and other feed stuffs contains high protein content and is a useful cattle-feed supplement.

The hydrolysis and distillation steps require a high energy input ; for woody feedstocks direct combustion or pyrolysis is probably more productive at present, although steam treatment and new low-energy enzymatic hydrolysis techniques are under development. The energy requirement for distillation is also likely to be cut dramatically. Alcohol can be separated from the beer by many methods which are now under intensive development. These include solvent extraction, reverse osmosis, molecular sieves and use of new dessicants for alcohol drying. It may soon be possible to *halve* the energy required for alcohol production to produce a greater net energy gain.

Chemical reduction. Chemical reduction is the least developed of the wet biomass conversion processes. It involves pressure—cooking animal wastes or plant cellulosic slurry with an alkaline catalyst in the presence of carbon monoxide at temperatures between 250°C and 400°C. Under these conditions the organic material is converted into a mixture of oils with a yield approaching 50%. If the pressure is reduced and the temperature increased, the product is a high calorific value gas.

7.2.2. Dry Processes

Pyrolysis. A wide range of energy-rich fuels can be produced by roasting dry woody matter like straw and wood-chips. The material is fed into a reactor vessel or retort in a pulverised or shredded form and heated in the absence of air. (Air would cause the products of pyrolysis to ignite). As the temperature rises the cellulose and lignin break down to simpler substances which are driven off leaving a char residue behind. This process has been used for centuries to produce charcoal.

The end products of the reaction depend critically on the conditions employed ; at lower temperatures—around 500°C—organic liquid predominate, whilst at temperatures nearer 1000°C a combustible mixture of gases results.

Liquefaction. Liquid yields are maximized by rapid heating of the feedstock to comparatively low temperatures. The vapours are condensed from the gas stream and these separate into a two-phase liquor : the aqueous phase (pyroligneous acid) contains a soup of water-soluble organic materials like acetic acid, acetone and methanol ('wood alcohol') ; the non-aqueous phase consists of oils and tars. These crude products can be burnt (with some difficulty), but it is usually more profitable to up-grade them to premium fuels by conventional refining techniques.

Other pyrolysis products include fuel gas—essentially carbon-monoxide and hydrogen and carbon char. The gas is generally burnt to maintain the temperature of the reactor ; the char can be manufactured into briquetts for use as solid fuel.

Pyrolysis can also be carried out in the presence of small quantities of oxygen ('gasification'), water ('steam gasification') or hydrogen ('hydrogenation').

Gasification. Pyrolysis of wet biomass produces fuel gas and very little liquid. An alternative technique for maximising gas yields is to blow small quantities of air or oxygen into the reactor vessel and to increase the temperature to over 1000°C. This causes part of the feed to burn. Fuel gas from air-blown gasifiers has a low calorific value (around 5 MJ/m^3) and may contain upto 40% inert nitrogen gas overall yields of 80-85% can be expected. Fuel gas from oxygen-fed systems has a medium calorific value (10-20 MJ/m^3). This gas can either be burnt or converted into substitute natural gas (methane) or methanol by standard catalytic processes. Methanol yields of around 50% can be achieved from biomass.

Steam-gasification. Methane is produced directly from woody matter by treatment at high temperatures and pressures with hydrogen gas. The hydrogen can be added or, more commonly, generated in the reactor vessel from carbon monoxide and steam. Recent analyses suggest that steam gasification is the most efficient route to methanol. Net energy yields of 55% can be achieved although higher yields are likely in the future as the technology is developed.

Hydrogenation. Under less severe conditions of temperature and pressure (300-400°C and 100 atmospheres), carbon monoxide and steam react with cellulose to produce heavy oils which can be separated and refined to premium fuels.

Many countries are actively developing commercial processes for biomass liquefaction and gasification.

