescent by reducing the velocity of flow, the longer the particles remain in the tank within certain limits, the better opportunity do they get of sinking to the bottom. This factor of time is called *detention period*. It is the tank capacity ($l \times b \times d$) divided by the velocity of flow, through the tank per hour, and is expressed in hours. Obviously for the same detention period, the less the depth, i. e. the shallower the tank, the more quickly would the particles reach the bottom. But the particles after reaching the bottom do not remain there on account of the vertical convection currents induced by the difference in temperature of water layers, and wind action, which causes horizontal movement at surface, and opposite movement below it, these resulting in a vortex motion. This churning effect is more pronounced in shallow tanks. There is one more point in favour of deep tanks, viz. they encourage flocculation (tendency of particles to combine). Thus both too deep and too shallow tanks are not desirable. The modern tendency is to design tanks 2·5 to 3 m. (8 to 10 ft.) deep—sometimes up to 5 m (15 ft.) depth.

If tanks are filled and emptied intermittently they will remain quiescent for some time, but in practice they are worked in most cases on a continuous system for reasons of economy and convenience.

Again, whatever a flow-through velocity is allowed, it must be (1) uniform for all fluctuations, and (2) uniform in all parts of the tank. The first is very difficult to achieve, since, even normal daily peak flow is 2 to 3 times the average, and more, when it rains. This is possible only when the sewage has to be pumped, and a balancing tank is provided on the suction side. But this would cause staleness and septicity in sewage. Various devices are therefore adopted, such as constructing separate tanks and channels, chambers of varying widths, or discharge weirs at various depths in channels etc., to counteract the fluctuations of flow.

For making the velocity uniform in every part, proper placement of outlets and inlets, and providing suitable baffling, are some of the remedies.

Theoretically, the detention period and the flowing-through time must be the same. But on account of the varying velocities in different parts of the tank, the incoming sewage does not displace all the sewage previously filled in the tank. Besides, even in the best designed tanks there may be some small stagnant pockets.

Different Forms of Sedimentation Tanks :—These are :

(1) *Grit Chambers or Detritus Tanks*, which have already been discussed.

(2) *Plain Sedimentation Tanks*, in which the settleable solids in sewage are allowed to precipitate by natural agencies.

(3) *Chemical Precipitation Tanks*, in which certain chemicals are used as coagulants to help the natural process, and these efficiently remove suspended solids and clarify sewage by coagulation of a large part of colloids.

(4) *Septic Tanks* :—In these, sedimentation and sludge digestion are sought to be done in the same chamber.

(5) *Imhoff Tanks* :—These are two-storey tanks, one above the other, so constructed that the sedimentation takes place in the upper chamber and the sludge is collected and partially digested in the lower chamber.

(6) *Secondary Settling Tanks* :—In these, instead of raw sewage, the effluent from either activated sludge process or

from trickling filters is clarified. Those used for the effluent from trickling filters are called *Humus Tanks*.

Sedimentation tanks may be of (1) The horizontal flow type, (2) Upward or vertical flow type, or (3) Radial flow type according to the manner in which the sewage is directed to flow in the tank.

Plain Sedimentation Tanks :—These are almost invariably used on every sewage purification work. Their object is to reduce the load, and simplify the subsequent treatment whether of dilution, filtration or æration.

Detention Period is the time that elapses between the moment that a particle of liquid enters the tank and the moment at which it leaves it, and depends upon the characteristics and the percentage of settleable solids in the sewage, and length and capacity of tank, and varies from one to three hours. Fig. 260 shows typical curves of the percentage of

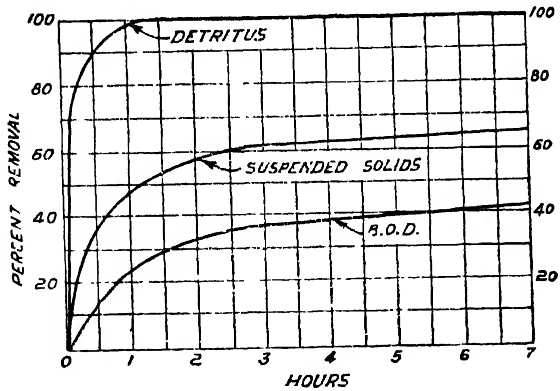


Fig. 260 – Graphs showing percentage removal of grit, suspended solids and B. O. D.

settlement of grit, suspended solids, and the reduction in B. O. D. in plain sedimentation tanks. It will be seen from these curves that the bulk of settlement occurs during the first ½ to ¾ hour, then it gradually slows down, and that after two hours the rate at which it takes place is negligible. Longer detention period might cause septicization of the organic matter, particularly in the hot climate like that of our country.

The capacity of the sedimentation tank at peak flow as determined by the detention period should be divided in two or three units and these should be constructed parallel to each other and used one or more at a time according to the fluctuation of discharge. This also facilitates the removal of sludge, if done by hand The depth of the tank varies from 3 m. (10 ft.) to maximum of 5 m. (15 ft.) according to the quantity of sewage to be treated. For rectangular tanks the length should be 2½ to 3 times the width.

Shape:—Upon this depends the route of the flow from the inlet to the outlet. The shape is usually oblong rectangular, but square tanks are not uncommon. Recently circular or radial flow tanks to suit the rotating type mechanism carrying scrapers have been popular as their efficiency is greater than that of the transverse flow types.

Velocity:—This should be such as to give time for the smallest particle to settle. It must also be uniform for all fluctuations and uniform at every cross section, with no short-circuiting, and no stagnant pockets. About 0·3 to 0·6 m. (1 ft. to 2 ft.) per minute depending upon the strength of the sewage, would be suitable. The best thing is to make experiments on the particular sewage in a pilot plant and determine the detention period and velocity and then fix the dimensions of the tank accordingly.

Inlets, Outlets and Baffles:—Instead of one large inlet a series of small submerged pipes with elbows at bottom to direct the flow horizontally would be more suitable. There should be baffles in front of them for proper distribution of currents, about 30 cm. (1 ft.) below and about 23 cm. (9 in.) above the surface of sewage, the latter serving as scum boards also and for preventing movements of floating material. 2 or 3 submerged overflow baffles in addition, placed across the direction of the flow, extending upwards a few meters (feet) above the bottom will keep the sludge undisturbed, and also break up bottom currents.

Similarly, a number of outlet openings, either round holes, or vertical narrow slots spread over the entire width in a baffle plate at the end of the tank would contribute to maintain a uniform velocity. A better arrangement is to provide a floating arm for removing the supernatant liquid, and also emptying the tank.

The floor of the tanks should slope down gently say, at 1 in 24 towards a sump at the inlet end. A sludge-draw-off pipe is laid from the sump with a sluice valve. If the tank is to be cleaned by hand it is first emptied by opening a valve at the outlet end. Then the sludge collected on the floor is pushed down the slope by wooden scrapers into the sump, and discharged through the pipe from the sump.

The capacity of the tank should be equal to the volume of flow over the detention period of 1½ to 2 hours plus for the sludge which would accumulate between the cleaning intervals. The latter may be a week or 10 days when hand cleaned, and two hours when mechanically cleaned.

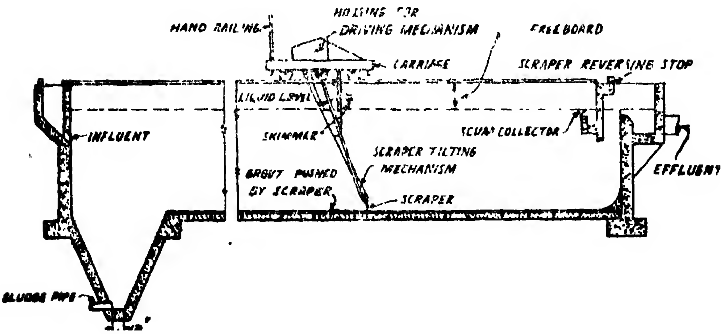


Fig. 261 – A longitudinal section of a sedimentation tank of horizontal type with mechanical sludge remover.

In some tanks hopper bottoms are provided in the centre towards which the floor is made to slope from all directions.

On account of the steep slope of the hopper, sludge accumulates there and can be withdrawn under hydrostatic pressure by opening a valve without interrupting the working of the tank.

Uniflow Settling Tank :—The latest improvement in the design of the plain sedimentation tank has resulted in increasing its efficiency considerably. The main disadvantages of the conventional settling tank is short-circuiting of the flow in some part, resulting in creating dead pockets at other places, especially at corners. Both these are avoided in the construction of the uniflow tank, illustrated in Fig.262 diagrammatically. Its main features are : (1) Submerged inlet at one end, protected by a deep baffle, which almost reaches the bottom, on top of the sump (2) The bottom of the tank is sloping steeply upwards away from the inlet end, so that the depth of the tank goes on decreasing in the direction of the flow, and is barely a metre or so at the

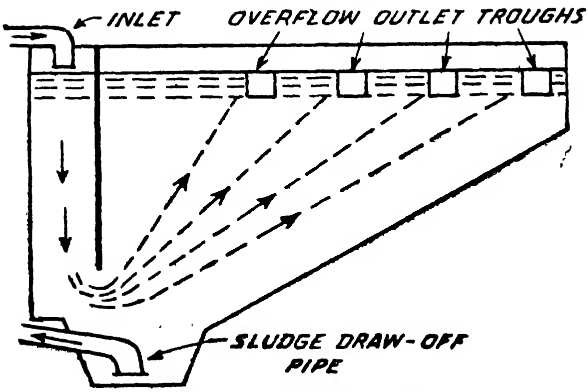


Fig. 262 – Uniflow Settling Tank.

end. (3) There are a number of shallow troughs at the surface across the tank at right angles to the flow for carrying the effluent away.

The action of the tank is like this : On account of the rising sloping bottom surface, and decreasing depth of flow,

. e. decreasing pressure, the flow is streamlined as shown by the dotted lines. It is further helped by the surface troughs which readily lead away the effluent, so that dead pockets are avoided. The flow has to travel through greater depths to reach the nearer trough, thus short circuiting also is eliminated. The sediment slides down the steeply sloping bottom into the sump, from where it can be easily removed under great hydrostatic pressure through the sludge pipe. The average depth of the tank is about two metres, unlike that 3·5 to 4·5 m. (12 to 15 ft.) in the conventional tank. This results in considerable economy in construction.

Mechanical Sludge Collection :—In modern sedimentation tanks, mechanical sludge scraping and collecting devices are provided. These have increased their efficiency. Fig. 261 shows a longitudinal section of a horizontal flow rectangular tank with link-belt sludge remover with its floor sloping towards a hopper bottom pit at the inlet end. The sewage is admitted through an opening about 0·6 m. (2 ft.) below the liquid surface. A travelling carriage resting on rails laid on the top of the longitudinal sides is worked by electric power and has got a scraper with steel blades resting on the bottom of the tank. As the carriage moves from the outlet end towards the inlet, it scrapes and pushes the sludge at the bottom into the hopper. On its return travel, the scraper is raised off the floor and a skimmer blade is lowered to touch the surface of the liquid so that it gathers and pushes the scum at the top into a pit near the top of the tank at the outlet end from which it is removed by hand. The mechanism works off and on at intervals of 2 or 3 hours.

Fig. 263 shows a longitudinal section of Sifeed sludge collector manufactured by M/s Dorr Company of New York. It is circular in plan with a dished bottom sloping towards the centre where a sump is provided for the collection of the sludge. Sewage enters through the ports at the top of a vertical pipe and flows radially towards the circumference, diffused on its way by a circular baffle with perforations in it and flows over a weir into the channel around the circumference of the tank. The raking mechanism is attached to and rotates with a central drum concentric with the central pier, deriving the power from an electric motor mounted at

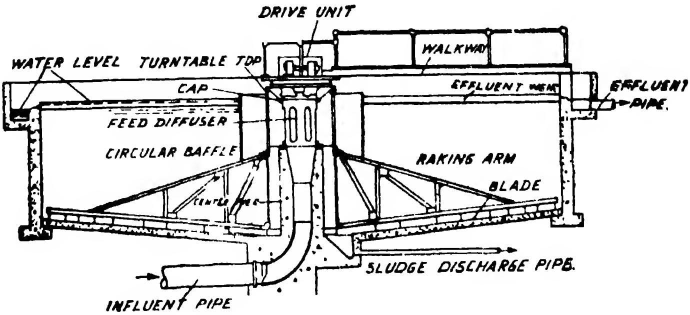


Fig. 263—Longitudinal section of Dorr Sifeed radial flow sludge collector.

the top. The turn-table is carried on rollers. The arms have blades attached to their bottom which scrape the sludge and push it towards the sump. Tanks ranging from 7·5 to 100 m. (25 ft. to 325 ft.) in diameter with rotating arms have been manufactured.

Fig. 264 shows a cross section of a pyramidal tank on the principles of Dortmund tank. It was once very popular, and a large number of them have been in existence working efficiently. Its essential features are that firstly, it is a vertical flow tank. The inlet pipe is extended to nearly one-third the depth, where, in order that it should not disturb and churn the already settled sludge at the bottom, it is given an upwards bend. At this place the velocity is reduced to about 2 cm. (0·09 ft.) per sec. This causes the particles to settle down quickly. The sides of the hopper should be smooth and inclined at no less than 55° to the horizontal so that no sludge will lodge on them. Desludging is done under hydrostatic pressure by means of an inclined pipe by opening a sluice valve from the top. The disadvantages are :—(1) the incoming sewage cannot be evenly distributed over the whole area especially if the diameter is large. (2) The depth of the tank being considerable, the cost of excavation, particularly, if there is rock, becomes prohibitive. To overcome this disadvantage, shallow multiple hoppers are provided. But this arrangement requires separate pipes for sludge

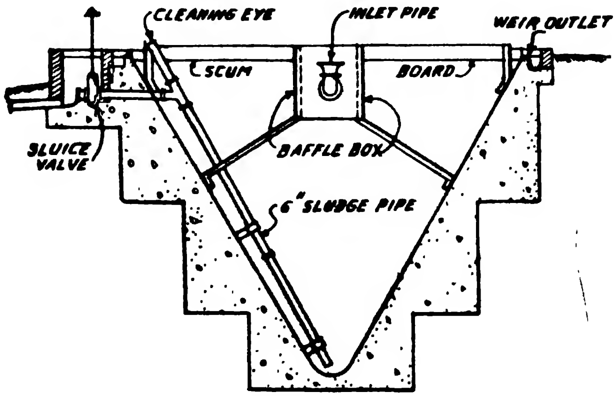


Fig. 264—A pyramid-shaped vertical flow Dortmund Tank.

draw-off, one for each hopper, and ultimately makes the construction more complicated and costly.

Chemical Precipitation :—When certain chemicals are added to sewage, they produce insoluble or slightly soluble 'floc', or precipitates, which adsorb, or gather together very small particles including colloidal ones to form large size clumps or floc and these while sinking down carry with them other particles to the bottom.

The chemicals commonly used are lime, alone or with ferrous sulphate orferric chloride, copperas, sulphuric acid, ferric sulphate or ferric chloride, etc. The dosage depends upon the character and strength of the sewage and the degree of clarification required.

Dissolved solids remain practically unaffected. The effluent is fairly clear with very small turbidity due to some colloidal matter still remaining. With reasonable dosage of chemicals 60 to 85 per cent of suspended matter and about 35 to 60 per cent of B. O. D. are removed. Thus this treatment gives results midway between plain sedimentation and biological purification, except that the solids in solution remain practically unchanged and can be removed only by the biological methods.

The advantages claimed are :— (1) Simplicity of operation. (2) Saving in space, and (3) More rapid and thorough clarification than by plain sedimentation. The disadvantages are :—(1) High cost of chemicals, especially if they are to be imported from foreign countries as in ours, (2) Skilled attendance is required, (3) Accumulation of large quantity of sludge, which presents great difficulty in disposal, and (4) On account of the dissolved impurities still remaining in the effluent, the latter is putrescible.

Chemical precipitation is suitable (1) where only a seasonal or occasional treatment of sewage is required such as at hill stations or at a religious fair where people congregate temporarily, (2) where the existing treatment works require some temporary relief till their extension is made, (3) for treating certain industrial wastes which do not respond to biological treatment or, (4) where plain sedimentation is ordinarily sufficient, but during summer when the river flow dwindles down and there is risk in discharging effluent from sedimentation tanks.

Activated carbon, which though not strictly a chemical, when added to sewage is found to improve conditions in respect of control of odour, improvement in sludge digestion, reducing scum, and also improving the quality of sludge. This is due to the adsorptive properties possessed by it which expose a very large surface area to colloidal matter.

Mechanical Flocculation :—Of late flocculation is accelerated by the use of mechanical equipment introduced in the chamber where chemicals are mixed. It is in the form of paddles which produce a series of eddies through which all the liquid has to pass, and recirculate the floc already formed by the chemicals. This has been found to be an economical and successful operation. Mechanical flocculation without chemicals has also been tried, but it is still in the experimental stage.

Magnetite Filter:—This is not the usual kind of filter, like sand filter, or trickling filter, which depend upon biological action for the purification of sewage. The action of a magnetite filter is purely mechanical and therefore it is classed under sedimentation tanks and dealt with in this chapter. There are two types: upward flow and downward flow. The latter is more suitable for sewage purification, and is illustrated in Fig. 265 by a vertical cross section. It consists of a circular masonry tank, in which at about one-third of its depth above the bottom, is placed a 8 cm (3-in.) bed, *b*, of finely ground particles of magnetite iron ore, of 0·80 to 0·85 mm. size of a fine mesh screen, *a*, of phospher-bronze for avoiding both rusting and magnetic effect. Sewage, which has been already settled in a sedimentation tank, or passed through a trickling filter is admitted from the influent channel, *c*, into the tank through holes in the tank wall; it then passes down through the magnetite sand, and finally through the opening *d*, at the bottom to the effluent channel after purification. While passing through the filtering material the suspended solids are arrested in the form of a deposit on the top of the bed. When sufficient deposit accumulates, and offers resistance to the flow, and as a result, the water level rises by about 10 cm. (4 in.), a float operates the cleaning mechanism. The latter consists of a bottomless round box containing a pump, *e*, in the centre, and an electromagnet, or a solenoid, *f*, round the periphery. The float sets the

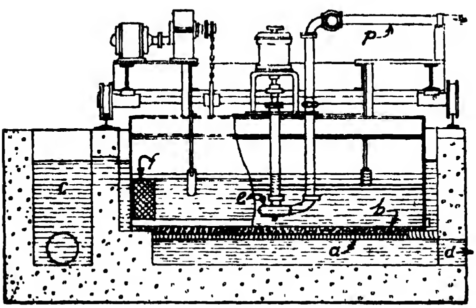


Fig. 265 – Magnetic filter. *a*-Phospher-bronze fine screen. *b*-Magnetite sand. *c*-Influent channel. *d*-Effluent port. *e*-Pump. *f*-Solenoid. *p*-Wash water pipe.

drive unit at the top in motion, which causes the box to rotate. The solenoid is also alternately magnetised and demagnetised. When magnetised, it attracts the magnetite sand, which then moves up with a jerk, and when demagnetised again, it falls down on the screen by gravity. At the same time, the pump comes into action, and by removing the dirty water through the pipe, *p*, lowers the level in the tank, so that water from below is sucked up through the filter. These two motions, viz. that of the magnetic particles moving up and down, and the water rising up through them at the same time, effectively wash the filter. All this takes place automatically as soon as the level of water rises a few inches.

At the filtering rate of 100 to 125 lit./sq. m. (2 to 2·5 gallons per sq. ft.) per minute, about 20 to 40 per cent of the suspended solids are removed in addition to those already removed beforehand by sedimentation.

Questions

(1) What is the Stokes' law of sedimentation of particles and what amendment did Hazen later suggest?

(2) Define detention period. Why does it sometimes differ from the flow-through time?

(3) Design a grit chamber for treating average daily quantity of 30000 cu. m. (6,500,000 gallons) and a maximum of 80,000 cu. m. (17,750,000 gallons) with a detention period of 30 seconds and average velocity of 0·3 m./sec. (1 ft. per sec.).

(4) What are the advantages and disadvantages of chemical precipitation? Under what special circumstances would it be more suitable?

(5) Compare the results in respect of removal of suspended solids, bacteria and B. O. D. from a plain sedimentation tank of good design working on continuous flow system with 10 hours detention and a chemical precipitation tank using reasonable dosage of chemicals. Why is there not much improvement in the removal of B. O. D.?

CHAPTER XXIII

SEPTIC AND IMHOFF TANKS

SEPTIC and Imhoff tanks both work on the same principles. They are not mere sedimentation tanks, but they also digest part of the sludge to a certain extent in addition. The action is both of precipitation and biological purification. The latter has been already explained in detail on page 308.

In a septic tank the effluent is always in contact with the sludge at the bottom and the scum at the top, and the sludge is continually undergoing decomposition in which gases are produced. Some of these gases are dissolved, and some, which rise from the sludge, buoy up particles of organic matter to the surface, to form the scum. Some of these are carried by the effluent. The effluent is therefore in a septic condition.

An Imhoff tank on the other hand, is a two storey compartment tank, in which the sludge is stored in the lower compartment and so, the gases produced do not so much affect the quality of the effluent.

The septic tank is usually a rectangular tank with its length 3 to 4 times the width, and depth varying from 1·5 to 3 m. (5 ft. to 10 ft.) or more. The detention period is from 10 to 15 hours, and in addition to this, considerable capacity for sludge storage also has to be provided; therefore, the tank requires a large capacity. Thus the size of a septic tank is comparatively very large. The bottom slopes down towards the inlet as in a sedimentation tank. In other respects also the same considerations for inlets, outlets, baffles, scum board, etc. as in the case of sedimentation tanks hold good also for septic tanks. To exclude flies and offensive odours a septic tank requires to be covered. A septic tank must be periodically cleaned of its accumulated sludge.

Septic tanks are very convenient and useful for small private houses, isolated establishments, such as a hotel or an institution like a hospital or a small group of houses. But when sewage of an entire town is to be dealt with, it has the following disadvantages :—

(1) The size required is too large and uneconomical.

(2) Their action is erratic. Comparison of analyses of effluents, not only from different tanks, but also from the same tank at different times shows a very wide fluctuation so far as suspended solids and B. O. D. are concerned, due to the fact that whenever septic action is violent, the gases given off stir up the liquid and tend to mix the particles of organic matter with the effluent.

(3) The effluent is dark and foul-smelling with high B. O. D. and is often worse than the influent.

(4) A septic tank requires a cover for the reasons mentioned above, which adds to its cost.

The use of septic tanks is at present confined to small, private installations of isolated buildings, to which however, they are admirably suited, as the effluent is small, and it is very easy to dispose of either by land treatment or dilution.

This latter aspect makes them eminently suited to our rural conditions.

The principal advantages of a septic tank are :—

(1) The sludge is relatively small, most of it being liquefied and digested. It is about 30 per cent less in weight and about 60 per cent less in volume than that from a sedimentation tank, as it is compacted at the bottom.

(2) For small installations the cost is not much—is at least within the means of private householders.

(3) Very little attention and skilled attendance is required.

(4) There are no mechanical moving parts.

(5) If some satisfactory arrangement is made of removing part of the sludge, occasionally under hydrostatic pressure

without disturbing the working of the tank, once installed, it is expected to give long, care-free service.

When sewage is discharged into a septic tank, the particles, both mineral and organic, which are lighter than water, rise to the surface to form "scum" and those which are heavier sink to the bottom to form "sludge". The organic matter at both these places is attacked by the myriads of anærobic micro-organisms. The scum, which is several cm. (in.) thick, is their main seat. However, there are a few also in the sludge. A constant interchange goes on between them. A minute bubble of gas is formed by the decomposition; presently it breaks away and buoys up a bit of sludge to join the scum. The particles, whether rising or falling, are at the same time borne forward by the slow but continuous motion of the liquid which is drawn by the outlet at the other end of the tank.

Principles of Design of a Septic Tank:—From the above discussion it will be seen that the following are the principles of design of a septic tank :—

(1) Air and light should be excluded from it as far as possible. This is not absolutely necessary. But when they are excluded, the anærobic action is more effective. For accomplishing this, the tank is built underground and is covered with either slabs of stone or R. C. C. or an arch.

(2) The positions of outlet and inlet pipes should be so arranged, and in general the design should be so made that the scum at the surface and the sludge at the bottom, where the bacteria are cultured are the least disturbed. For doing this (i) The inlet and outlet pipes are bent down almost upto the mid-depth of the tank at which level the inlet pipe discharges the raw sewage and the outlet pipe draws the digested sewage. (ii) The tank is purposely made deep and of large capacity, so that when the incoming sewage meets a large body of water, its velocity is at once deadened. (iii) A scum board, consisting of a thin slab of slate or flagstone is often suspended from the top into grooves in the sides of the tank to dip about 25 cm. (9 in. or a foot) below the surface. This prevents the movement of the scum by the wave action,

(3) To allow the raw sewage to remain as long as possible inside the tank for being digested. A minimum detention period of 12 hours is required in small domestic tanks, where the sewage comes in a fresh condition and therefore requires a longer period for being digested. (The sewage in the case of large towns while passing through long sewers is subjected to a process of continuous disintegration and thus reaches the purification works in a finely divided state). To accomplish this (i) The tank is made long, narrow and deep so as to increase its length of travel. (ii) The tank is divided into two or three compartments by means of partition walls and a zigzag or circuitous course is given to the flow from one end to the other. Thus the raw sewage first falls down through inlet pipe in the first compartment, then it rises upwards in the second compartment through the vents at the bottom of the partition, then it falls again in the third, to rise again through the outlet pipe.

(4) The cubic capacity of the tank should be such as would leave adequate space at the bottom for the sludge of the mineral matter to be deposited, and to afford slight flexibility to the tank so that if the number of users of the privy sometimes increases, the tank should be capable of digesting additional sewage. Generally a minimum of 100 lit. (3 cub. ft.) per head is provided in small domestic tanks, and 75 lit. (2½ cub. ft.) per head in tanks for large establishments.

(5) There should be a space of 15 to 25 cm. (6 to 9 in.) above the surface of water and below the bottom of the slab in which the gases should collect. A ventilating pipe* of 75 mm. (3 in.) diameter and a manhole on the top of the deepest chamber or compartment for the facility of emptying the tank, whenever found necessary, are other requirements.

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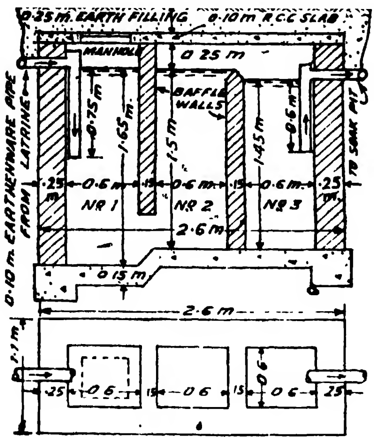
* Authorities are divided on the point of providing a vent pipe. Some are of the opinion that introduction of a vent pipe retards bacterial action and assists in the formation of scum beyond the amount considered necessary. According to them the gases collected in the space above the liquid exert pressure and assist the necessary outflow action. However it is safe to provide a vent pipe as it would expel the explosive marsh gas.

The site should be as far away from the house as possible on the leeward side and rain water flowing on the surface should be excluded from it. The outer walls should be of 25 cm. (9 in.) brick-in-lime or cement and inner partitions of 13 cm. (4½ in.) with the floor of 15 cm. (6 in.) concrete, all the inner surfaces being plastered with cement. The width should be narrow, still not less than 0·6 m. (1¾ ft.) to enable a man to enter and do repairs when necessary.

Figs. 266, 267 show a typical septic tank embodying the above principles. It is designed to serve about 15 persons. It is 1·8 m (6 ft.) long and 0·6 m. (1¾ ft.) wide on the inside. The inlet and outlet pipes are both of 100 mm. (4 in.) diam. stoneware, with open T-junction at top. The floor of the inlet chamber is 15 cm. (6 in.) lower and there is a manhole cover at its top. The raw sewage from the inlet chamber rises to the top of the middle chamber and falls over the tapered top gently into the third chamber. The partition between the inlet chamber and the middle one is carried upto the roof. This serves as a scum board. This liquid which falls down in the third or outlet chamber rises again and is ultimately carried by the outlet pipe with its mouth at 0·6 m. (2 ft.) below the surface. There is a space of 25 cm. (9 in.) provided for the accumulation of gases above the surface. There is a cover of 100 mm. (4 in.) R. C. C. slab at the top, and above this there is a layer of 25 cm. (9 in) of earth so that from the outside the entire tank is concealed from view.



Figs. 266, 267.

Before starting the use of the tank, it is filled with water.

The following table gives the inner dimensions of tanks which have been found to be suitable by experience :—

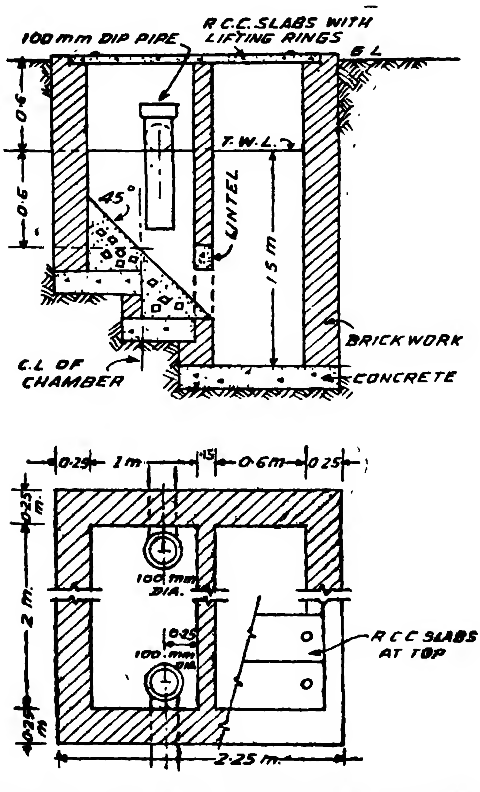
TABLE NO. 23.

No. of Users	Length m.	Breadth m.	Depth below water surface m.	Cubic contents cu.m.	Capacity per head lit
10	1·65	0·60	1·35	1·34	134
15	1·8	0·60	1·50	1·62	108
20	1·8	0·60	1·65	1·78	99
30	2·25	0·60	1·80	2·43	81
40	2·75	0·60	2·00	3·30	82
50	3·00	0·60	2·15	3·87	77
100	3·75	1·0	2·15	8·06	81

The figures of the depth given above are those of the actual depths of water. A space of 15 to 30 cm. (6 in. to 1 ft.) should be provided above the water surface for accumulation of gases. The minimum capacity of a septic tank should be that for 10 persons given above.

The Privy :—The privy suitable for a septic tank should have a closet pan like one of those shown in the figures on pages 48 and 49 either of Indian or European type with P or S trap connected to it. In that case the privy is just like the one on water carriage system and may be built even inside a house close to a bedroom. Of course the septic tank should be as far away as possible as already mentioned, and the drain connecting the privy and the septic tank should be of 100 mm. (4 in.) stoneware pipe with the minimum fall prescribed, viz. 1 in 40. The entire house connections should be made according to the rules for house drainage.

Disinfectants :—As far as possible disinfectants should not be used beyond very small quantities which may be absolutely necessary, since they kill bacterial life. Soap and grease are also harmful, since soap has a deleterious effect on bacteria, and grease is likely to coagulate at the surface in a hard mass, disturbing the scum. However, in Indian homes soaps are generally used sparsely even in bath rooms and to that extent they are not harmful.



Figs. 268, 269 – Vertical section and plan of an improved septic tank.

An Improved Design of a Septic Tank:—The following design based on the principles recommended recently by the British Ministry of Works is illustrated in Figs. 268, 269. The septic tank shown in it is suitable for a maximum of 20 persons. The special features are: (a) Two separate compartments are formed, one for the sewage and the other for the deposition and digestion of sludge. This is the basic principle involved in the design of an Imhoff tank. The result is that unlike in the ordinary designs of septic tanks sewage does not remain constantly in contact with sludge which is continually undergoing decomposition. Besides, the sewage chamber is very shallow with mean liquid depth of about 60 cm. (2 ft.) (b) The floor of the sewage chamber is very steeply (45°) sloping, leading the arrested solids of sludge through one long, or a number of short, narrow slots in the partition wall to the sludge chamber. (c) A vent pipe is provided on the top of the sludge chamber to allow gases to escape to the atmosphere, and means provided for opening the top and inserting a suction pipe so that sludge can be removed. In the original design a vent pipe is not provided, but instead, it is recommended that R. C. C. cover slabs should not fit quite closely, in order to give ventilation to the tank and to allow escape of sewage gases. But for tropical climates a vent pipe is desirable. (d) The inlet and outlet pipes are both placed in the sewage chamber, so that the sludge in the other chamber is not disturbed by the movements. Such septic tanks with suitable increase in their capacity can be safely built to take care of the sewage of 20 average size families.

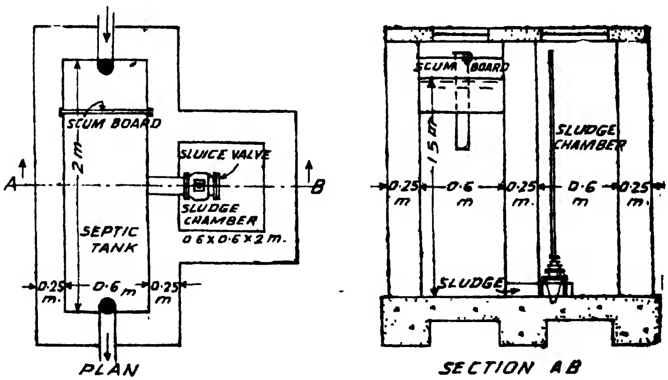
Products of Digestion and Their Disposal:—These are three: (1) Gases, (2) Effluent, and (3) Sludge.

(1) **Gases** are evolved as a result of bio-chemical action by which complex organic substances in the sewage are resolved into their simple molecules or elements, such as CO_2, SO_2, CH_4, H, O, N, etc. They are partly dissolved in the effluent and partly pass off to the atmosphere through ventilating pipes. So the question of their disposal does not require any special effort.

(2) **The Effluent**:—This consists of the original water used for ablution and flushing, urine, and the moisture in the night soil, plus water produced by the decomposition, or putrefaction of the solid organic matter, which as we have already mentioned, is liquefied in the septic tank. It also contains the above gases dissolved in it, and undigested or partly digested particles of organic matter, both in solution

and suspension, a few particles of mineral matter, and a large number of bacteria, some of which may be pathogenic. If this effluent is allowed to flow, without further treatment, in street gutters or, admitted into streams having flows less than at least 200 times the flow of sewage, it will not only produce bad smells and attract flies, but will form sludge banks in the stream, and create conditions dangerous to public life. Hence it must be suitably treated. This secondary treatment is described on the next page.

(3) **Sludge** :—This consists mostly of particles of mineral matter mixed with those of organic matter also, which may have settled down. In the latter a constant chemical change is taking place, by which bubbles of gas are formed in the sludge at bottom, which rise to the surface carrying with them mineral as well as organic particles, which pass out of the tank through the effluent. This action is violent in the tropical atmosphere and has a beneficial result that the quantity of sludge which would otherwise have accumulated at bottom and reduced the capacity of the tank, is much reduced, and it has been found that tanks which require to be cleaned every six months, or at least every year in temper-



Figs 270, 271 – Plan and section of a septic tank with a sludge chamber.

ate climates have been in efficient operation without having occasion to remove the sludge once even in 12 years in India

However, it is a safe practice to provide sufficient capacity in the first instance, for accumulation of sludge at bottom, unless means are provided for removing it occasionally without disturbing the scum. One way of removing it is shown in Figs. 270, 271 in which a special sludge chamber 0·6 × 0·6 × 2 m. (2′×3′×6′) deep is built in continuation of the septic tank, with a 100 mm. (4″) pipe connection at bottom with a sluice valve. When the valve is opened a little for a few seconds, sludge, which is in a liquid condition will flow into the chamber, which may either be collected in a bucket, if the floor of the chamber is kept low, or may be pumped by a small hand pump. It smells much less than the putrefying black mass often accumulating in street gutters.

Disposal of Sludge:—As the quantity of sludge from small private septic tanks is very small its disposal is very easy. The simplest and most economical way is to pour it into a shallow trench—not more than a foot deep in soil to be immediately covered by earth at least 25 cm. (9 in.) thick.

Secondary Treatment of Effluent:—In this the objective is to oxidise the impurities with the help of aerobic bacteria which work only in the presence of oxygen (air). This is accomplished by exposing the effluent to free air. The methods employed are (1) *Filtration*, in artificial filters. (2) *Land-filtration*, (3) *Surface Irrigation*, and (4) *Sub-surface Irrigation* in soakage pits or trenches. The filter is made by constructing a mound 1 to 1·25 m. (3 to 4 ft.) high of large pieces of clinker, over-burnt bricks, rubble, etc. loosely packed, and filled with gravel, sand, etc. supported by barbed wires all round, nailed to vertical posts, in the open air. The effluent is evenly spread on the top, which trickles down, and while doing so comes in contact with free air. This method is not convenient for small private installations as, in order to command sufficient head to spread the liquid above the top of filters, it must be pumped. (2) Land filtration and (3) Surface irrigation, we have already discussed in the chapter on Land Treatment. The only difference is that this is on a very small scale. For land filtration, a porous soil must be available, and must be first ploughed and then mulched from time to time to prevent its pores from being clogged.

Both these methods, though very efficient means of disposal, are unsuitable for small private installations in this country for the following reasons:—

(1) Constant attention is required in cutting off sewage from one portion of land and diverting it to another at regular intervals. The caste prejudices come in the way because none except a person of the sweeper class is to touch it.

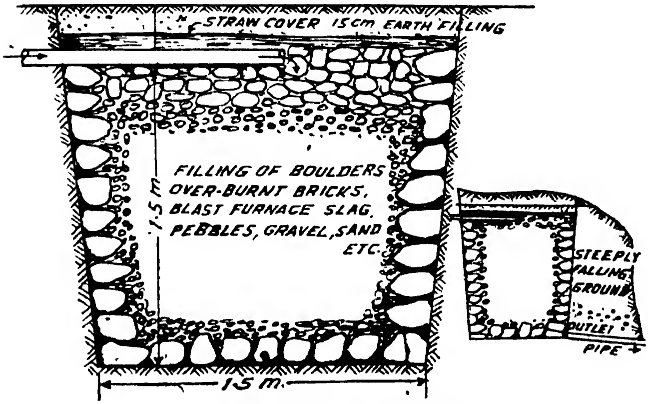
(2) For uniform distribution which is quite essential for success, the land must be thoroughly levelled and lines of more or less impervious drains such as of half-round stoneware pipes laid in concrete with branch stops for facility of of diversion of sewage must be laid at a considerable expense.

(3) Even with such regular well-laid drains, the flow of sewage of small domestic installations being very small, unless some means of storing the effluent in dosing tanks and sending it in flushes, such as by an automatic siphon or a tipping trough are provided, the small flow soaks into the ground just at the head of the drain, leaving the entire area dry. At the head of the drain where it is concentrated, it causes nuisance of putrefaction, flies and perhaps of hook worms. Dosing tanks with either an automatic siphon or tipping trough are shown later in Figs. 277 to 281.

Another very simple and safe method of disposal of effluent from small, private septic tanks is to build a small chamber, say, 0·6 × 1 m. (2′ × 3′) and of the same depth as the septic tank in continuation of it on the outlet side to receive the effluent, which may be pumped by a small 25 mm. (1 in.) hand-pump once a day. As the quantity will be small, if bath room water is not admitted to the septic tank, the labour involved will not be much. This water may be led alongside a green hedge and forced there through a perforated pipe in the form of fine spray. This will result in oxidising the bulk of the impurities by exposure to air. It will be further purified by the surface soil, and the roots of the hedge plants.

(4) **Sub-surface Irrigation**:—For small family installations of septic tanks, a soak-pit or a soak-trench is very

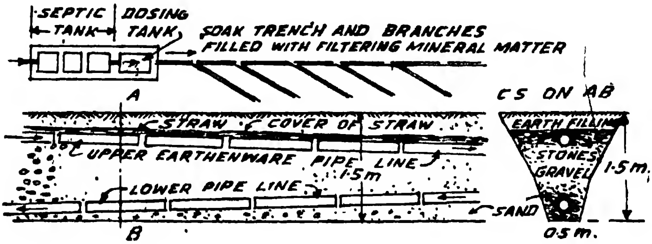
convenient, provided the sub-soil layers are of a porous nature, such as sandy or gravelly earth, soft *muram*, laterite, etc. and if there is no well within about 15 m. (50 ft.) from it. A soak-pit is shown in Figs. 272, 273 suitable for a septic



Figs 272, 273—Soak-pits.

tank of medium size of say, 25 people. It is about 1·5 m. (5 ft.) square at bottom by 2 m. (6 ft) deep excavated with sloping sides so that they will not fall in. It is lined on the sides and the bottom with boulders or overburnt bricks and filled between with blast furnace slag, gravel, etc. very loosely, so as to leave as many voids as possible. The effluent from the septic tank is led in a pipe which pours its contents on the top of the filter in the centre at about 25 cm. (9 in.) below the ground surface. A layer of straw or any other suitable material about 5 cm. (2 in.) thick should be spread on the top of the filter or better still, pieces of Shahabad or other flagstones with open joints, and on this, a layer of loose earth, *muram*, gravel, etc. is spread up to the ground surface. If the situation of the pit is near the edge of a precipitous bank of a *nallah* or a river, an outlet pipe at the bottom as shown in the small-sized sketch in Fig. 273 should be laid so that the water purified by the filter should flow out. The bottom and sides of the pit absorb the water. The unstable gases in the effluent absorb air from the atmosphere through the top layer of loose material and the purification is effected by the ærobic bacteria living in the hollow spaces of the loose mineral material of the filter. Sometimes a vertical ventilating pipe about 75 mm. (3 in.) diam , with its bottom end resting on the loose material at about 30 cm. (a foot) below the surface is provided with advantage.