7.3. Photosynthesis

The most important chemical reaction on the earth is the reaction of sunlight and green plants. Radiant energy of sun is absorbed by the green pigment chlorophyll in the plant and is stored within the plant in the form of chemical bond energy. Photosynthesis in the plants is an example of biological conversion of solar energy into sugars and starches which are energy rich compounds. So if plant fast growing trees having high photo-synthesis efficiency we can harvest and burn them to produce steam in a similar manner as in thermal power stations ultimates to produce the electric power. Such an "energy plantation" would be a renewable resource and an economical means of harnessing solar energy. However, photo-synthesis concepts are less attractive as the average efficiency of solar energy conversion in plants is about 1% and the overall efficiency of the conversion sunlight to electricity would be about 0.3% compared to 10% for photo-voltaic cells.

$\therefore$ Final net trapped energy $= 0.6 \times 9.2$

$= 5.52\%$ of insolation.

This table gives only a specific case. However in literature we find that photosynthetic efficiencies have been quoted from 0.1 to 5%. This variation is mainly because of two reasons :

(*i*) There is a wide variation in efficiency from plant to plant.

(*ii*) There are two basis which are being used for calculation of efficiencies. Some people calculate it on the basis of yearly insolation independent of the duration of maturity of a given crop. For example, even if a particular crop matures in 3 months, the chemical energy stored is presented as a fraction of the total insolation throughout 12 months. On the other hand some efficiencies stated are based upon the insolation received only in the duration of maturation of a particular crop.

7.4. Biogas Generation

Introduction. Biogas, a mixture containing 55-65 percent methane, 30-40 percent carbon dioxide and the rest being the impurities (H_2, H_2S, and some N_2), can be produced from the decomposition of animal, plant and human waste. It is a clean but slow burning gas and usually has a calorific value between 5000 to 5500 kcal/kg (20935 to 23028 kJ/kg) or 38131 kJ/m^3. It can be used directly in cooking, reducing the demand for firewood. Moreover, the material from which the biogas is produced retains its value as a fertilizer and can be returned to the soil. Biogas has been popular on the name, "Gobar Gas" mainly because cow dung hag been the material for its production, hitherto. It is not only the excreta of the cattle, but also the piggery waste as well as poultry droppings are very effectively used for biogas generation. A few other materials through which biogas can be generated are algae, crop residues (agro-wastes), garbage kitchen wastes, paper wastes, sea wood, human waste, waste from sugarcane refinery, water hyacinth etc., apart from the above mentioned animal wastes. Any cellulosic organic material of animal or plant origin which is easily bio-degradable is a potential raw material for biogas production.

Biogas is produced by digestion, pyrolysis, or hydrogasification. *Digestion* is a biological process that occurs in the absence of oxygen and in the presence of anaerobic organisms at ambient pressures and temperatures of 35-70°C. The container in which this digestion takes place is known as the *digester*.

Anaerobic digestion. Biogas technology is concerned to micro-organisms. These are living creatures which are microscopic in size and are invisible to unaided eyes. These are different types of micro-organisms. They are called bacteria, fungi, virus etc. Bacteria again can the long time involved, and 60% conversion is common. Gas yield is about 0.2 to 0.4 m^3 per kg dry digestible input at STP, with throughput of about 5 kg dry digestible solid per m^3 of liquid.

It is generally considered that three ranges of temperature favour particular types of bacteria. Digestion at higher temperature proceeds more rapidly than at lower temperature, with gas yield rates doubling at about every 5°C increase. The temperature ranges are (1) psicrophilic, about 20°C, (2) mesophilic, about 35°C and (3) thermophilic, about 55°C. In tropical countries unheated digesters are likely to be at average ground temperature between 20 and 30°C. Consequently the digestion is psicrophilic, with retention times being at least 14 days. In colder climates the digesters have to be heated, probably by using part of the biogas output, and a temperature of about 35°C is likely to be chosen. Few digesters operate at 55°C unless the purpose is to digest material rather than produce excess biogas.

The *biochemical processes* occur in three stages, each facilitated by distinct sets of anaerobic bacteria :

1. Insoluble biodegradable materials, *e.g.* cellulose, polysaccharides and fats, are broken down to soluble carbohydrates and fatty acids. This occurs in about a day at 25°C in an active digester.