There is not much difference between a soak-pit and a soak-trench. The latter is a long and narrow trench with sloping sides filled with similar material. Its length depends

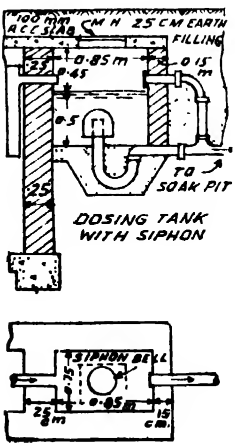


Figs. 274, 275, 276.

upon the kind of the soil and subsoil. If it is loose and porous like sandy or gravelly earth, soft *murum*, or laterite, a trench only 3 to 5 m. (10 to 15 ft.) long, 0·6 m. (2 ft.) wide at bottom, 1 to 1·25 m. (3 to 4 ft.) deep, with sloping sides, may suffice. If it is very stiff soil, even a 15 m. (50 ft.) length may be insufficient. If it is very stiff soil, it is possible to save space by providing branch trenches taking off from the main as shown in Fig. 274. A still better plan would be to lay two lines of 10 cm. (4 in.) earthenware porous pipes with butt joints, one at about 30 cm. (a foot) depth below the surface of the ground giving a slight slope in one direction, and another line of pipes 0·60 or 1 m. (2 or 3 ft.) below it in the same trench with its slope in the *opposite* direction as shown in Fig. 275. The pipes should be laid on a bed of sand, and the space between them should be filled with boulders, clinker, gravel etc. and sand. On the top of the upper pipe line a layer of straw or leaves about 5 cm. (2 in.) thick or flagstones with open joints should be spread and on the top of it a layer of loose *murum*, gravel, etc. should be filled up to the ground surface.

The trouble with soak trenches (and also with land filtration and irrigation) is that the discharge from the septic tank which is more or less of the nature of a drizzle, is absorbed by only a small area near the tank, which consequently gets saturated with it, leaving the remaining portion of the trench dry. This can be remedied by storing the effluent in an extra chamber called a "dosing chamber", built in continuation of the septic tank and discharging it in large automatic flashes at intervals by means of either a siphon, or a tipping trough. This has, not only the advantage of more uniform distribution, but it provides a good flush to the drain. If surface irrigation is practised, the flow travels a long distance irrigating a larger area on its way, and the soil gets rest in the interval between the flushes.

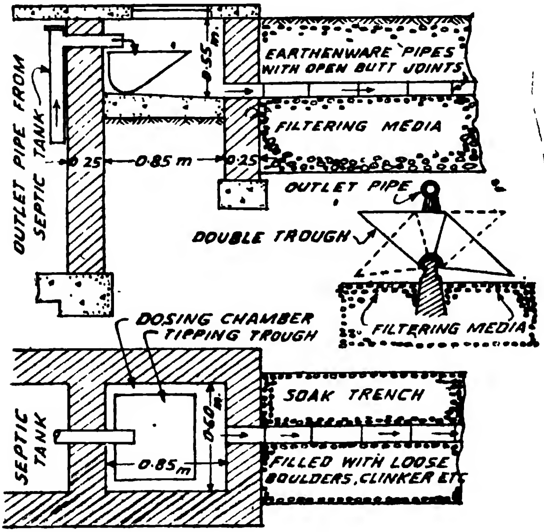
Figs. 277, 278 show an automatic siphon in section and plan respectively. The dosing chamber in which the siphon is installed, is attached to the septic tank. The long vertical wall on the left hand side in Fig. 277 is the extreme end wall of the septic tank carrying the outlet pipe through it. The inside dimensions of the dosing chamber, which is designed for a small family septic tank installation, are 0·75 × 0·85 m. (2 ft. 6 in. × 2 ft. 9 in.) in depth up to the ceiling. The siphon is similar to the one shown in Fig. 154 on page 89 and consists of a bell or a dome with a U-shaped vertical pipe inside it. To the shorter end of the latter is attached a horizontal discharge pipe with a vent pipe attached at some distance,



Figs. 277, 278—Dosing chamber with a siphon.

As the effluent from the outlet pipe of the septic tank falls into the dosing chamber the level slowly rises, until the top of the vertical pipe inside the dome is reached. As the effluent then begins to flow over it. drives out some of the air entrapped inside the dome. This in turn, increases the flow into the vertical pipe and sets siphonic action, until the contents of the chamber above the bottom edge of the dome are emptied with great velocity into the drain.

A single tipper trough is shown in Figs. 279, 280. It consists of a metal trough of diamond-shaped sides in elevation fixed on a horizontal pivoted axle. As the liquid flowing from the outlet pipe of the septic tank gradually fills the trough, it is tipped on one side and emptied by its own weight on account of its peculiar shape. Fig. 281 shows a



Figs. 279, 280—Section and plan of a single trough.
Fig. 281 — Section of a double tipping trough.

double trough made by putting a partition in the centre. When one section is filled and tipped by its own weight, the other section, which is empty, is brought under the outlet pipe, which in turn is filled and tipped. The action is automatic.

The siphon has the advantage that there are no moving parts, and therefore there is nothing to go out of order. However, all these conveniences increase the cost of the installation.

An Aqua Privy, or Village Septic Tank:—One of the cheapest and simplest designs suitable for the purse of the average village house-owner is shown in Figs. 282, 283, 284.

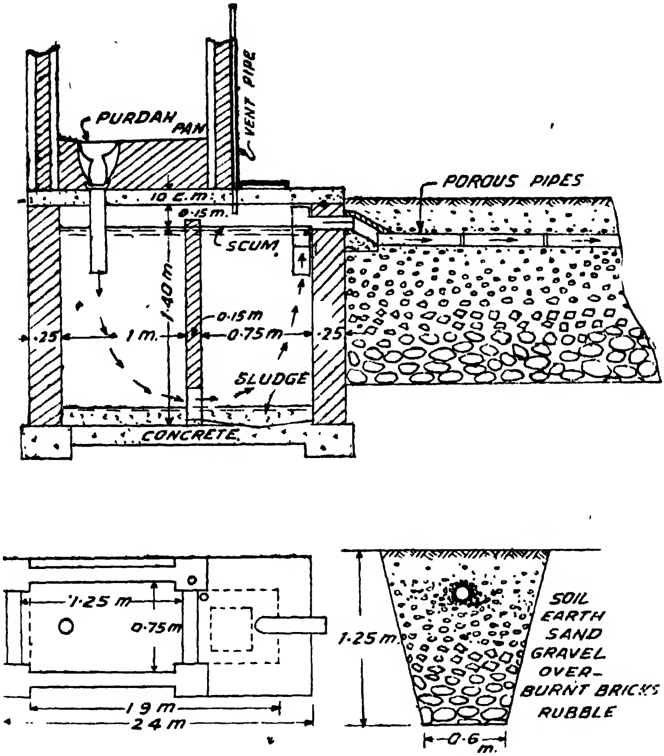


Fig. 282—Longitudinal section of a septic tank with the privy built on its top, and of the soak trench.

Fig. 283—Plan of the septic tank.

Fig. 284—Cross section of the soak trench.

The tank is 1·75 m. (5 ft. 6 in.) × 0 75 m. (2 ft. 6 in.) × 1·55 m. (5 ft.) deep and holds water 1·40 m. (4 ft. 6 in.) deep. Economy is effected by constructing the privy just on its top so that there is some saving in the cost of foundations and also in that of a trap. Instead of a trap, a 100 mm. (4 in.) stoneware pipe 0·60 m. (2 ft.) long is jointed to the bottom of the closet pan, with about 30 cm. (1 ft.) of its bottom end dipping into the water so as to form an effective seal. Ordinary closet plan either of the Indian or European commode type can be used, but where there is scarcity of water, a special

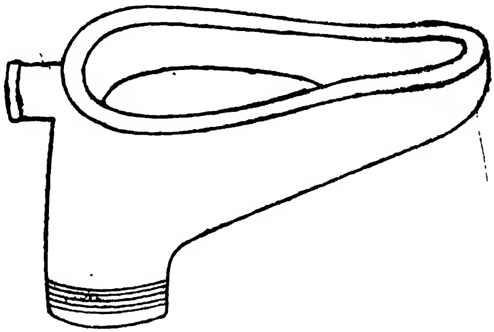


Fig 285—Purdah pan.

pan called a "purdah pan", illustrated in Fig. 285 may be used as shown in the design. This pan has the advantages that it is cheaper, and that as it has two steep slopes on the inside as shown in the longitudinal section in Fig. 282 the excreta slide down with a very small quantity of water. The pan is much thicker and sturdier than the usual one and is white glazed only on the inside.

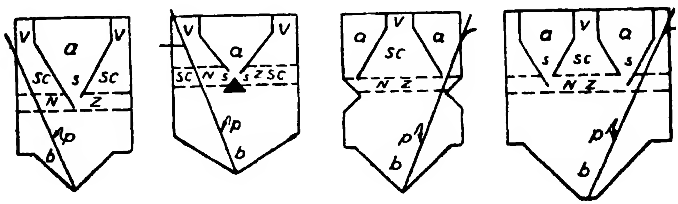
The tank is divided into two compartments by a partition. The latter rises about 15 cm. (6 in.) above the surface and thus serves also as a scum board. There is a hole about 25 cm. (9 in.) square left at the bottom of the partition for the passage of sewage from the first to the second compartment. However, instead of one big hole, 2 or 3 small ones with their bottom level at about 30 cm. (1 ft.) above the floor would be better, since this arrangement will make the sewage spread out and flow through the entire width and leave some space at the bottom for the sludge deposit. A ventilating pipe is provided just touching the outside surface of the privy wall. The floor of the second chamber is made to slope towards the middle and there is a manhole provided on the top to facilitate cleansing of the tank whenever necessary.

Just outside the septic tank there is a soak-trench, 0·6 m (2 ft.) wide at bottom and 1·25 m. (4 ft.) deep with sloping sides (see the section in Fig. 284) and it is filled with non-corrodible, rough-surfaced, hard material of irregular shapes, like rubble, overburnt bricks, furnace clinker, gravel, etc. to form a filter. On the top of the latter a few half-round roof tiles are laid in a sloping line to guide the effluent away. However, a dosing tank with an automatic siphon or a tipping trough is better.

A privy of the above type with the septic tank just below it, should be away from the house.

Imhoff Tanks

The Imhoff tank was first developed by Karl Imhoff in Germany, as an improvement over the septic tank. The



Figs. 286–289—Cross sections of different forms of Imhoff tanks.

a—Sedimentation tank; *b*—Sludge chamber; *s*—Slot; *sc*—Space for scum; *vv*—Gas vents; *p*—Sludge withdrawal pipe. Horizontal dotted lines indicate neutral zone, NZ.

patent rights for it have already expired. The principles on which it works are illustrated in Figs. 286–289 in which *a* is a sedimentation tank. Sewage enters in it at one end through a submerged inlet and flows out of it very slowly through a submerged outlet at the opposite end. While doing so the solid particles precipitate and slide down the steeply sloping walls at the bottom, and drop into the sludge chamber, *b*, through the long gap called 'slot', *s*, at the bottom of the sedimentation tank. In the sludge chamber the solids are attacked by anærobic bacteria and a part of them is converted into liquids and gases. The gases rise and escape through the gas vents, *vv* on both sides or middle of the upper chamber according to the design. Some solid particles also rise with the gases to form scum which accumulates in the space, *sc*. The sludge, when digested, is removed by the inclined pipe, *p*, with its lower end resting on the bottom of the sludge chamber, under hydrostatic pressure when a valve at the top is opened. A typical rectangular Imhoff tank is shown in plan and section in Figs. 290, 291.

Design of an Imhoff Tank :—*Shape* :—An Imhoff tank may be rectangular or circular in plan, and may be of transverse flow type or radial flow type. But usually, circular tanks are used for small flows. Generally there is a long and narrow, rectangular sedimentation tank, at top and below it, the digestion chamber may be either a long, triangular hopper parallel to the upper sedimentation tank, with cross walls or partitions at 6 to 7·5 m. (20 to 25 ft.) intervals with openings in them, or two or three hoppers, pyramidal in shape in cross and longitudinal sections also.

Sedimentation Tank :—This chamber should have a V-shaped bottom with sides sloping at 50° to 60° with the horizontal, with their upper surfaces very smooth. The slot should be 15 to 25 cm. (6 in. to 9 in.) wide, though 20 cm. (8 in.) is very common, and the overlap 15 to 20 cm. (6 in. to 8 in.) The space provided for the collection of the scum should be ample. The gas vents should be at least 0·5 m. (18 in.) wide, and their area at the surface should be 25 to 30 per cent of the surface area of the sedimentation tank.

Detention Period :—This depends upon the character and strength of the sewage. Indian sewages are generally strong on account of insufficiency of water supply. Hence the rate of surface loading should be between 25000 to 35000 lit./sq.m. (500 and 700 gallons per sq. ft.) per day. The quantity of settleable solids can be roughly calculated by means of an Imhoff cone (page 315) and from it the capacity determined, or better still, preliminary experiments should be made in a pilot settling tank to determine the time required for settlement of the solids and after making due allowance for the shallow depth of the pilot settling tank, an idea of the working detention time gained for the particular sewage. Generally the detention period is 1½ to 2½ hours.

A flow-through velocity not exceeding 0·6 m. (2 ft.) per minute should be allowed. The length of the tank is 3 to 5 times the width,—3 times is very common. A shallow depth is liable to cause disturbance due to wind, temperature difference of water layers, etc. Still, it should be on the shallow side rather than deep, 2 to 2·5 m. (6 to 8 ft.) would be reasonable for normal size tanks.

Both the inlet and outlet should be of the submerged type 30 to 50 cm. (12 to 18 in.) below the water level, and should be designed to produce not more than 0·6 m. (2 ft.) velocity per min. They should have hanging baffles and scum boards in their front, about 25 cm. (9 in.) above water surface and 30 to 50 cm. (12 to 18 in.) below it to minimise eddies at the inlet and prevent scum flowing with the effluent at the outlet. The sewage should leave the tank over a long weir to minimise fluctuations in sewage level.

The inlet and outlet should be capable of being used so as to reverse the flow. This is usually done every two weeks

Figs. 290, 291—(*See opposite page*)

Plan and a cross section along AA of an Imhoff tank. In front of the inlets there is a weir of the full width of the tank, and a little beyond it is a baffle plate also of full width, 30 cm (1 ft.) below and 25 cm. (9 in.) above sewage surface. This arrangement is also provided at the outlet end. The side-slopes at bottom of the sedimentation tank, are steep, and have upper surfaces smooth so that solid particles easily slide down and fall into the sludge chamber. There are channels provided on both sides of the tank for facility of reversal of flow once in two weeks. The inclined sludge withdrawal pipe is extended to the top for the facility of rodding, flushing or even pumping sludge from the bottom. There are two hopper chambers for sludge each provided with its own sludge withdrawal pipe. The gas is collected at the centre in an air-tight tank (not shown). The dotted lines with arrows show the course of flow when the flow is reversed.

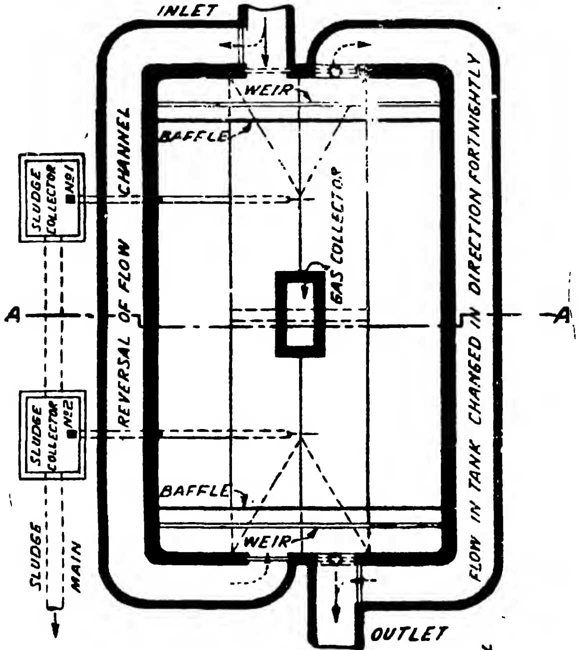


Fig. 290.

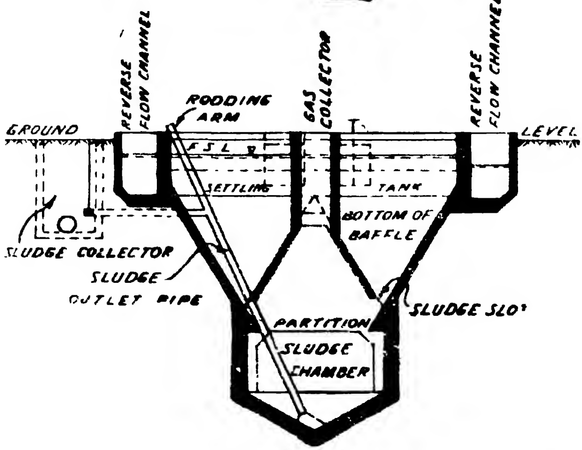


Fig. 291.

Figs. 290, 291—Plan and section of a typical Imhoff tank.

or so to equalise the deposition of sludge in the digestion chamber which otherwise tends to deposit in greater quantities near the inlet, and less as the sewage flows forwards. There should be a central walk-way at top for inspecting and cleaning the tank, every part of which, should be easily accessible.

Digestion Chamber :—The capacity of this chamber is an important consideration in the design of Imhoff tanks. Many a tank has given trouble from foaming for lack of adequate capacity. It depends upon the average working temperature, the quantity of settleable solids in the sewage, and the frequency of sludge withdrawal. At temperatures above 15°C (60°F.) the bacterial activity is vigorous, and therefore, digestion, rapid. The capacity would depend upon the number of days during winter when the temperature would be low, so that the decomposition may be either sluggish, or at a stand-still. The sludge therefore should be stored during this period for which the necessary capacity is required. Generally, a two months' storage capacity should suffice for this country, especially in the southern part of the country, where the winter is not severe, this should prove ample. A capacity of from 50 to 75 lit. (2 to 2·5 c. ft.) per capita is provided in Europe. In America it is slightly less. With the average high temperature prevailing in this country 25 to 35 lit. (1 to 1·25 c.ft.) per capita should be sufficient. A strong sewage obviously contains large amount of solids, and the frequency of sludge-withdrawal depends upon the efficiency of the digesting chamber, since it is undesirable to draw off raw or undigested sludge.

The effective capacity of a digestion chamber is the volume 45 cm. (18 in.) below the bottom of the slot. The space within this 45 cm. (18 in.) is called the neutral zone, and sludge or scum should never be allowed to reach this zone.

A hopper at the bottom formed by the sides sloping down at 30° to 45° with the horizontal, is convenient for collecting the sludge, compacting, and also withdrawing from the lowest level. But this is not necessary. There are tanks in use with a flat bottom also. The greater the depth the more compact becomes the sludge, but for economic reasons the overall depth may be 6 to 10 m. (20 to 30 ft.)

Sludge-withdrawal:—The inclined pipe for withdrawing the sludge with its lower end resting at about 25 cm. (9 in.) above the bottom of the digestion chamber should be of 15 to 20 cm. (6 to 8 in.) diameter. Its horizontal branch, on which a sluice valve is mounted, should be at 1·25 to 1·5 m. (4 to 5 ft.) below the surface of liquid in the sedimentation chamber to exert sufficient hydrostatic pressure for sludge-withdrawal when the valve is opened. The main pipe should go straight to the top for inspection, flushing or cleaning. If there are a number of hoppers, each one should be provided with its own sludge-withdrawal pipe. Only a small quantity of sludge should be drawn at a time, leaving enough ripe sludge in the chamber for seeding purposes. If there is one long trough at the bottom i. e. if there are no partitions in the sludge chamber, pipes should be provided at intervals of 6 to 8 m. (20 to 25 ft.) for withdrawing sludge.

For facility of fitting a metal dome for gas collection, ledges should be provided as shown in Fig. 290.

Maintenance of an Imhoff Tank:—A new Imhoff tank should be put into service in hot weather season. An indication that an Imhoff tank is giving satisfactory service is the absence of scum on the surface of the flow channel. At least it should be very small in quantity. It should be daily collected and put into the gas vents. The gas vent should be daily stirred by means of a rod to release any bubbles of gas sticking to the scum. The scum should never be allowed to get hard. It should be loosened every day. The sloping surfaces on the sides of the slot should be scraped by means of a long-handled squeegee from the walk-way, and the slots kept free from any obstructions. The sludge level should never be allowed to reach the neutral zone.

Troubles from Foaming:—An Imhoff tank is often liable to give trouble from foaming, when large quantities of scum mixed with foam rise and overflow into the sedimentation tank. This is accompanied by very disagreeable odour. Foaming may be caused by :—

(1) Insufficient capacity of the digestion chamber.

(2) Violent biological action causing gases to be evolved which buoy up undigested particles of organic matter.

(3) Fermentation caused by high acidity due to industrial wastes, or unbalanced volume of raw sludge.

(4) Soaps used in large quantities to rectify hardness of water supply, by the consumers.

Measures to Control Foaming :—(1) Adding hydrated lime to concrete acidity. (2) Drawing off sludge more frequently. (3) Seeding with properly digested sludge from an efficiently working tank, or putting a truck-load of horse manure into the digestion chamber. (4) Allowing the tank to rest for a few days.

Imhoff tanks have never been popular in England. They have not so far been tried in this country. The modern trends even in Germany and America where hundreds of them have been in successful operation are to use them for partial digestion of sludge, and to complete the process in separate digestion tanks. With this end in view the capacity of digestion chamber is recently reduced to half of what the practice allowed so far.

Separate sludge digestion tanks are discussed later in this volume.

Mechanical Imhoff Tank :—Messrs Dorr & Co. of New York have developed and patented a mechanical Imhoff tank called 'Clarigestor' 5 to 12 m. (15 to 40 ft.) in diameter suitable for towns having 10000 to 25000 population. It is a two-storey tank as usual, but instead of hopper bottoms both the upper and lower chambers have concrete dished bottoms. The sewage enters the sedimentation chamber through a pipe having an inlet at the centre of the hopper chamber, and flows radially over a circumferential weir and is collected by an effluent channel. During the course of its flow the sludge is deposited on the bottom of the upper chamber.

Instead of a slot there is a trap door at the centre which allows the sludge to drop down into the sludge chamber, but prevents entry of sewage or gases from the bottom. A vertical shaft driven by power in the centre has revolving arms attached to it at four different levels. The upper arms carry skimming blades for collection of the scum and are near the

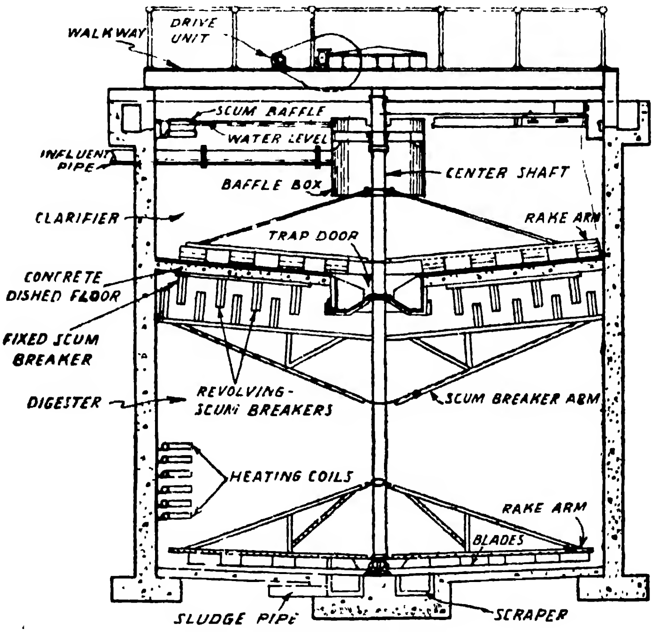


Fig. 292 — Dorr clarigestor.

surface of sewage. The arms at the next place are near the floor of the sedimentation chamber with blades to scrape raw sludge deposited there and to push it into the central trap door. The third place is a little below the ceiling of the sludge chamber with vertical blades where the arms revolve between the fixed hanging blades attached to the ceiling to break the scum which collects there, and the fourth and lowermost place of arms is at the bottom of the sludge chamber for raking and stirring up the sludge, which promotes its digestion. A gas dome at top collects the gas, which may be utilised for heating the sludge chamber. A few heating coils are shown on the left hand side near the bottom. A sludge withdrawal pipe is at the lowest level in the sludge chamber.

Advantages claimed are : (1) Less depth on account of the elimination of hopper at bottom. (2) Skimming the scum, squeezing the sludge, breaking scum, etc. is all done continuously by mechanical means. (3) Digestion of sludge is rapid and more perfect. (4) More gas is released on account of the churning action.

Design of an Imhoff Tank

Example No. 21 :—Design an Imhoff tank for treating the sewage on the separate system of a town having a population of 10,000, which is supplied with a quota of 150 lit. of water per head per day. Assume detention period of two hours for the sedimentation in the tank, and provide 35 lit. per head capacity in the sludge chamber.

Solution :—Total daily quantity of sewage

$$= 10{,}000 \times 150 = 1500000 \text{ lit.} = 1500 \text{ cu. m.}$$

Capacity of sedimentation tank for 2 hours' detention

$$= \frac{1500 \times 2}{24} = 125 \text{ cu. m.}$$

Assuming a length = 15 m. + 1 m. for partitions in the lower chamber and width = 4·5 m.

Total length = 16 m. and width 4 m. (4·5 − 0·5 for thickness of two partitions).

$$\text{Effective depth} = \frac{125}{15 \times 4} = 2{\cdot}08 \text{ cu. m.}$$

The actual depth will be much more since part of the section will consist of sides sloping at 50° to 60°.

Let us assume that the upper tank to be formed of a rectangle of 0·75 m. depth and a triangle below it of 2·5 m. (See Fig. 293).

Then the capacity of the rect. portion

$= 16 \times 4 \times 0{\cdot}75 = 48$ cu. m.

That of the triangular portion 4 m. wide at

top and 2·5 m. deep $= 16 \times \frac{4+0}{2} \times 2{\cdot}5 \qquad = 80$ cu. m.

Total 128 cu. m.

We wanted about 125 cu. m. This will therefore suit. We shall provide a slot in the centre and two gas vents, one on each side as in Fig. 293. The width of the gas vents must be a minimum of 25 per cent of width of the tank. We shall assume 5·5 m. as the total inside width of the tank and then check the area of the gas vents.

Width of gas vents = 5·5 − (4 + 2 × partition thickness 0 15) = 1·2 m.

$\frac{1{\cdot}2}{4}$ = 30% (about) which is adequate.

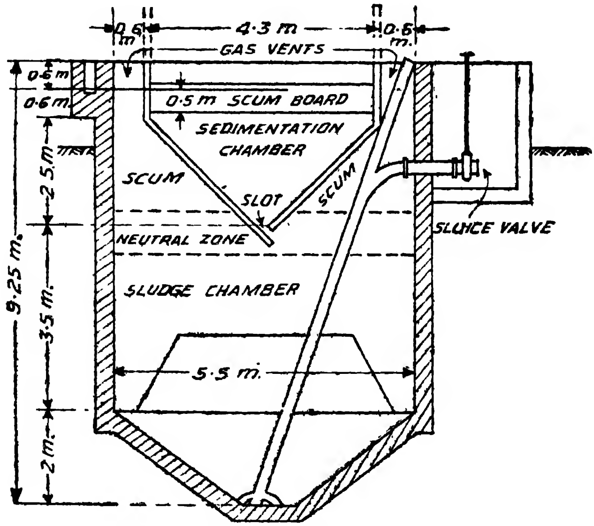


Fig. 293 — Cross section of an Imhoff tank for the design in Example 21.

Depth :—Minimum free board	...	...	0·5 m,
Depth of sedimentation tank = that of rect. portion 0·75 m. + that of triangular portion 2·5 m.			
		Total	3·25
Depth of neutral zone	...	...	0·50
		Total	3·75 m.

This is up to the dotted line indicating the bottom of the neutral zone in Fig. 293.

Let us now calculate the capacity and design the sludge chamber.

Required capacity (minimum) = 10,000 × 35 = 350000 lit. = 350 cu.m. Supposing 3 hoppers are made in the 15·5 m. length (16 − 2 × 0·25 thickness of partitions) each 5·16 m. × 5·5 m. with sides 3·25 m. vertical below the bottom of neutral zone and sloping at 50° below it of 2 m. depth, the volume = 5·5 × 5·16 × 3·25 = 92·24 cu.m. (*a*) plus the volume of the prism, the top area of which is 5·5 m. × 5·16 m. and bottom area at 2 m. depth with sides sloping at 1:1 is 1·5 × 1·16 = 1·74 sq. m. The volume of such a prism is $= \frac{1}{6}d\ (A + a + 4m)$ where d = depth, A and a are areas at the top and bottom and m is that at mid-depth.

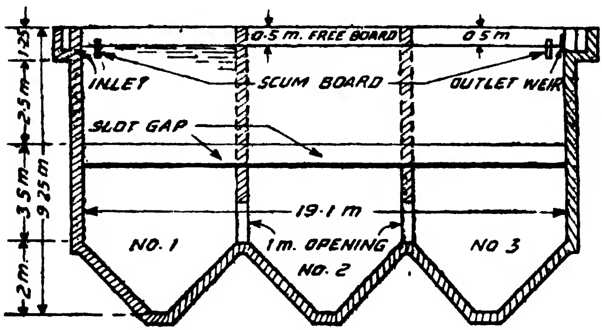


Fig. 294.

This volume

$$= \tfrac{1}{6} \times 2 \{5{\cdot}5 \times 5{\cdot}16 + 1{\cdot}5 \times 1{\cdot}16 + 4(3{\cdot}5 \times 3{\cdot}16)\}$$

$$= 24{\cdot}79 \text{ cu. m.} \quad \ldots \quad \ldots \quad (b)$$

Total capacity = (a) + (b) = 92·24 + 24·79

= 117·03 say 117 cu. m.

that of 3 hoppers = 351 cu. m.

We want minimum of 350 cu. m. So the design is correct.

The width of the slot will be 20 cm. and the overlap 25 cm. to serve as an efficient trap. Cross and longitudinal sections of the Imhoff tank are given in Figs. 293 and 294.

Questions

(1) What is the difference between a sedimentation tank, a septic tank and an Imhoff tank? Why is a septic tank very convenient for domestic use?

(2) What are the essential features of an Imhoff tank?

(3) Why is the reversing of flow occasionally required in an Imhoff tank?

(4) With the following data calculate the capacity of sludge chamber per capita of an Imhoff tank:

Suspended solids per day per capita ...	... 0·1 kg.
Suspended solids deposited in the tank with two hours detention ...	... 62·5%
Digestion of solids in sludge chamber ..	... 25%
Average moisture of sludge in sludge chamber ...	90%
Storage period	... 60 days
Sp. gr. of sludge	... 1·06

Solution: Capacity per capita

$$= 0·1 \times \frac{62·5}{100} \times \frac{75}{100} \times \frac{100}{10} \times \frac{1}{1·06 \times 1} \times 60 = 26·53 \text{ kg.}$$

= 26·53 lit. per capita.

(5) Design an Imhoff tank for treating the sewage of a town of 15,000 population with water supply at 140 lit. (30 gallons) p. h. p. d. Detention period 2 hours, sludge capacity at 30 lit. (1·2 c. ft.) per head,

CHAPTER XXIV

SEWAGE FILTRATION

Theory of Filtration:—We have already discussed the two stages through which organic matter passes for being purified and finally stabilised. The first stage is that of splitting up the complex compounds into simpler elements by the anærobic action as in septic and Imhoff tanks. The action involved in filtration is that of the second stage viz. of building up a few new compounds which are stable by combining with oxygen. The former reduces the B. O. D. by reducing the quantity of organic matter; filtration, on the other hand, does the same thing by satisfying the B. O. D. with the help of ærobic bacteria. The action is the same as that of land treatment. Land treatment, however, requires a very large area while filtration accomplishes the same in a very limited area. In sewage filtration mechanical action of filtration is very little, only the coarsest particles being arrested by the filtering media. It is the ærobic life that flourishes on the surface of the filtering material, which oxidises and nitrifies the organic matter. The finer the filtering material, the larger is the total superficial area giving lodgement to the ærobic bacteria. But the possibility of clogging and reduction in the voids which supply the air are the factors which limit the size of the filtering media.

Contact Beds

Contact beds are a form of filters. Clean gravel, broken stone, slag, or such other hard, inert material having rough surfaces, and of size varying from 1 to 8 cm. (½ to 3 in.) is filled in water-tight tanks or basins with concrete floor and drains at bottom, generally not exceeding 2 m. (6 ft.) in depth. They are alternately filled with settled sewage, allowed to stand full, emptied and allowed to rest again to complete one cycle. When a bed is first put into service, practically no improvement in the character of the sewage takes place. But after a few weeks the surfaces of the contact material are coated with a jelly-like organic film in which myriads of bacteria live and feed on any organic matter coming in contact with them.

The filling of the bed with treated sewage is accomplished with great care within an hour or two, in such a way, as not to disturb the organic film mentioned above. The bed is then allowed to stand full in contact with the sewage for a period not exceeding two hours. During this period the solids and colloids in the sewage adhere to the surface of the film, and the latter further adsorb the solids in solution. At this time anærobic action just starts reducing some of the nitrates to nitrites or even to gaseous nitrogen. If this period exceeds two hours, septic conditions will be set up.

The emptying should also be completed within an hour or two without disturbing the gelatinous film in the least. Then the bed should be allowed to rest for 3 to 6 hours. During this period air enters the interstices of the filter, starts ærobic action and maintains it in full vigour by which the organic matter is oxidised and nitrites and nitrates are produced. The entire cycle takes 8 to 10 hours. Out of this period not more than two hours should be taken by the contact or standing-full operation and at least three hours should be allotted to rest and æration.

After about 4 to 5 years of service the contact material requires to be thoroughly washed and dried in the sun; it can then be reused.

Contact beds working satisfactorily remove about 60 to 80 per cent of organic matter, and about 70 to 80 per cent of suspended solids.

The rate of treatment in contact beds is relatively slow. About 225-375 lit./cu.m. (40 to 60 gallons/cube yard)/day may be expected from an average bed. Various attempts to increase the rate by making improvements in sewage distribution were made and these led to the development of trickling filters. The success of the latter both as regards the quality and quantity of sewage treated, have put contact beds practically out of use at present

Trickling Filters

These are known also by the names percolating, or sprinkling filters. Until a few years ago trickling filters were very popular on account of their relatively low cost, simplicity of operation, better quality of effluent produced than any other method previously tried, and above all its capability of giving satisfactory service under very widely varying climatic and other conditions. But recently its popularity is waning in favour of activated sludge process, which, in spite of higher operating costs, has some inherent advantages. Still, attempts are being made to develop high-duty trickling filters, and the results of experiments made, promise a great future for this method of disposal.

For treating sewage with trickling filters three operations are necessary: (1) Primary treatment with screening, removing grit, and plain sedimentation, (2) Filtering in trickling filters, and (3) Final sedimentation in humus tanks. The first is essential to prevent clogging of filters, second is the main operation for oxidation and the third is required to remove from the effluent of trickling filters dead organic matter sloughed from the filter, which is characteristic of trickling filters.

A trickling filter differs from the contact bed in the fact that the purification of organic matter in a contact bed goes through two stages viz. anærobic and ærobic. In a trickling filter on the other hand, there is no anærobic action at all. Another difference is that a contact bed is alternately filled and emptied, while in a trickling filter sewage is trickling down continuously. Third difference is that the contact beds are usually below ground level with water-tight walls, whereas percolating filters may be above ground with honeycombed walls.

In the course of 2 or 3 weeks after trickling filter is started, the surfaces of the filtering material get coated with a slimy 'zoogleal film' containing fungi, protozoa, algæ, plankton and bacteria. This film possesses the remarkable power of transferring to itself the colloidal and dissolved organic matter from the trickling sewage; next, of absorbing to itself from the transferred surface, the nutriment necessary for the maintenance and growth of the film; and finally of transferring back to the sewage the end products of decomposition such as nitrates, carbonates, etc. This process may be due to the combined action of physical, chemical and biological changes. The protozoa feed on bacteria, and thus reduce the number of *B. coli*. In course of time this material deposited on the surfaces of stones becomes thick and heavy and sloughs off and is carried by the effluent. At times it gathers in such large quantities that the filter is then said to be "unloading". This happens in particular seasons, and after that with minimum thickness of zoogleal film the filter works efficiently again.

Shape:—The shape of the filter may be rectangular or circular. Both circular filters are very common. The shape depends upon the method of distribution of sewage used. When the area is restricted, rectangular filters are better than circular ones, as the latter waste a considerable odd-shaped space between the rows of circular filters.

Depth:—This is from 1·5 to 3 m. (5 to 10 ft.). Deeper filters treat relatively much larger volumes, e g. a 3 m. (10-ft.) filter operates at a rate 8 to 10 times as great a volume with equally good effluent as a 1·25 m. (4-ft) one. Normal depth is 2 to 2·5 m. (6 to 8 ft.)

Size depends upon the permissible loading, which, again, depends upon the character and strength of the sewage and the coarseness or fineness of the filtering material. With continuous flow sedimentation tank, with a detention period of 10 to 12 hours, the rate of charging is as follows:—

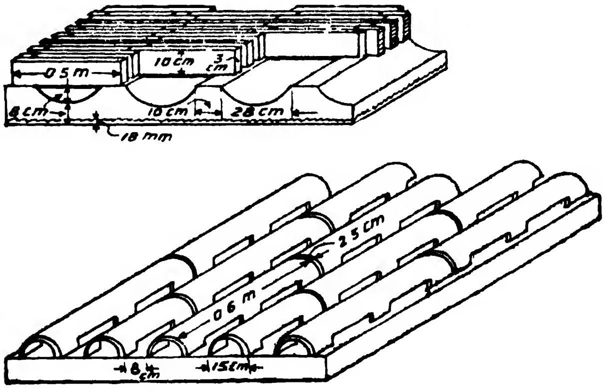
TABLE NO. 24.

Sewage Strength	Filter	lit. per cu. m.
Strong sewage :	(a) Coarse	200
	(b) Medium	260
Average sewage:	(a) Coarse	425
	(b) Medium	600
Weak sewage :	(a) Medium	600
	(b) Fine	1000

There are divergent views as to whether the walls should be solid or pierced through for æration. The latter allow free air but the former conserve heat, reduce aerial nuisance, and are capable of sustaining hydrostatic pressure. For this country, however, air-spaced walls are distinctly advantageous.

Floor and Underdrains:—The floor should be of smooth water-tight concrete with a suitable surface fall towards the centre in small filters, and away from the centre in large ones.

Sometimes a false bottom of either half-round stoneware pipes, or slotted tiles interlocked with each other (Figs. 295, 296) is laid at the bottom to serve as under-drains, or channels 75 to 100 mm. (3 to 4 in.) diam. are made inside the concrete floor, parallel to each other, at a distance of 30 to 45 cm. (12 to 18 in.) between centres, all falling at about 1 in 100 towards a collector drain in the case of rectangular filters, or



Figs. 295, 296—Two types of under-drains for trickling filters

radial ones to join a circumferential collecting drain in the case of a circular one. A drainage system with a false bottom of drains is better as it allows circulation of air as compared with channel drains in the floor which lie submerged.

Efficiency of a Filter:—This depends upon a number of factors:—

(1) *Character and Strength* of the sewage. If the organic load is great, less volume must be used to obtain good results. Similarly, excessive acidity or alkalinity caused by industrial wastes is injurious to the biological action of filters.

(2) *Depth* of filters. This has been discussed above.

(3) *Temperature* :—At low temperatures the bacterial activity is retarded.

(4) *Size of Filtering Material*:—Smaller size has a larger aggregate surface area tending to produce better results, but the filter is liable to get clogged.