2. Acid forming bacteria produce mainly acetic and propionic acid. This stage likewise takes about one day at 25°C.

3. Methane forming bacteria slowly, in about 14 days at 25°C, complete the digestion to ~ 70% CH_4, ~ 30% CO_2 with trace amounts of H_2 and perhaps H_2S. H_2 may play an essential role, and indeed some bacteria (*e.g. clostridium*) are distinctive in producing H_2 as the final product.

The methane forming bacteria are sensitive to pH, and conditions should be mildly acidic (pH 6.6 to 7.0) and certainly not below pH 6.2. Nitrogen should be present at 10% by mass of dry input, and phosphorus at 2%. A golden rule for successful digester operation is to *maintain constant conditions* of temperature and suitable input material. As a result a suitable population of bacteria is able to become established to suit these conditions.

When comparison of methane percentage from different organic matter was done for example cowdung. Poultry dropping and dairy waste scum, then best result was observed in dairy waste. 75 to 79 methane percentage found in dairy waste biogas while in cowdung, biogas was only 65 percent.

Advantages of anaerobic digestion. There are number of advantages of anaerobic digestion.

1. *Calorific value of gas.* One of the main benefits is the production of a biproduct the biogas which has a calorific value and can

therefore, be used as an energy source to produce steam or hot water. Because in dairy industries energy source is very important for dairy use, so there is no problem of gas storage or supply, but gas can be directly useful in heat energy.

2. *New sludge production.* The conversion of organic matter to methane and carbon dioxide results in a smaller quantity of excess sludge.

3. *Stable sludge.* In the case of municipal digestion the main reason for their installation was to produce a non-putrescable and inoffensive sludge and in many cases only a proportion of the gas produced was utilised.

4. *Low running cost.* There is no airation in the anaerobic treatment naturally in this digestion, running costs are a quarter of the equivalent aerobic system.

5. *Low odour.* Since the system is enclosed the odours are contained. Compounds which are responsible for odour are broken down during digestion. The only slight odour of hydrogen sulphide normally presents in gas. However if the gas is burnt the problem will not arise.

6. *Stability.* A well adapted anaerobic sludge can be presented unfed for a considerable period of time without appreciable deterioration.

7. *Pathogen reduction.* Work has shown that passage of the effluent through the digester reduces the number of pathogens present, so reducing subsequent disposal problems.

8. *Value of sludge.* The cases where aerobic sludge is treated anaerobically the resultant sludge has a higher nitrogen content giving it increasing value as a fertilizer. It has also been reported that the sludge acts as a soil conditioner.

9. *Low nutrient requirement.* As a consequence of the low production of the bacterial solids the nutrient requirement is also low.

In addition using of biogas in industries will curtail the consumption of coal. If biogas is used instead of coal in boilers, it will lessen the air pollution.

7.5. Factors Affecting Biodigestion or Generation of Gas

The following are the factors that affect generation of biogas :

(1) pH or the hydrogen-ion concentration

(2) Temperature

(3) Total solid content of the feed material

(4) Loading rate

(5) Seeding

(6) Uniform feeding
(7) Diameter to depth ratio
(8) Carbon to Nitrogen ratio
(9) Nutrients
(10) Mixing or stirring or agitation of the content of the digester
(11) Retentation time or rate of feeding
(12) Type of feed stocks
(13) Toxicity due end product
(14) Pressure
(15) Acid accumulation inside the digester.

1. *pH or hydrogen ion concentration*. pH of the slurry changes at various stages of the digestion. In the initial acid formation stage in the fermentation process, the pH is around 6 or less and much of CO_2 is given off. In the latter 2-3 weeks time, the pH increases as the volatile acid and N_2 compounds are digested and CH_4 is produced. To maintain a constant supply of gas, it is necessary to maintain a suitable pH range in the digester.