(5) *Method of Distribution of Sewage*:—Equable, even distribution will obviously result in a batter effluent.

Filter loadings are expressed in various ways such as (1) Volume treated per cubic meter of material. This does not take account of the organic load. (2) Number of persons served per hectare (acre) or per cubic meter e. g. 100 persons per 30 cu.m. (4000 per acre ft.) per day. This is still more vague as the water consumption per head must also be considered. (3) 5-day B. O. D. applied, e. g. 0·1 kg. (5·75 lbs) of 5-day B. O. D. applied per cu.m. (1000 cubic ft.) of material. This is more scientific. But that too does not consider the depth of the filter.

Operational records of different trickling filters working satisfactorily show that about 425 to 500 lit. /cu.m. (70 to 80 gallons per cu. yard) per day is treated by a 3 m. (10 ft.) filter or 0·1 kg. of 5-day B. O. D. per cu.m. of material are required for average sewage.

Distribution of Sewage:—The old time system of perforated troughs and splash plates are no longer now in use. Distribution is generally made by either (1) fixed nozzles on top of pipes, or (2) moving distributors.

(1) *Fixed Nozzles*:—For this system pipes are laid in parallel rows supported on masonry piers, about 15 cm. (6 in.) above the filter surface and nozzles of gunmetal 12 to 20 mm. ($\frac{1}{2}$ to $\frac{7}{8}$ in.) diam. are fitted into holes drilled on their top. These nozzles have an upward spray and are designed for

either square or round atomization. The pipes are so laid that the loss of head from dosing tank to each nozzle is as uniform as possible. All the pipes and nozzles must be capable of being cleaned. Fixed nozzle system absorbs more head than rotating arms. With fixed sprinklers certain areas are likely to be dosed at variable rates, hence they give good effluent with slightly deeper filters.

(2) *Moving Distributors*:— These are of two kinds :— (i) revolving arms, and (ii) travelling distributors. Revolving arms are suitable for circular filters 30 to 60 m. (100 to 200 ft.) diams. They consist of perforated pipe arms either two or four in number revolving round a central column, either on the principle of jet if the head is sufficient, or driven by an electric motor. The spray of revolving arms is downwards and therefore causes less aerial nuisance.

The distribution is made by means of dosing tanks. There are overflow troughs to which automatic siphons are attached. In the case of rectangular filter-beds the troughs move to and fro and in that of circular filters they move round the centre of the revolving mechanism, and the siphons supply the doses intermittently in cycles of 5 to 15 minutes. The resting time is usually equal to the working period. Since the discharge diminishes as the tank empties, the shape of the tank is so adjusted that the discharge does not much vary. The velocity of flow should be a minimum of 12 m. (40 ft.) per minute to prevent clogging of pipes.

Ventilation:—As the lower portions of the filter do not get free air especially when they are built underground for fear of freezing, some sort of ventilation, according to some authorities, is necessary. But here in India we can safely build filters above ground, and if some sort of false bottom under-drainage is provided, there is no necessity of any special ventilation. If the drainage underneath consists of channels in floor, ventilation may be necessary as the drains will, in that case, be submerged under water.

Maintenance:—The nozzles which are likely to be choked every now and then, must receive constant attention. Clogging of filter due to either breaking down of filtering material or overdosing may occur. Occasionally filters may be "unloading". The troubles from clogging are got over by pricking up and harrowing the surface, and hosing with water. A remedy for unloading of filter is to pre-treat sewage with chlorine.

Humus Tank :—The final sedimentation is desirable as there is always a large amount of light, flocculent humus-like floating matter associated with the effluent from trickling filters. That is why this tank is called a humus tank. The design is in every respect similar to that of plain sedimentation tank. The detention period is from 2 to 3 hours. The sludge from humus tank is not suitable for drying and is therefore commonly pumped into sludge digestion tank.

Results:—The effluent from trickling filters though full of flocculent solids is odourless, and requires a small amount of diluting water as its relative stability is high. After it is settled in humus tank, there is a high percentage of dissolved oxygen in it. Trickling filters remove 70 to 90 per cent of bacteria, 70 to 80 per cent of colloidal matter, and 70 to 90 per cent of B. O. D.

The efficiency of filters can be increased by enclosing the filter from sides and also the top and forcing air by means of blowers of adequate capacity. This incidentally prevents fly breeding and ærial nuisance which in themselves are great advantages.

Advantages of Trickling Filters:–(1) A high rate of purity of effluent as compared with contact beds.

(2) Requires little attention except for cleaning pipes and nozzles, and very little skilled attendance.

(3) Dependability to produce a good effluent *under very widely varying weather and other conditions*.

(4) Can withstand overloading without material damage.

(5) Less mechanical wear and tear as compared with activated sludge process, as mechanical equipment is much less.

Disadvantages :—(1) Loss of head is the greatest disadvantage. It varies from 2 to 3·5 m. (6 to 12 ft.) according as the method of distribution is employed. Fixed nozzle system involves the greatest loss, and rotary arms the least. This loss of head is in addition to that in the depth of the filter.

(2) The filter is subject to the nuisance caused by psychoda fly and occasional bad odours, particularly if the sewage is septic. The preventive remedies are removing all weeds, grass, etc. from the surrounding area, and keeping it clean, pre-treating sewage with chlorine, destroying flies by applying a flame to the surface of masonry of filters, spraying D. D. T., etc. Rotary arm distributors which direct the spray downwards create less aerial nuisance.

(3) A very large area, and a large mass of filtering material is required and the quantity of sewage treated is comparatively small.

(4) High cost of construction.

(5) Final settlement in humus tank is necessary.

Design of Percolating Filter Beds

Example No. 22 :—Design percolating filters for treating a D. W. F. of settled strong sewage of $4{\cdot}5 \times 10^6$ lit. per day. The filtering aggregate is to be of medium size.

Solution:—As the aggregates are medium and sewage strong, we shall assume a rate of 250 lit./cu. m. from Table No. 24.

$$\text{Capacity required} = \frac{4{\cdot}5 \times 10^6}{250} = 18000 \text{ cu. m.}$$

Assuming a normal depth of 2 m. of filters,

$$\text{Area} = \frac{18000}{2} = 9000 \text{ sq. m.}$$

If each filter is of 45 m. diameter,

The area of 6 filters $= 6 \times 0{\cdot}7854 \times 45^2 = 9540$ sq. m.

This leaves about 5 per cent margin of reserve. Therefore 6 filters each of 45 m. diam. and 2 m. deep should be provided.

Design of Humus Tanks

Example No. 23 :—Design Humus tanks for treating the effluent from the above trickling filters.

Solution :—The capacity of humus tanks is usually taken at 12 per cent of the total daily D. W. F.

$$= \frac{4{\cdot}5 \times 10^6 \times 12}{100} = 540000 \text{ lit.}$$

$$= 540 \text{ cu. m.}$$

It is advisable to provide four tanks of conical Dortmund type. If the diameter at the top is 10 m. and depth 7·5 m.

$$\text{Volume (of cone)} = \tfrac{1}{3} h \times \frac{\pi D^2}{4}$$

$$= 0{\cdot}7854 \times 100 \times \tfrac{1}{3} \times 7{\cdot}5.$$

$$= 196 \text{ cu. m.}$$

$$\text{Total volume of } 3 = 588 \text{ cu. m.}$$

Bio-filter

Of all the methods of sewage treatment so far considered trickling filter is very satisfactory. Still great improvement was needed in reducing the loss of head, reducing fly and odour nuisance and increasing the rate of effluent treated. With this end in view scientists focussed their attention on this subject and soon found that,

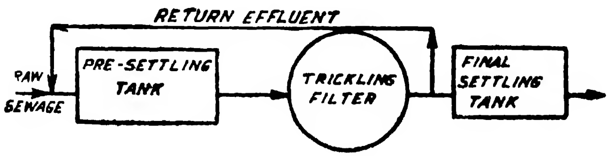
(1) The main action of coagulating colloidal matter, and gathering fine particles of suspended matter together by the colloids to form larger and easily settleable particles takes place in the upper layers only of the filter. In the lower layers these particles deposit on the surface of stone and form a zoogleal film, which oxidises and nitrifies both the suspended and dissolved solids. When the deposits of dead organic matter grow thick, they drop away and flow with the effluent.

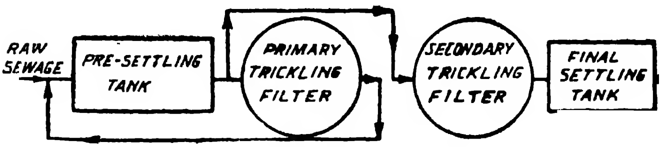
This led the scientists to cut the depth of filters to half. If still better effluent were required, two filters could be built within the same original depth and worked in series.

(2) It was also discovered that the rest allowed between successive doses was not only unnecessary, but it cut off the food supply during the interval, of the organisms and they suffered. Hence non-stop dosing was adopted.

(3) It was further found that a longer contact, and seeding the influent with more vigorous ærobic bacteria by means of recirculation of part of the filtered effluent to the pre-settling tank was very helpful.

On these principles a shallow, continually fed trickling filter was developed called 'bio-filter'. Its working is shown in the following flow diagrams :





Figs. 297, 298 – Flow diagrams of one-stage and two-stage operations of trickling filters.

In Fig. 297 part of the trickling filter effluent is pumped into the pre-settling tank and recirculated with the influent of the latter, and in Fig. 298 there are two trickling filters, the whole effluent of the first is pumped back into the pre-settling tank, and from it recirculated to the second trickling filter, and finally settled in the humus tank. There may be several other variations like these. The result of all this is the production of a much larger quantity of purer effluent. The advantages of re-circulation are :

(1) The original quantity of influent is increased, so that while treating this increased quantity naturally a longer contact is availed of.

(2) The increased quantity has a flushing effect which causes effective 'unloading' of the filter, thus keeping the film just thick enough to be efficient.

(3) When well ærated filter effluent is pumped back and mixed with raw sewage, seeding with ærobic organisms automatically takes place.

(4) By adjusting the quantity of recirculated sewage, the rate of loading can be made uniform, e. g. when at certain hours of the day or night the flow of sewage is minimum, it can be increased by adding sufficient quantity of recirculation flow, to maintain uniform distribution.

A bio-filter can treat 20 to 30×10^6 lit. of sewage per hectare (10 to 15 mill. gallons per acre) as against 2 to 3×10^6 lit. (1 to 1½ mill. gallons) of the conventional trickling filter.

Dunbar Filter

This is so named because it was first developed and used at Dunbar, a town in Germany. It is a long and narrow filter, the proportion of length to breadth being 3 or 4 to 1. The depth is about 1 to 1·25 m. (3 to 4 ft.). The walls may be of masonry or concrete, and the floor of concrete sloping cross-ways on either side towards a central longitudinal drain. The filter is filled with crushed stone of varying sizes and depths as shown below :—

At bottom 40 to 45 cm. (15 to 18 in.) layers of 15 to 8 cm. (6 to 3 in.) size crushed stone.

above this 10 cm. (4 in.) layers of 40 to 10 mm. (1½ in. to ⅜ in.) size gravel.

above this 10 cm. (4 in.) layers of 10 to 3 mm. (⅜ in. to ⅛ in.) size sand and gravel.

At top 45 cm. (18 in.) layers of 3 mm. (⅛ in.) and finer granular sand.

Pre-settled sewage is applied on the top until the filter is clogged, and a pond of 8 or 10 cm. (3 or 4 in.) depth is formed on the top, then it is allowed to rest and the sewage is diverted to another unit. In a few hours all the water sinks down, leaving a film of gelatinous material at the top. This is allowed to dry in a day or two after which it is gently brushed over and removed in the form of powder. The filter is then ready for use again. At least three such units must be made to be used alternately.

The special advantage of this filter is that the effluent is so stable that it requires no further settling treatment and there is no sludge produced. The filter is therefore very useful for small populations such as of tubercular or other sanatoria.

Taking the areas of the beds under rest also into consideration, it treats about 18 million litres of sewage per hectare (0·4 mill. gallons per acre) per day.

Questions

(1) What is the difference between a contact bed and a trickling filter ?

(2) What are the principles involved in the working of trickling filters ?

(3) What is meant when a filter is said to be unloading itself ?

(4) State the advantages of a trickling filter.

(5) Why is the performance of a bio-filter or improved percolating filter superior to that of the conventional trickling filter ?

(6) Design trickling filters for treating sewage of average strength of a town of 30,000 population, supplied with 200 lit. (45 gallons) of water p. h. p. d. if the material is of medium size.

CHAPTER XXV

ACTIVATED SLUDGE PROCESS

LONG AGO experiments were carried out for many years by blowing air through sewage with a view to oxidising it. But the results were disappointing. Perhaps, air was not blown for a sufficiently long time. Eventually Dr. Fowler discovered that if air is *repeatedly* bubbled through sludge, it produces a light, brown, flocculent mass, which, when examined under a microscope shows that it teems with myriads of ærobic and facultative bacteria, including a variety of both freely swimming, and attached protozoa, together with occasional moulds and yeasts, exactly similar to the contents of the zoogleal biological film deposited on the surfaces of stone and clinker in a percolating filter, which is responsible for the purification. It was also noticed that there was no trace of the original anærobic bacteria, which must therefore have been destroyed.

Activated sludge is therefore, that sludge which settles down after sewage is freely aerated and simultaneously agitated for a sufficiently long time.

We have already seen in the last chapter that the finer the ballast used in a percolating filter, the better is the purification effected. This is mainly due to the fact that finer material presents greater total surface area for the deposition of the zoogleal film i. e. collects a larger number of purifying bacteria. But such a fine material is sure to get soon clogged. In activated sludge process, instead of stone or clinker pieces, the medium consists of extremely fine particles of suspended matter themselves, presenting comparatively a still larger surface area and a greater number of bacteria, than even the finest filtering medium that can be imagined, and still, these particles do not get clogged, since, they are kept in constant agitation.

In contact beds and percolating filters the inner surface of the biological film is in contact with the medium, leaving only the outer surface in effective contact with sewage. In aeration tanks of activated sludge process, every fine particle is surrounded by the film and as it is moving about, the whole surface is thus available for contact with sewage.

What actually happens inside is still a mystery, but the generally accepted theory is that at first a sort of clotting effect takes place, whereby coagulation of the finely dispersed colloids and dissolved impurities occurs; in this way the polluting matter is transferred from the sewage to the sludge and thus clarification occurs. Up to this point the action is mostly physical. Then a slow biological process starts, which attacks carbonaceous and nitrogenous matters, oxidising them to carbon dioxide, nitrites, and nitrates.

The activated sludge process consists of three basic operations: (1) sewage which has been usually passed through sedimentation tank is mixed with 20 to 35 per cent of activated sludge by volume. It is then called "mixed liquor." (2) The mixed liquor is ærated and simultaneously agitated for 4 to 10 hours depending upon the strength of the sewage and the degree of purification required, and, (3) it is then finally settled in tanks, and the supernatant purified effluent is either discharged into a stream, or disposed of in other suitable ways. The sludge which precipitates at the bottom is biologically active. Part of it is pumped back to the æration tank for "seeding", and the remaining is disposed of in the usual way as discussed in the next chapter.

A very noteworthy feature of the process is the rapidity with which organic matter is oxidised when the sewage is first brought into contact with the active sludge. About 60 per cent of the organic matter is oxidised during the first hour, and only 30 to 35 per cent in the next five or six hours. This high rate of purification during the first hour has suggested the possibility of utilising the process (1) for partial purification to the required degree, and discharging the effluent into a stream according as the available dilution would justify it, or, (2) after one hour's treatment in an activated sludge plant, to complete the oxidation of the remaining organic matter in percolating filters. The latter has been found to be very economical. For, after an hour's æration, and subsequent settlement of sludge, the effluent will be quite free from colloidal matter, and well charged with oxygen, and therefore can be treated in percolating filters at double the ordinary rate. When this is done, it would, however, be necessary to reactivate the sludge before it is returned to æration tanks for seeding.

The basic operations mentioned above are illustrated in the flow diagrams in Figs. 299, 300.

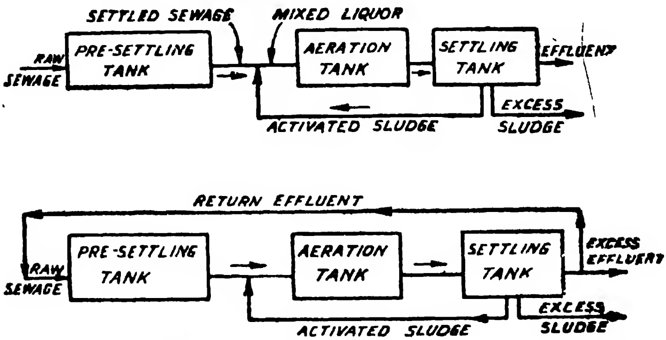


Fig. 299, 300 – Flow diagrams showing the processes under which sewage passes through an activated sludge plant.

Preliminary Treatment :—The preliminary treatment consists of passing the raw sewage through 10 to 20 cm. ($\frac{1}{2}$ to $\frac{3}{4}$ in.) screens and detritus tanks to separate sand, grit, coarse floating matter and then settling it in plain sedimentation tanks with a short detention period of $\frac{1}{2}$ to $\frac{3}{4}$ hour, with the object of reducing organic load on æration tanks. The total cost of all this preliminary treatment is less than that of treating raw sewage directly in æration tanks.

Return Sludge :—The quantity of activated sludge to be returned by pumping for recirculation to æration tanks varies from 20 to 35 per cent of the pre-settled sewage by volume. In some plants the return sludge is re-ærated, or reactivated before it is mixed with sewage. It is very important that the return sludge should be thoroughly activated as indicated by its golden brown colour and dense, compact mass. Under-aerated sludge is light brown, light in weight, and fluffy.

More sludge is produced than that required for seeding. Part of it is returned to the primary sedimentation tank as shown in Fig. 300. For, it has been observed that this activated sludge improves the settling properties of the crude sewage and further, that the combined settled and activated sludge is easier to digest and dry, than activated sludge alone.

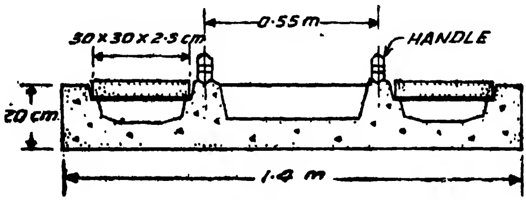
Sludge Index :—Instead of adding the quantity of return sludge by volumetric measurements which are deceptive, it is better to do so by "sludge index". The latter may be determined by collecting a sample at the outlet of the æration tank, settling it for 30 minutes and drying it to find the suspended solids. The percentage ratio of the volume in cubic centimeters to one gram of dry suspended solids is the sludge index. For normal sludge it is from 150 to 350 for Indian conditions. A higher index indicates that there is something wrong which must be corrected by plant control.

Return of Effluent :—When the sewage arriving at works is more or less in a septic condition, as most Indian sewages are, one of the two measures must be adopted : (1) returning part of the effluent from the plant for recirculation to primary sedimentation tank, or (2) chlorinating the sewage. The first is simple and more effective. It helps in two ways: (a) it dilutes the sewage, and (b) the oxygenated effluent supplies some free oxygen. For this purpose pumps with additional capacity to pump up to 50 per cent or even more of the effluent should be provided.

Free æration even to the point of saturation and thorough mixing of sewage and activated sludge are the basic principles of success of an activated sludge point. For the best results the particles of sludge must move about in the sewage with a velocity of 0·5 m. (1½ ft.) per sec. This is accomplished by one of the three methods

(1) Diffuser air system.
(2) Mechanical æration system, and
(3) Compound system or a combination of the above two.

(1) **Diffuser Air System** :—In this, compressed air is blown through sewage in æration tanks. If it were blown through nozzles, or perforations in pipes, it would rise quickly in bubbles and escape at the surface. It is therefore forced through pores of tiles, called "diffusers" placed at the bottom. The air should be filtered to exclude particles of soot and dust, which are likely to choke the pores in course of time. The diffusers are 1·5 to 2·5 cm. ($\frac{5}{8}$" to 1") thick and of various sizes, 10 cm., 15 cm. or 20 cm. × 20 cm. × 1·5 cm. thick (4", 6" or 8" × 8" × $\frac{5}{8}$" in British practice) and 30 cm. × 30 cm. × 2·5 cm. (12" × 12" × 1" in American), and are fixed in cement or bituminous compounds in c.i. or aluminium frames, consisting of shallow boxes, and are made air-tight by means of rubber rings. (See Figs. 301, 302).



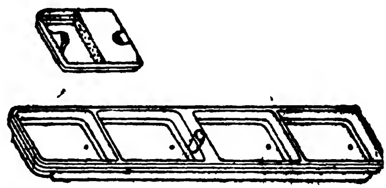


Fig. 301 – L. section of a concrete frame and diffuser.
Fig. 302—Aluminium box frames for holding diffuser plates.

The æration tanks for this system are 3 m. (10 ft.) wide by 3 m. to 5 m. (10 ft. to 15 ft.) deep and 10 to 12 m.(30 to 40 ft.) long. There are two methods of working. (i) *ridge and furrow*, and (ii) *spiral flow*. In the former there are ridges and furrows of concrete made parallel to the length of the tank, and diffusers placed in the bottom of the furrows as shown in Fig. 303. This method gives good results but, a angle frame, rotating at 16 r. p. m. beats the air into the sewage, and gives the latter a forward wave motion. A continuous path of 1200 to 1800 m. (4000 to 6000 ft.) length is made by putting lengthwise, parallel partitions and allowing the liquid to recirculate several times in the same tank.

The Hartley method is similar to the Sheffield system, except that the paddles rotate round an inclined axis at the end of the channels and that inclined baffles are also provided in addition across the channels to further aid agitation.

The Simplex Aeration tank has a hopper bottom with a vertical steel tube suspended with its open end about 15 cm. (6 in.) above the bottom of the tank. There is a steel cone with vanes, which, by rotating by means of a gear at the top end of the tube, draws the mixed liquor up through the tube and sprays it over the surface. The spray absorbs oxygen from the atmosphere and keeps the surface in motion (See Fig. 305).

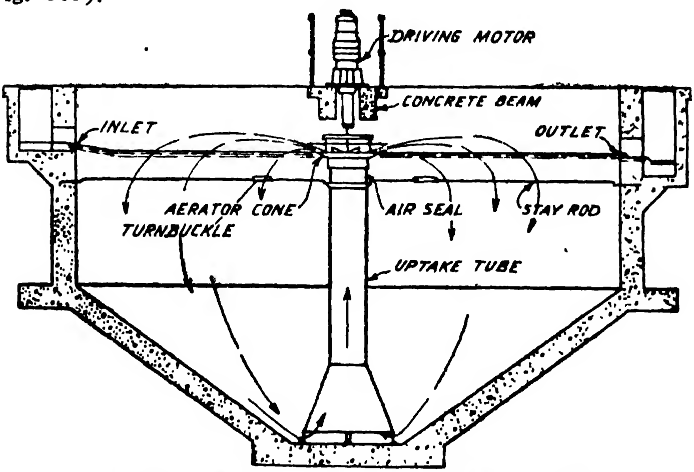


Fig. 305 – L. section of Simplex mechanical aeration tank.

The Link-belt aeration tank is 2·5 to 3 m. (8 to 10 ft.) deep and 3 to 3·75 m. (10 to 12 ft.) wide. There is a paddle wheel about 0·75 m. (30 in.) diam. suspended near the top partially submerged, extending the full length of the side, with blades in the form of narrow ribbons. A vertical baffle partition wall at about 0·5 m. (18 in.) from the side wal of the tank with an opening in the bottom, forming a sort of a lift-channel carries a narrow trough at right angles at the top. When the paddle wheel is rotated, it pushes the liquid down in the tank which then rises through the opening at the bottom of the partition and up behind the latter into the trough and is forced across the surface, producing waves and bringing fresh surfaces in contact with air. (See Fig. 306).

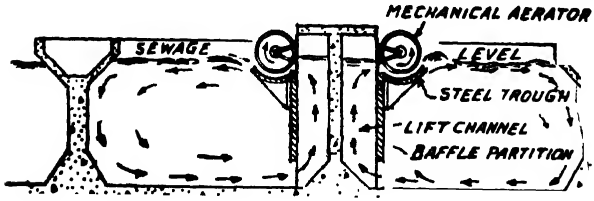


Fig. 306—A Link-belt aeration tank.

Combination Aerators:—An example of this is found in Imhoff type æration tank patented by Dorr & Co. under the name Dorrco Aerator. It consists of a tank 3·75 to 4·5 m. (12 to 15 ft.) deep, and about 7·5 m. (25 ft.) square, having two rows of diffusers fixed in the bottom. There are paddle wheels with two blades, mounted on a horizontal shaft in the centre, making 10 to 12 r. p. m. in a direction opposite to that of the rising air bubbles. The detention period is 5 hours. The principle is illustrated in Fig. 307.

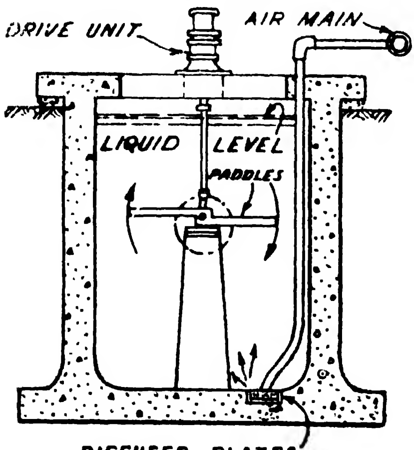


Fig 307—Dorrco Aerator combining mechanical and diffuser aeration.

Pre-aeration of Raw Sewage:—Immediately after activated sludge comes in contact with sewage, a sudden avidity for absorbing oxygen arises. In order to satisfy it, the influent is ærated in special tanks, on some plants, for half an hour before it is discharged into æration tanks. The results are promising, but the matter has still been in an experimental stage.

Tapered Aeration :—Experimental investigations have proved that if samples are collected at different points throughout the length of æration tanks, and tested, it is found that the B. O. D. of the mixed liquor is maximum near the inlet and that it becomes progressively less until at the outlet end it is the least. If, therefore, distribution of air is made in the proportion of the B. O. D. it will roughly be as follows : 40 per cent in the bays near the inlet, 25 per cent in the middle bays, 20 per cent near the outlet, and 15 per cent in the sludge reæration tanks if provided This is called tapered æration, and can be practised for the sake of economy, in the case of diffuser æration by partially closing the air valves, and in mechanical æration by reducing the speed of ærators in requisite proportions.

During the past few years, as a result of research, several new systems of æration, giving higher efficiency, at lower cost have been evolved. They are all based on the principle that more thorough the contact of air (oxygen) with the sewage, the quicker and more efficient the purification. There are several patents incorporating the above principle on the market, but out of them the following two are popular and in common use. They are : (1) The Inka system, developed by Dorr, Oliver Inc. and (2) The Kraus, or Dual Aeration system.

(1) **Inka Aeration System*** :—This is illustrated in an isometric view in Fig. 308 and a longitudinal section in Fig. 309. In the conventional æration tank the diffusers are placed at or near the bottom of the tank. In the Inka system

* By courtesy of M/s. Dorr Oliver Inc. The illustrations in Figs. 308 and 309 are taken from their Bulletin.

instead of diffusers, an æration grid is used and is placed near the top. The tank is comparatively shallow, and is divided

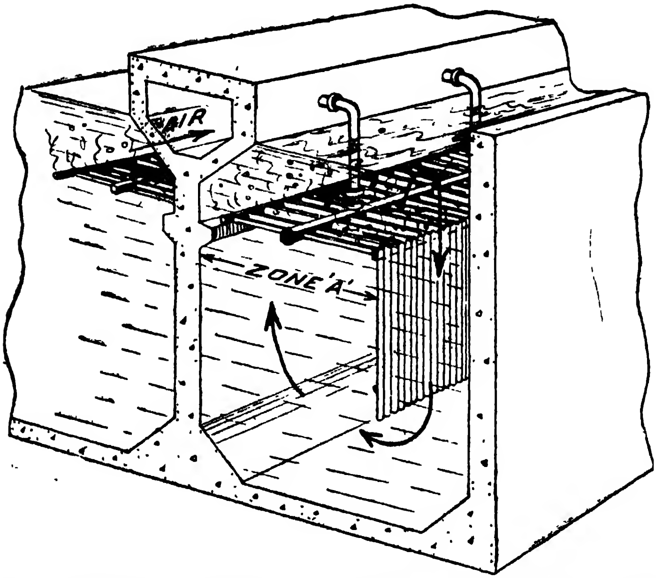


Fig. 308—Isometric cross section of the Inka tank, showing grid and baffle.

into two compartments, by a vertical baffle, starting from the top, where air is admitted, extending downwards to a point a little above the bottom. Air under pressure is admitted

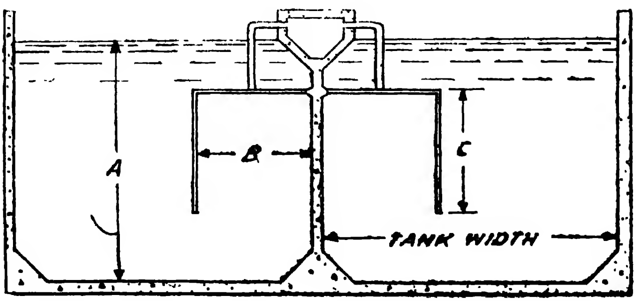


Fig. 309—L. section of the Inka tank.

into the upper zone "A", through the central manifold and then through the grid consisting of a header and cross pipes extending at right angles to the header. The introduction of a large volume of air under pressure, creates a mammoth pump (air lift) effect, causing mass circulation upwards in one compartment, and downwards in the other as shown by the arrows. Since the depth of liquid in the tank is small, large volumes of air could be forced at much lower pressure, requiring lower horse power. There is a further saving as the air does not require to be filtered as in case of diffusers, for fear of clogging pores.

(2) **The Kraus, or Dual Aeration System** :—In this system air under pressure is introduced at two places in directions opposite to each other, one from the top and the other from the bottom, either diagonally as shown in Fig.

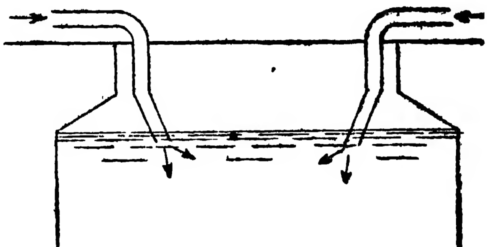


Fig. 310—Diagrammatic section of the Kraus or Dual Aeration tank.

310, or vertically. The flow of air in one direction and the counterflow in the opposite, facing it cause a great turbulence with the formation of millions of tiny air bubbles, ensuring contact of air and liquid on a very large interface.

Comparison between Diffuser and Mechanical Aeration Systems :—(1) Mechanical æration is very simple requiring only a motor and an agitator, whereas the diffuser air system requires compressors, distribution pipes, valves, diffusers, etc.

(2) Diffuser air system is more flexible, has better performance, and has the advantage that it can be used as air-lift. Reactivation of sludge, if getting septic, is possible with it.

(3) With diffused air system the plant is much less sensitive, as it can withstand sudden variations in strength better.

(4) Mechanical æration is more economical especially on small plants.

Starting and Maintenance:—When a new activated sludge plant is first started, more air should be supplied in the beginning until in 2 or 3 weeks normal conditions are established.

The working of an activated sludge plant is a highly technical job. A well-equipped laboratory and a chemist who knows how to apply the various tests and exercise controls, is quite necessary.

The key to success of an activated sludge plant, particularly under Indian conditions, is *to keep everything on the move.* There should be no stagnation anywhere. The sewage and sludge should pass through the plant as quickly as possible without getting the least chance to get septic.

Thus, sand, silt, etc. in the detritus tanks, and sludge in the primary sedimentation tanks should be promptly removed at least every two hours in the summer, every 3 hours in the cold season, and every 6 hours in the rains, as there is plenty of dilution water in the latter season which prevents early septicity. Similarly, the activated sludge in the final settlement tanks should be continually removed. If it is required for recirculation to the æration tanks, it must be biologically active. If allowed to stagnate it would be useless unless reactivated.

In some works special tanks for reactivating sludge are provided as standard equipment, in which sludge is rejuvenated before it is returned to the inlet of aeration tank.

The diffusers are likely to give trouble if not regularly inspected and serviced. Even though the air supplied to compressors is passed through filters, their pores get frequently clogged with deposition of dirt, soot, oil, or crystals of ferric hydroxide formed by chemical reaction, on the underside. Sand-blasting, acid washing, scorching the surface with stove flame and grinding the surface are some of the remedies. But it is cheaper and easier to adopt preventive measures in the first instance.

Bulking of Sludge :—Oftentimes trouble is experienced from sludge in the final settlement tanks becoming fluffy. It is slimy and deflocculated with decrease in density, the water contents increase and the sludge index rises. This may be due to one or more of the several causes, *viz.* (1) under-æration, (2) addition of certain industrial wastes especially those with high percentage of carbohydrates, or those possessing bactericidal or antiseptic properties, (3) growth of certain filamentous fungi, called *sphaerotilus*, etc. Appropriate remedy must be applied after finding out the root cause. Thus, increasing *p*H value to 8 or more by adding hydrated lime which will cancel the effect of acid fermentation of carbohydrates; chlorination, or injecting more air, reduction in the quantity of the return sludge, etc. are other remedies.

Final Sedimentation Tanks :—These do not differ from those for primary or plain sedimentation tanks. They may be of any shape. but the trend is towards the circular, especially if mechanical sludge-removers are installed. The detention period is generally 1½ to 3 hours. But for Indian conditions it should be not more than two hours to avoid septicity. The depth is usually 3 to 3·75 m. (10 to 12 ft.) The area of the tank is determined by the rate of flow, which may be from 30 to 60 cu. m. per sq. m. (600 to 1200 galls. per sq. ft.) per day, and varies from plant to plant. On large plants mechanical sludge removers are used, which scrape the sludge from the hopper bottom and remove it continually without causing the least turbulence. The mixed liquor should enter through a submerged inlet protected by a baffle and should flow at a velocity not exceeding 2 m./mt. (6 ft./mt.). To maintain an even flow multiple V-notched weirs should be used for the outlet. There should be preferably an automatic regulation device for continual sluge-withdrawal.

Controls:—For proper control of the operation the following routine tests must be applied:—

(1) *Mixed Liquor*:—(*a*) Settling solids at the inlet and outlet ends, (*b*) Suspended solids at both ends, (*c*) Dissolved oxygen in samples collected at various points, after settling for a certain fixed period.

(2) *Return Sludge*:—(*a*) Quantity, (*b*) Suspended solids, (*c*) Sludge index.

(3) *Final Settlement Tank Effluent*:–(*a*) Suspended solids, (*b*) Oxygen dissolved, (*c*) 5-day B.O.D. or permanganate test.

Results of Operations:—The activated sludge process is capable of purifying sewage to any degree of refinement. The following results are quite normal:—

Reduction of suspended solids	96 per cent
Reduction of bacteria	90 per cent
Stability by methylene blue	72 hours

Advantages:—(1) Clear, sparkling, odourless effluent possible.

(2) No odours during the process as compared with other methods, and no fly nuisance.

(3) Degree of stabilisation or nitrification is controllable according to the quantity and character of the stream into which the effluent is to be finally discharged. Treatment may be partial or full as required.

(4) Relatively low initial cost as compared with the total cost of trickling filter installations, cost of land, cost of huge mass of filtering material, cost of distribution mechanism, etc.

(5) Small area is required as compared with percolating filters.

(6) The sludge has some commercial fertilising value.

Disadvantages :—(1) Very sensitive to variation in the quality of the sewage, particularly in respect of industrial wastes which may cause bulking. Trickling filters are the best in this respect.

(2) High operational cost.

(3) Constant skilled attention is required.

(4) Large quantity of sludge produced, which is difficult to dewater, and dry on sand beds. Its disposal becomes a serious problem.

Design of Aeration Tanks

Example No. 24 :—Design æration tanks for the diffuser system on the ridge and furrow principle to treat 5000000 litres sewage per day.

Solution :—Quantity of sewage	5,000,000 lit.
Add 30 per cent for activated return sludge	1,500,000 lit.
Total	6,500,000 lit.
	= 6500 cu.m.

If detention period of 8 hours is assumed,

$$\text{Capacity required} = \frac{6500 \times 8}{24} = 2167 \text{ cu.m.}$$

Take a depth of 4 m. and width 6 m.

$$\text{Length} = \frac{2167}{4 \times 6} = 90 \text{ m.}$$

6 Units each 15 m. × 6 m. × 4 m. deep may be provided.

Design of Blower Capacity and Diffusers

If 10 cu.m. compressed air is assumed per cu.m.

Total air $= 5000 \times 10 = 50{,}000$ cu.m. per day

Blower capacity $= \frac{50{,}000}{24 \times 60} = \mathbf{34{\cdot}7}$ cu.m. / min.

One sq. m. of diffuser air supplies $0{\cdot}75$ cu.m. of air

$\therefore$ Diffuser area $= \frac{34{\cdot}7}{0{\cdot}75} = 46{\cdot}3$ sq. m.

$46{\cdot}3$
$= \mathbf{7{\cdot}7}$ sq. m.

Each diffuser measures $0{\cdot}2 \times 0{\cdot}2 = 0{\cdot}04$ sq. m.

No. of diffusers $\frac{7{\cdot}7}{0{\cdot}04} = \mathbf{198}$ per unit in four rows.

100 of these should be placed in 4 rows in the $5{\cdot}2$ m. length near the inlet, 64 in the next bay of $5{\cdot}2$ m. and 34 in the last $4{\cdot}9$ m. for tapered æration.

Design of the Secondary Settling Tanks

Example No. 25 :—Design final settling tanks for settling the above effluent.

Solution :—The capacity required is 12 per cent as was done in the case of humus tanks for settling effluent from percolating filters (vide page 400). This gives a detention period of about 3 hours.

$$\text{Capacity} = \frac{4{\cdot}5 \times 10^6 \times 12}{100} = 540000 \text{ lit.}$$
$$= 540 \text{ cu. m.}$$

If three tanks having a square section 7 m. $\times$ 7 m. in the upper 3 m. and bottom pyramidal sloping at 45° with a depth of 3 m. (see Fig. 311), are provided,

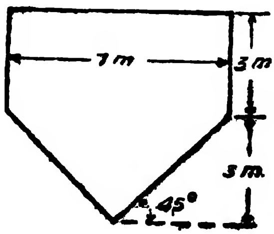


Fig. 311.

Volume of each

$= 7^2 \times 3 + 7^2 \times \frac{3}{3}$

$= 147 + 49 = 196$ cu. m.

That of 3 units $= 3 \times 196 = \mathbf{588}$ cu. m. which would suit.

Design of Sludge Rejuvenating Tank

We have proposed to take 30 per cent of activated sludge to be returned to æration tank, i. e.

$= 4{\cdot}5 \times 10^6 \times 0{\cdot}3 = 1{\cdot}35 \times 10^6$ lit.

$= 1350$ cu. m.

With 4 m. depth, area required $= \dfrac{1350}{4} = 337{\cdot}5$ sq. m.

Four units each 17 m. × 5 m. × 4 m. depth may be used.

Questions

(1) What is activated sludge, and what actually happens inside æration tanks according to the present accepted theory?

(2) How does return of effluent from secondary settling tanks to primary ones help? Under what circumstances is it more profitable?

(3) Describe the processes of diffuser and mechanical æration systems and discuss the pros and cons of two systems. What are the relative advantages of the combination of these two?

(4) Write brief notes on:

(a) Pre-æration of raw sewage;

(b) Tapered æration;

(c) Sludge index,

(5) What does "bulking of sewage" exactly mean? What are the probable causes of bulking of sewage in the activated sludge process?

(6) Design the æration tanks on the diffuser æration system for Surat City with a prospective population of 3 lakhs supplied with 200 lit. (45 gallons) of water p. h. p. d., 80 per cent of which reaches the sewers.

CHAPTER XXVI

DISPOSAL OF SLUDGE

Disposal of Sludge:—Sludge is the suspended solid matter deposited at the bottom of sedimentation tanks, mixed with a large quantity of water. There is no difference between sludge and scum in composition. Scum is the solid matter in sewage buoyed up by gas bubbles and caused to float at the surface.

Raw sludge from plain sedimentation tanks is grey, slimy and offensive in smell, with sp. gr. of about 1·02 and water contents varying from 95% to 98%. When it gets septic it is black, putrid, and slightly slimy.

The sludge from an Imhoff tank is thick, granular, and has a tarry odour, and sp. gr. 1·04 to 1·06 and water contents about 90% to 92%.

The sludge from trickling filters is greyish brown, flocculent, like humus, and contains dead larvæ of flies and mosquitoes. It is inoffensive when fresh. Sp. gr. about 1·02 to 1·03 and water contents 92 per cent.

The sludge from the final settlement tanks of activated sludge plant is dark brown, and odourless when fresh with sp. gr. about 1·0 and water contents 98% to 99·5%. The significance between 95 per cent and 99 per cent will be apparent when it is realised that in the former the volume of solids is five times the latter, and that for the same amount of solids 99 per cent sludge is five times as much in bulk as 95 per cent sludge.

Sludge digested in separate digestion tanks under control is black, quickly drainable, and of a little musty odour, which is not offensive. The nitrogen contents vary from 1·5 to 2·5 per cent and phosphoric acid 0·5 to 1·0 per cent. These two give it its fertilising value. It contains 10 per cent of dry solids of which nearly half is volatile matter.

With 70 to 80 per cent of moisture, sludge is viscous, and no longer flows. At 10 per cent moisture, it is dry and powdery.

From the above it will be seen that sludge is mostly water, and contains very little of solid matter. But it has high potentialities of pollution and so tenaciously holds water that it is very difficult to separate it.

The total volume of sludge varies from 1 to 10 per cent of the sewage flow. It is the greatest from activated sludge process, and next to it from chemical sedimentation tanks and it is the least from trickling filters (humus tanks).

The quantity of sludge can be calculated as shown in the following examples:

Example No. 26:—The sewage of a certain town contains 600 p. p. m. of suspended matter. Supposing that 55 per cent of this is settled down in the plain sedimentation tank and the sludge collected has water contents of 95%, calculate its quantity per mill. lit. both in bulk and weight. Assume sp. gr. 1·02.

Solution:—600 p.p.m. means 600 lit. per mill. lit.

Volume of suspended matter in the sedimentation tank

$$= 600 \times 0{\cdot}55 \text{ lit.}$$

Out of 100 parts of sludge there are 5 parts of solid matter.

$$\therefore \text{ The bulk of sludge} = (600 \times {\cdot}55) \times \frac{100}{5} = \mathbf{6600} \text{ lit.}$$

Since sp. gr. of sludge is 1·02, one lit. of it will weigh 1·02 kg.

$\therefore$ The wt. of sludge per mill. lit. of sewage

$$= 6600 \times 1{\cdot}02 = \mathbf{6732 \text{ kg.}}$$

Example No. 27:—Supposing 3 per cent of the remaining solids in the above example are digested in the æration tanks, and 20 p.p.m. pass out with the final effluent, what quantity of sludge will be produced in the final settlement tank of the activated sludge plant? Take sp. gr. of sludge equal to unity and 99 per cent water contents.

Solution :—The quantity of sludge produced in the final settlement tank of activated sludge plant

$$= (600 - 600 \times {\cdot}55) - \frac{3}{100}(600 - 600 \times {\cdot}55) - 20$$

$$= 600 \times {\cdot}45 - \frac{\;}{100} \times 600 \times {\cdot}45 - 20$$

$$= 600 \times {\cdot}45 \times {\cdot}97 - 20 = 241{\cdot}9 \text{ lit.}$$

Since water contents of sludge are 99%, for one lit. of dry sludge there must be 100 lit. of wet sludge.

∴ Volume of wet sludge = 241·9 × 100
= 24190 lit.

As the sp. gr. is 1, one lit. of sludge will weigh 1 kg.

∴ Wt. of wet sludge = **24190 kg.**

Methods of Disposal of wet sludge are :

(1) *Bargeing out into Deep Water* :—This is not possible in the case of inland towns, but only in cities which are favourably situated on the banks of large rivers or tidal water. Under favourable conditions this is the most economical and effective method of disposal. The question has been already discussed in connection with the method of dilution.

(2) *Land Treatment* consisting of either (*a*) trenching or (*b*) ploughing. In (*a*) trenches 1 m. wide and 0·6 m. deep (3′ wide and 2′ deep) are excavated in parallel rows about 1·5 m. (5 ft.) apart. After they are filled with sludge, the excavated earth is heaped on them. When sufficiently dry, new trenches are dug in between the old ones. When these are also dry, new trenches at right angles to the previous system are dug, and filled. If the soil is porous and thin at surface the method is good and economical. 1, 1·25, and 1 5 sq. m. (1¼, 1½ and 1¾ sq. yds.) of land is required per head for weak, medium, and strong sewages respectively. No crops are raised. For (*b*) i. e. ploughing, the sludge is mixed with milk of lime or powdered lime and spread on land, which is then ploughed. The land may be cropped if there is sufficient area in reserve for alternate resting. 1·25 to 1·75 sq. m. (1½ to 2 sq. yds.) are required per head, if it is of the proper type.

(3) *Lagooning*:—In this method earth tanks or ponds 0·6 to 1·25 m. (2 to 4 ft.) deep are made, under-drained with 75 or 100 mm. (3" or 4") agricultural drain pipes spaced at 2·5 to 3 m. (8 to 10 ft.). The bottom of the tank is then covered with a 15 cm. (6 in.) layer of clinker or ashes. They are filled with sludge and allowed to rest for 2 to 6 months. The moisture is partly drained and partly evaporated and the level shrinks to a little more than half the original, when the contents are dug out and used as manure. The site must be on the leeward side of and far removed from human habitation, as offensive odours are bound to be given off. It is not satisfactory from the point of public health. Its only merit is cheapness.

(4) *Incineration*:—This is a very costly method and therefore unsuitable for this country.

(5) *Drying on beds*:—With plenty of sun almost all the year round, this method is logically the most attractive, but the difficulty is of dewatering the sludge to enable the beds to absorb the water and expose only the solid matter to the sun. This has been described later in detail.

There are various methods employed in America such as filter presses, chemical precipitation, centrifuges, etc. for dewatering sludge, but they are unsuitable for this country mostly on the score of high costs. The only practicable method, viz. of separate sludge digestion tanks, which makes disposal of sludge by drying on beds easy, and from which power gas and manure can be produced is described here.

Digestion of Sludge in Separate Tanks:—This is accomplished in air-tight tanks with a dome at top for collecting gas. Sewage (or sludge) contains in itself anærobic bacteria which are further cultured by creating the most congenial environments for their growth by exercising proper controls so that, not only the sludge is digested, and rendered odourless, easy to dewater and dry out on beds and a large quantity of gas suitable for generating power is made available, but in addition, all the fertilising properties are preserved, so that the process yields valuable manure. The controls are in respect of temperature, pH value, quantity of feed, and thorough mixing of the fresh feed with the sludge already digested in the tank.

Tank:—This may be either of masonry or concrete with a floor of concrete. The shape may be either rectangular, square or circular. But, if a mechanical stirring equipment is provided, a circular shape is convenient. Otherwise a circular or a pyramidal tank with a hopper bottom is preferred The depth may be from 6 to 12 m. (20 to 40 ft.). The capacity is calculated just like that of the sludge chamber of Imhoff tanks, though usually 30 days storage may be sufficient. For Indian conditions a provision of 35 to 55 lit. (1·2 to 2·0 c. ft.) per capita is ample. The dome at the top may be either fixed or floating for collection of gases. In many Western countries the tank is heated. In our country it is unnecessary.

Fig. 312 shows a conventional, hopper-bottomed concrete tank. There is a feed pipe on the right hand side and the digested sludge is withdrawn from the bottom under hydrostatic pressure by opening the valve at the top on the left hand side The gas which collects at the top is drawn through the pipe at the top by opening a valve.

The Process:—The process is biological, in which the digestion of raw sludge, when mixed with digested sludge, starts first with acid fermentation of carbonaceous matter by the secretion of enzymes by the active anærobic bacteria in the digested sludge. At this time offensive smells are given off but soon inoffensive alkaline reaction sets in and as a result of breaking down of fats, proteins and carbohydrates, methane gas, which has a great calorific value is produced. Effective digestion and methane production depend upon the quick change-over from the acid stage to the alkaline one.

The factors of greatest importance in the digestion of sludge for maximum production of gas are:—(1) the maintenance of a constant temperature within the range 25° to 30°C

(80° to 85° F) at which the organisms of the right type rapidly develop. (2) Maintenance of alkaline condition within the alkaline region of $pH = 7{\cdot}3$ to 7 6. (3) Proper proportion of

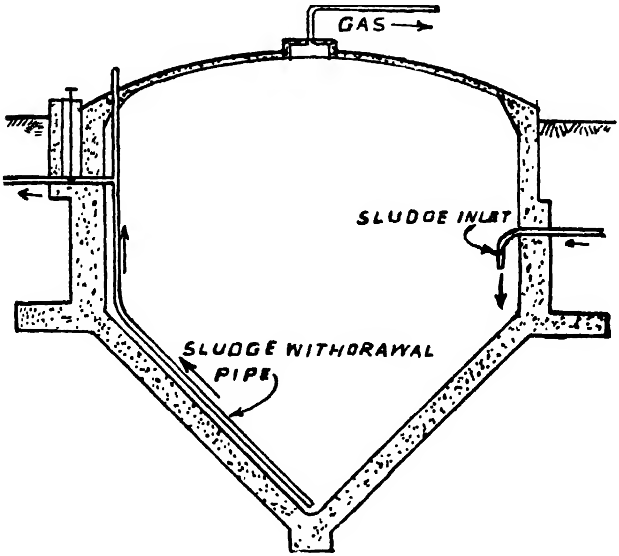


Fig. 312 – A hopper-bottomed sludge digestion tank.

fresh sludge to feed the bacteria in the digested sludge and (4) Sufficient intermingling or mixing of the fresh sludge with that already digested.

Consolidation of Sludge :—It is found by experience that for quick digestion, the optimum moisture in sludge should be 95 per cent. In some plants the sludge, prior to being pumped into digestion tank is consolidated. This is done in deep hopper-bottomed tanks with or without the aid of sludge thickening and scraping mechanism. The sludge consolidated under the weight of superincumbent liquid is drawn from the bottom under hydrostatic pressure, and the supernatant water is allowed to overflow a weir at the top.

(1) *Temperature*:—There are two ranges of temperature in which optimum digestion takes place. The first is the *mesophilic range* of 25° to 45°C (80° to 110° F) and the other, *thermophilic range* of 45° to 60°C (110° to 140° F). Digestion takes place more quickly in the thermophilic range, but it is a costlier method of heating coils, in which hot water, steam or heated air is circulated, must be provided even in this country. Hence in most cases the mesophilic range is employed. Even for this, artificial heating has to be resorted to in cold countries. It is not necessary in ours.

(2) *pH Control*:—When sludge is inoculated or seeded in proper proportions and kept at the proper temperature, it automatically assumes and maintains a state of alkalinity in a very short time. In fact if the right temperature and correct dosing are maintained, acid fermentation may be altogether prevented, in which case no offensive odours are produced. A *p*H value of 7·3 to 7·6 is considered to be the most favourable. Occasions may, however, arise by causes, such as withdrawal of too much sludge at a time, overdose of raw sludge, or sudden inflow of industrial wastes, etc., which may give rise to acidity. This can be corrected by adding hydrated lime or soda in proper proportions.

(3) *Dosing of Fresh Sludge*:—Unless there is sufficient ripe sludge in the tank to supply the necessary number of bacteria to digest the fresh sludge added, acid conditions are bound to be produced making subsequent control difficult. As a general rule not more than 30 lit. (one cub. ft.) of raw sludge should be added for every 1 cu. m. (30 cu. ft.) of ripe sludge in the tank. The capacity of the digester should be at 25 to 50 lit. (1 to 2 cu. ft.) per capita (on dry basis).

(4) *Effect of Stirring*:—The digested sludge remains at the bottom, and fresh feeds are at the top. Unless the latter are well mixed with digested sludge, teeming with active seeding material, the raw sludge will not be digested; stirring also equalises the temperature in heated tanks. In some plants mechanised stirring and scraping equipment is provided. It is more or less similar to the Dorr Clarigestor

illustrated in Fig. 292, page 386. Violent stirring also has been found to be detrimental.

Supernatant Liquid:—The liquid which collects at the top of the digestion tank is very foul, and contains a very large amount of suspended matter. If it is returned to the raw sewage it might upset the working of the entire plant. It is therefore either treated with some chemicals and settled in a separate tank or settled in two tanks in series—one primary and the other secondary, without any chemicals, and the liquid from the secondary is discharged into the incoming sewage.

About 50 per cent of the gas is produced during the first 24 hours, about 90 per cent is available in 10 to 14 days, leaving only 10 per cent to be recovered by continuing the process for weeks. It has consequently been found most economical to carry out the digestion in two stages. The first stage is for gas production and is carried out in closed tanks as described above. Then the sludge from the primary digestion tanks is digested in secondary tanks which are open, in which no attempt is made to collect gas, but the process is continued only to make the sludge inoffensive and easy to dewater.

It has also been found out that activated sludge, precipitated sludge from primary settling tanks, and ripe sludge mixed in the ratio of 1:1:2 are digested far more readily than is either of the former, alone or with ripe sludge.

Gas Production:—The amount of gas produced varies from 20 to 25 lit. (0·60 to 0·75 c.ft.) per day per capita. It includes methane, CO_2, H,N,O, and H_2S. Out of these methane predominates (about 65%), next is CO_2 which forms 30%, and all other gases together less than 5 per cent. The gas has a calorific value of 5300 to 5700 k.cal./cu m. (600 to 650 B. Th. U.). As it is explosive with a certain percentage of air, every precaution must be taken to prevent explosions.

High Rate Sludge Digestion Tank:—The shortcomings of the conventional sludge digestion tank are: (1) for digesting a certain quantity say 1 kilolitre of sludge, 30 to 35 kilolitres of ripe sewage have to be mixed up. (2) 50 to 60 days, detention period is normally required for proper digestion. Both these combined mean that a very large tank capacity is required for digesting sludge of a town or city with the cost of the plant soaring high. (3) The depth of such huge tanks is essentially considerable, and therefore the digested sewage at the bottom is compressed and consolidated under the high hydrostatic pressure, the supernatant liquid lies above it, and lastly the scum, which is very light accumulates at the top. This stratification of three different layers tends to create a sort of thermal stratification also, which impairs the efficiency of the tank. (4) This stratification results in dividing the gas-forming bacteria at two places, viz. at bottom in the digested sludge, and at top in the scum. Thus the formation of methane gas is retarded, than if they were working at one place in unison.

As a result of research and experimentation on pilot plants a new process has been recently developed, based essentially on mixing or churning the raw and digested sludge together, and thus preventing the formation of stratification. This is further helped by introducing heat into the tank. With these improvements the detention period has been reduced from 50 days to 10 or 15 days, and with the consequent reduction in tank capacity the cost has been proportionately reduced.

The mixing is effected in several ways: (1) Recirculation of sludge gas, produced as a result of sludge digestion. Part of the gas produced is heated and compressed, and is introduced through diffusers placed at the bottom of the tank. In some patents, instead of gas, heated air is similarly forced through diffusers to create turbulence. (2) Mechanical mixing. This is shown diagrammatically in a longitudinal section of a high rate digestor at Jamaica (U. S. A.). Each tube is located at a distance of 0·6 of the radius from the centre of the tank. The mixers are driven by 10 H. P. motors. The propeller may be operated in the vertical direction also to loosen debris from the blades. The level of the liquid is carefully controlled and its level is never allowed to vary more than 8 cm. from the optimum, since by a suitable arrangement, as the heated raw sewage is pumped

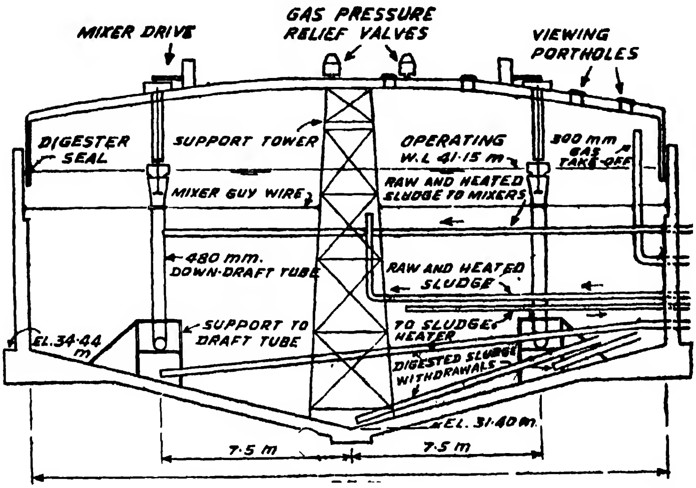


Fig 313 – High-rate sludge digestion tank with mechanical mixer, used at Jamaica.

into the tank, an equal quantity of digested sewage flows out. Four withdrawal pipes are provided. One takes suction at the bottom, and the other three go out to points 120° apart, and 7·5 m. out from the centre. The centre draw-off is used in conjunction with a pump, but the outer draw-offs are gravity lines. A 300 mm. gas pipe removes the gas collected at top. The sludge from the high-rate tank is admitted to another tank of equal size called the "residual gas extractor tank". The undigested or high-ash sludge from the bottom of the digestor cone is pumped out from time to time Sludge recirculation at a higher level is effected by having the sludge heater pumps discharge into the raw sludge feed pipe.

The advantages of the high-rate digestion tank are: (1) Far much less capacity of tank and consequent saving in capital cost. (2) The entire process is stable, with no upsets whatever, and (3) Solid destruction is accelerated, and also the heat losses are much less.

Advantages of Sludge Digestion :—(1) It prepares the sludge for disposal without nuisance, since digested sludge can be easily drained, and dried on sand-beds.

(2) It reduces the bulk to about 30 to 45 per cent of the original volume of solid organic matter by digestion.

(3) It compacts the sludge and reduces the water contents to 90 per cent.

(4) It produces valuable gas for power.

(5) It preserves the fertilising value of sludge which would be destroyed if incineration were to be adopted.

Design of a Sludge Digestion Tank

Example No. 28 :—Design a tank for digesting and producing gas from the sludge of a town of 50,000 population, having roughly 0·05 kg. of dry contents per head per day in it. The sludge is consolidated in a tank previously so that its moisture contents are reduced to 95% and its sp. gr. is 1·02.

Solution :—Weight of dry sludge per day

$$= 50{,}000 \times 0{\cdot}05 = 2500 \text{ kg.}$$

For every 5 kg. of dry weight, there is 100 kg. of wet sludge, the sp. gr. of which is 1·02.

∴ Total weight of daily wet sludge

$$= 2500 \times \frac{100}{5} \times 1{\cdot}02 = 51000 \text{ kg.}$$

1 cu. m. of this sludge weighs 1000 kg.

$$\text{Volume} = \frac{51000}{1000} = 51 \text{ cu. m.}$$

Assuming that only 3 per cent of raw sludge is to be mixed with ripe sludge in the digester,

$$\text{Required tank capacity} = \frac{51 \times 100}{3} = 1700 \text{ cu. m.}$$

$$\text{Add 30\% margin for fluctuations} = \underline{510 \text{ cu. m.}}$$

$$\text{Total capacity} = 2210 \text{ cu. m.}$$

$$\text{This is } \frac{2210}{50000} = 0{\cdot}0442 \text{ cu. m. per head per day.}$$

$$= 44 \text{ lit.}$$

If the sludge from the sedimentation tank also is to be added to this, the capacity required may perhaps be double this. Assuming the volume of gas produced per capita per day to be 20 lit. = 0·02 cu. m. the gas produced per day will be 50,000 × 0·02 = 1000 cu. m. Taking 5500 k. cal. as the calorific value per cu. m. 1000 × 5500 = 550,0000 k. cal. will be produced per day. Allowing 5 per cent of heat to be lost by radiation net gain would be at least 5225000 k.cal.

$$\therefore \quad \frac{5225000}{24 \times 3600} = 60{\cdot}47 \text{ k. cal. / sec.}$$

1 k. cal. / sec. = 5·6925 p. s. (Metric HP.)

∴ Gross power with 35% efficiency

$$60{\cdot}47 \times \frac{5{\cdot}6925 \times 35}{100} \qquad \mathbf{120{\cdot}5 \text{ P. S.}}$$

Taking 70% mechanical efficiency, about 84 (metric) B. H. P./24 hrs. would be the net power available.

There will thus be considerable power in reserve after meeting the demand for driving the plant, which at 0·5 B. H. P./day per 10,000 population will not be more than 25 B. H. P. maximum. If the sludge from primary settling tanks is added, the power will be still greater.

Drying Beds :—Beds for drying sludge are made by first of all excavating trenches about 0·5 m. (18 in.) wide and 0·5 to 0·6 m. (18 to 24 in.) deep with a slight bed-fall, say, about 1 in 100 in the direction in which the ground is sloping. They are 8 to 10 m. (25 to 30 ft.) between centres. Kerb walls either of masonry or concrete are built round the beds with a free board of 0·6 m. (2 ft.) above the top of the beds. Each bed is about 12 to 20 m. (40 to 60 ft.) wide, by 30 to 35 m. (100 to 120 ft.) long. In the trenches clay pipes or porous concrete pipes about 150 mm. (6 in.) diam. are laid with open joints on a 15 cm. (6") layer of 4 to 8 cm. (1½ to 3 in.) size crushed stone, and the top and sides are filled with the same material up to the ground surface. On their top, bed of graded gravel 2·5 to 4 cm. (1 to 1½ in) size and 30 cm. (1 ft.) thick, and on its top again a 8 to 25 cm. (3 to 9 in.)

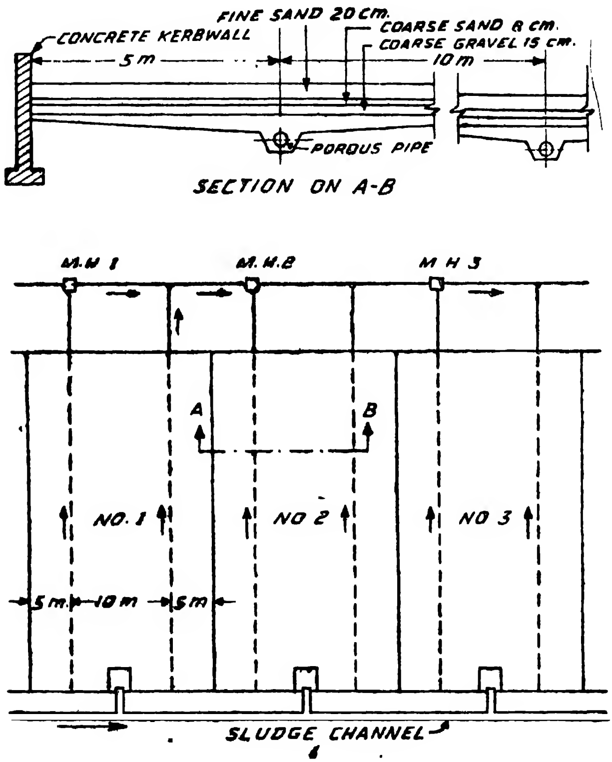


Fig. 314, 315—L. section and plan of sludge-drying beds. The thick lines on plan represent concrete kerb walls and the vertical dotted lines, drains of porous pipes. Each plot is 20 m. × 30 m. (60' × 100').

layer of 3 to 6 mm. ($\frac{1}{8}$ to $\frac{1}{4}$ in.) sand is spread making the entire bed 0 4 to 0·5 m. (15 to 18 in.) thick above the ground surface. Sludge is run into the beds at the middle of the shorter side on the top of a slab so that it should not scour the sand, the depth of the sludge at any time being 20 to 30 cm. (8 to 12 in.). The water soon soaks into the ground and part is evaporated. Cracks are formed in the surface as the layer shrinks, further increasing the surface for evaporation. It takes about 1 to 2 weeks for the layer to dry. Thus the same bed can be used about 25 times in a year. A 30 cm. (12 in.) original layer of wet sludge is reduced to about 8 to 10 cm. (3 to 4 in.). It is then shovelled off. It is inoffensive and may be used as a fertiliser as it contains about 2 to 2·5 per cent of nitrogen and 0·5 to 1 per cent of phosphorus, or it may be used for filling depressions. When the preceding layer is completely removed, a fresh layer may be laid on the same bed. Fig. 314 shows an enlarged section of a bed across two trenches and Fig. 315, a plan. There is an inlet channel with branches for sludge on one side and outlet pipes for collecting percolating water with manholes for inspection on the other, shown on the plan.

Example No. 29 :—Calculate the area of land required for drying the sludge from the digesting tank for 50,000 population designed in Example No. 28.

Solution :—The volume of wet sludge from the sewage of 50,000 population worked out was 51 cu. m. per day. If it is spread in a 20 cm. layer on underdrained sand-beds, the area required

$$= \frac{51}{1} \times \frac{1}{0{\cdot}2} = 255 \text{ sq. m.}$$

In the tropical atmosphere of this country it dries out in about 10 days, since the major part of the moisture percolates to the underdrains. Still allowing 2 weeks on an average, including wet days of rainy season, the same bed can be utilised $\frac{52}{2}$ = 26 times.

$$\therefore \text{ Area required} = \frac{255 \times 365}{26} = 3580 \text{ sq. m.}$$

Making 100 per cent allowance for space for storage, repairs to bed and rest, etc.

Net area required = 2 × 3580 = 7160 sq. m.

This works out to less than 0·14 sq. m. per head in this country.

Questions

(1) A certain crude sewage has 450 p. p. m. of suspended solids. When it is settled in primary sedimentation tank with two hours' detention, 60% of the solids are removed and the water contents of the sludge will be 95%. What will be the volume of the sludge per mill. litres of sewage settled?

Answer : 86·4 kg.

(2) What are the characteristics of sludge from the final sedimentation tank of activated sludge process?

(3) The sewage of a town containing 250 p. p. m. of suspended solids of which 60% are organic is treated in an Imhoff-tank so that 50% of the organic matter is digested and the moisture content of the sludge withdrawn is 95%. What would be the bulk of the sludge per mill. litres of crude sewage?

Answer : 19·94 cu. m.

(4) Describe the action of a sludge digestion tank. What controls are required for maximum efficiency?

(5) What would be the capacity of digestion tank if the sludge in problem (3) above is digested in it? What will be the amount of gas, B. Th. U.s, and B. H. P./24 hrs. produced?

CHAPTER XXVII

DISPOSAL OF INDUSTRIAL WASTES *

With the rapid industrial development of the country during the past decade the problem of treatment of industrial wastes has become very acute. At any rate the final disposal must be in the nearest river or stream, and the objective to be achieved is to maintain the stream water within certain standards of purity.

The acids from certain industries such as bleaching, dyeing, electro-plating, dyestuff manufacturing, etc., alkalis from soap works, and phenols from coal gas manufacture are most detrimental to the bacterial life. Industries like dairies, slaughter-houses, corn products, biscuit and other food manufactures, breweries, etc. contribute such a large load of organic matter that the usual methods fall too short for treating them.

The problem is made still more difficult by the fact that these wastes may be discharged in sudden irregular and intermittent rushes. If they were received at some constant rate during all the 24 hours or at least, 12 hours of the day it would be possible for the Engineer in charge to anticipate and take adequate measures.

The first and obvious remedy is to construct tanks of adequate capacity in which to store and balance the discharge. But if the wastes be of organic character, it is very likely that their long detention in the balancing tanks might cause septicity, and render the problem of treating them at sewage works more complicated and expensive. The remedy is to provide means of removing sludge in such tanks. But it would increase the cost.

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* A large part of the information contained in this chapter is culled from the paper published by Dr. Bhoota and Shri Rao on "Industrial Waste Treatment" published in *Chemical Age of India* [*No.* 4, *Vol.* 10 (1959)].

Classification of Industrial Wastes:—The great variety of wastes produced by still greater varieties of industries are too complex and difficult to be classified. Different authorities have classified them in different ways. Amongst the most scientific classifications is: (a) Organic, (b) Inorganic, and (c) Mixed. As a general rule the inorganic wastes need chemical and/or mechanical treatment, as they do not respond to biological treatment. The organic wastes, on the other hand, are best treated by biological methods.

Methods of Treatment:—These may be classified under: (1) Mechanical, (2) Chemical, (3) Biological, and (4) Combination of these.

(1) **Mechanical Treatment**:—This is the basic primary treatment of all methods, as it reduces a considerable part of the load of the wastes. It includes (a) screening, (b) floatation, (c) centrifugeing, (d) sedimentation, (e) filtration (mechanical), (f) drying, and (g) incineration. The treatment plant might involve one or more of these operations.

Sedimentation and mechanical filtration are most extensively used. To these is often taken the help of coagulants. Mechanical filtration is effective only when the "sludge" obtained from sedimentation operation contains relatively coarse, and easily dewaterable suspended solids, and is useful when the dewatered sludge can be utilised in the factory, such as in paper, textile, iron-and-steel and several other industries. When the dewatered sludge is not utilised, the most economical way of disposing it, particularly in tropical countries like ours is to resort to sludge drying beds, which act as filters.

The flow of wastes may not be uniform, it may vary from a mere trickle at some time to a sudden rush at others.

Vacuum filters are most commonly used in industrial waste treatment. To avoid the replacement of filter cloth, and reduce clogging, a new type of vacuum filter with a medium entirely composed of coil springs, in the form of long cords has been developed with great success in the U. S. A., and is used both for treatment of sewage and industrial wastes.

(2) **Chemical Treatment**:—In this different chemical reagents are added to neutralise the acids or alkalis in the composition, which is, in most cases, inorganic; they also help to precipitate and oxidise them. Sometimes in addition to chemicals, coagulants are used to aid in flocculation and sedimentation. For determining the particular chemical reagent required, prior careful analysis of the waste is necessary. In treating certain kinds of wastes, the *p*H value of the liquor has to be closely controlled. The following flow diagram (Fig. 316) illustrates the operations of a typical chemical treatment plant.

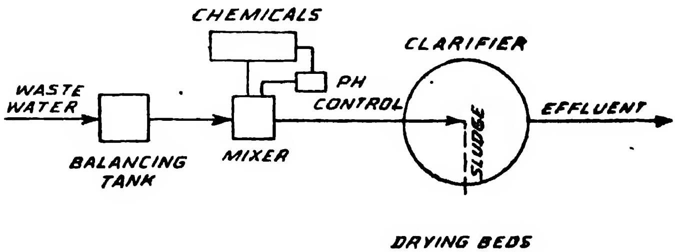

Fig. 316—Flow diagram for treatment of wastes from a chemical plant.

(3) **Biological Treatment**:—A large number of industrial wastes contain organic matter, which responds to biological treatment. Though it is possible to remove it by other methods it is often the most economical These methods are : (a) Biofilter, or trickling filters, (b) Activated sludge, (c) Digestion, and (d) Combination of the above, and miscellaneous. Of these biofilter and activated sludge are ærobic processes, and digestion is anærobic.

In the biofiltration or high-rate trickling filter method, not only organic substances of animal or vegetable origin, are oxidised, but, those of synthetic origin also like phenols, cyanides, pharmaceutical wastes, chemical plant wastes, etc. This method is very simple and extremely flexible, and allows, with variations, such as single-stage, two-stage, etc. to obtain any desired degree of purification. This is shown diagrammatically in a flow-diagram in Fig. 317, which is a plant for antibiotic factory waste treatment.

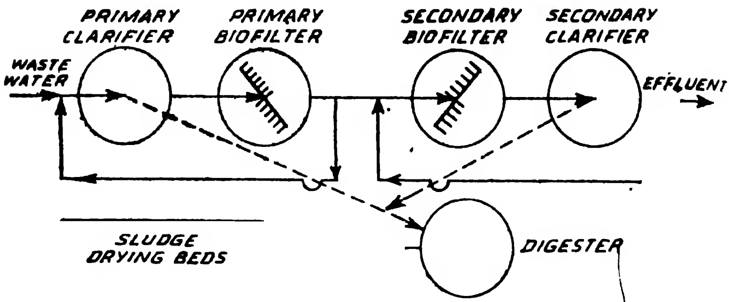

Fig. 317—Flow diagram for treatment of wastes from antibiotic plant.

Then activated sludge and / or biofilter process is often used for treating industrial wastes, especially when the major portion of the impurities are of organic character. If a choice is to be made between activated sludge process and biofilters the latter is to be preferred. For, though less space is required for activated sludge treatment, it is rather sensitive. It is more easily upset by fluctuation in either the rate of flow, or its composition. There is a tendency of the sludge to swell and become light. Such bulking makes the work of clarification difficult. On the other hand trickling filters are capable of dealing with "shock" or sudden loads within reasonable limits. The best way is to test on a pilot plant in the beginning, and determine which of the two processes is suitable and economical. Very often the activated sludge process is followed by trickling filter treatment. This ensures a higher degree of purification.

Digestion :—The process of digestion is similar to the one we have already considered while describing the treatment of sewage. The only difference is that whereas in sewage treatment only sludge is digested, here the liquid wastes are treated. This is a very economical method for treating wastes in which the dissolved and colloidal solids mostly of organic matter, with high B.O.D. values constitute the major portion of the polluting matter. The liquid wastes are simply allowed to rest from 5 to 10 days depending upon their impurities. A 5-day detention is found to have removed 60 to 80% B.O.D. The remaining purification of the supernatant liquid is effected by biological treatment, but it does not cost much as only a few impurities are to be removed. As the digestion is always followed by biological treatment, it is often called "predigestion".

Disposal of sludge from industrial wastes does not usually present a problem, unless the waste is particularly obnoxious, or otherwise objectionable. As it contains a large volume of water, the most suitable and economical way is to dispose of it by drying in beds, directly or after dewatering.

If it is possible to enter into an agreement with manufacturers that they will scrupulously observe certain rules before discharging their waste water into public sewer, much improvement could be effected. These conditions usually are that:

(a) Wastes shall not be discharged into sewers at a temperature exceeding 65° C. (150° F.).

(b) Grit and coarse matter shall be removed to the satisfaction of the sanitary authorities.

(c) The flow shall be metred and flows in excess of certain limits shall be regulated and equalised, and,

(d) There shall be regular chemical analysis provided.

Failing this it should be possible for the Engineer, with the help of his chemist, to evaluate a few times in the year the strength of the trade wastes of each industrial concern in point of the extra expenditure required for treating such wastes, to find out average results and charge the industry on that basis. The strength of the trade wastes may alternatively be converted into equivalent relative volume of domestic sewage. This should not be difficult since the total solids contained per 4500 liters (1,000 gallons) or contributed per head of population, are more or less constant. This has been suggested in the form of "population equivalents" on page 322 of this volume.

In short, the main line of dealing with trade wastes comprises:

(1) Neutralisation of the liquid by adding suitable cheap chemicals.

(2) Regulating and equalising the discharge.

(3) Settling suspended matter in separate sedimentation tank, and,

(4) Taxing the industries on the basis of the strength of the wastes from the point of view of the extra labour and expense of treatment, or on the basis of population equivalent.

CHAPTER XXVIII

CONCLUSIONS, REVIEW, COMPARISONS

Preventing Septicity in Sewage :—From the foregoing discussion one thing must be clear that in the interest of economy and simplicity of treatment, it is essential that the sewage arriving at the outfall works should be in as fresh a condition as possible. This is particularly important in a tropical country as ours where sewage soon gets stale. The measures to be adopted for attaining this aim are both preventive and remedial. They are :

(1) **High Velocity of Flow** :—The sewers should be so designed as to create a minimum of 1 to 1·25 or even 1·5 m. (3 5 to 4 or even 5 ft.) velocity per sec. This is advantageous in various ways : (a) It conveys the sewage more quickly to disposal works. (b) It reduces the sizes of sewers and effects initial economy. (c) With sewers, thus made self-cleansing, there is much less chance of blockage and consequent putrefaction. (d) It reduces the cost of maintenance and cleaning, and (e) It insures longer life to sewers, especially if they are of concrete, as the latter gets corroded by the action of sulphur gases which are given off when sewage putrefies.

(2) **Installation of a Number of Small Pumps** :—Where the country is flat as in the Northern parts of India, steep gradients are not possible unless pumping is resorted to. Modern pumps are very efficient, and with the contemplated electric grid system, electric power should also be cheap in a not-very-distant future. Pumps should therefore be safely installed. But instead of making deep excavations and installing one or two high power pumps, a large number of small units to lift the sewage *half a meter (a foot) or so* at every place should be established. The advantages are : (a) The sewers would be shallow, and therefore the excavations less and accessibility easy. (b) With modern efficient pumps the break-downs should be few and far between. Even if any failure occurs it will not stop the flow ; a non-return gate will allow the sewage to head up a foot or more, (for which there is always sufficient free-board), and flow temporarily until the fault is remedied. If the pumping units are of the

same make and size, only a few spare parts would be required and they will not cost much. (c) This arrangement is bound to prove cheaper than spending large sums annually on continual cleaning, and removing blockages in flat sewers.

(3) **Chlorination of Sewage** :—This has been tried with great success in a large number of towns in the West to prevent septicity and check odours. This is, however, practicable where chlorine is cheap and is not required to be imported from foreign countries.

(4) **Ventilating Sewers** :—Over and above the ventilation of sewers ordinarily practised by providing ventilators along sewer lines, if either air is pumped into sewers by blowing into them at the lower ends, or is extracted from the upper ends, it is found by experience at Los Angeles* that corrosion of concrete pipes by the formation of sulphuretted hydrogen gas is checked. This method has been in use at Melbourne. However, it is doubtful how far it would be economically successful in this country.

Comparison of Different Methods:—Coarse screening and grit removal are necessary whatever the method adopted They are required especially for the protection of pumps.

Fine screening has been almost wholly replaced in recent years by sedimentation.

Plain sedimentation, even at its best does not affect the colloids and dissolved impurities in sewage. Chemical precipitation removes most of the colloids, but not the dissolved organic matter.

The largest area of land is required for irrigation, the next in descending order are: land filtration, intermittent sand filtration, contact beds, trickling filters, activated sludge process, high-rate trickling filters, plain sedimentation, chemical precipitation, and fine screening.

Septic tanks digest a considerable amount of sludge, but the effluent produced is very septic, and therefore difficult and costly to treat. Their use is therefore confined to rural, domestic or isolated situations where the small amount of

* Report on Disposal of Sewage submitted to the Bombay Municipal Corporation by N. V Modak.

effluent can be successfully treated by land filtration, or irrigation.

Trickling filters are simple in operation and efficient, but they consume 2·5 to 4 m. (8′ to 12′) head, which necessitates pumping. There is, besides, a great probability of ærial nuisance and nuisance due to flies. However, with the improvements made recently in respect of reduction of depth, recirculation of purified effluent, and continual feed have resulted in enhancing its merits especially in checking fly and odour nuisance on account of the dissolved oxygen supplied with the recirculated effluent, it promises a great future. Entirely closed percolating filters working on fresh air pumped into them by blowers are both efficient and free from both the nuisances.

Imhoff tanks require a great depth and are not suitable in deep sand or in rock. The probable trouble from foaming cannot be altogether ignored. However, as there are no mechanical appliances required, nor the necessity of a chemist, they may prove useful in small towns and villages of India. At least they are worth giving a trial to.

Contact beds consume the least head and are less liable to the nuisance from flies and offensive odours, but the effluent is of a poorer character as compacted with that from trickling filters. Besides they are uneconomical.

Activated sludge process has the disadvantages of its heavy maintenance cost on power for working the plant, the necessity of constant skilled attention, and its sensitive nature which causes it to get upset by variations in quality and quantity of sewage, and the problem of disposal of a large quantity of sludge, difficult to dewater. These detract from its numerous advantages, especially freedom from ærial and fly nuisance and uniformly good quality of effluent produced. The high operating cost and particularly the maintenance of a well equipped laboratory and the necessity of highly trained, competent staff make it unsuitable for any but large cities.

A few comparative figures of results of different processes are given below :—

TABLE NO. 25 ‡

Relative Amount of Sludge from Different Settlement Tanks

Preliminary Process	Sludge Deposited Parts per 100,000	Wet Sludge (90% water per mill. lit.)
Quiescent settlement with chemicals	37·5*	3·8 tonnes
Continuous flow settlement ,,	35·5*	3·6 ,,
Quiescent settlement alone	28·0	2·6 ,,
Continuous flow settlement alone	25·0	2·5 ,,
Septic tank	14·5	1·7 ,,

* 5 parts per 100,000 of chemicals added to the sewage

TABLE NO. 26

Relative Purification Obtainable by Different Methods of Tank Treatment

	Ammonia Nitrogen	Oxygen absorbed in 4 hours	Suspended Solids
Domestic sewage of average strength	4	10 to 11	28 to 30
Chemical precipitation and settlement (2 hours)	3·5 to 4	4·5	1 to 4
Chemical precipitation and 8 hours continuous flow settlement ...	3·7 to 4	5·5	3 to 6
Quiescent settlement (2 hours) ..	3·8	6·5	5·8
Continuous flow settlement (15 hours)	3·8	7 5	10 to 15
Septic tank 24 hours continuous flow	4·5 to 5	7·5	10 to 15

The initial cost depends upon a number of varying factors such as land, construction, machinery, etc. and the operating cost depends upon a still greater number of varying factors including character of sewage, climate, dilution available for final discharge of effluent, degree of purification aimed at, and so on. So it is impossible to make comparisons in respect of cost.

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‡ Taken from the 5th report of the Royal Commission on Sewage Disposal.

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