The digester is usually buffered if the pH is maintained between 6.5 to 7.5. In this pH range, the micro-organisms will be very active and biodigestion will be very efficient. If the pH range is between 4 and 6 it is called acidic. If it is between 9 and 10 it is called alkaline. Both these are deterimental to the methanogenic (Methane production) organisms. It should always be remembered that there should not be any sudden upset in the pH by the addition of any material which is likely to cause an imbalance in the bacterial population.

The ideal pH valves for digestion of sewage solids are reported to be in the range 7 to 7.5. But a slightly higher value of 8.2 has been reported to be optimum for digestion of raw animal or plant wastes.

2. *Temperature*. Methane bacteria work best at a temperature of between 35°—38°C. The fall in gas production starts at 20°C and stops at a temperature of 10°C. At one experiment 2.25 cu m of gas was produced from 4.25 m^3 of cattle dung everyday when the digester temperature was 25°C. When the temperature was raised to 28.3°C, the gas production increased by 50% to 3.75 cu m/day.

There are two significant temperature zones in anaerobic digestion. These have been studied in some detail for digestion of sewage sludges for 90% digestion. Fig. (7.5.1) shows the time required for 90% digestion at various temperatures, and the two temperature zones. It has been established that two types of micro organisms, mesophilic and thermophilic are responsible for digestion at the two temperature ranges. The optimum mesophilic temperature lies at about 35°C, while of feeding will depend upon the retention period and type of feed stocks. More gas will not be produced by excess feeding. Due to variation of retention period undigested slurry may come out. When pure cow dung is the feed material., 1/50 (one fiftieth) of the total digester mass serves as the daily feed.

12. *Type of feed stocks.* As already stated, all plant and animal wastes may be used as the feed materials for a digester. When feedstock is woody or contains more of lignin, then biodigestion becomes difficult. This cow and buffalo dung, human excreta, poultry droppings, pig dung., waste materials of plants, cobs, etc. can all be used as feed stocks. To obtain an efficient biodigestion, these feed stocks are combined in proportions. Predigestion and finely chopping will be helpful in the case of some materials. Animal wastes are predigested. Plant wastes do not need predigestion. Excessive plant material may choke the digester.

13. *Toxicity.* The digested slurry, if allowed to remain in the digester beyond a certain time, becomes toxic to the micro organisms and might cause fall in the fermentation rate.

Biological systems needs some trace elements like calcium, magnesium, potassium etc. Production of biogas is reduced when these elements or present in higher concentrations. Synthetic materials are toxic to methanogenic bacteria. Pesticides and disinfectants from farms can kill bacteria.

14. *Pressure.* Some work conducted at National Environmental, Engineering Research Institute (NEERI) Nagpur and other places indicated that the pressure on the surface of slurry also affects the fermentation. It has been reported to be better at lower pressures.

15. *Acid accumulation inside the digester.* Intermediate products such as acetic propionic butyric acids are produced, during the process of biodigestion. This causes in a decrease of the pH, especially when fresh feed material is added in large amount. These acids may be converted into methane by addition of neem cake. However the buffering nature of the digester should not be upset. Cow dung operated plants remain well buffered and the problem of acid accumulation does not arise in the continuous fermenting systems. Acid accumulation is usually occured in batch digestion systems.

7.6. Classification of Biogas Plants

Biogas plants are mainly classified as :

(1) Continuous and batch types (as per the process).

(2) The dome and the drum types.

(3) Different variations in the drum type.

7.7. Advantages and Disadvantages of Floating Drum Plant

Advantages :

(1) It has less scum troubles because solids are constantly submerged.

(2) No separate pressure equalizing device needed when fresh waste is added to the tank or digested slurry is withdrawn.

(3) In it, the danger of mixing oxygen with the gas to form an explosive mixture is minimized.

(4) Higher gas production per cu m of the digester volume is achieved.

(5) Floating drum has welded braces, which help in breaking the scum (floating matter) by rotation.

(6) No problem of gas leakage.

(7) Constant gas pressure.

Disadvantages :

(1) It has higher cost, as cost is dependent on steel and cement.

(2) Heat is lost through the metal gas holder, hence it troubles in colder regions and periods.

(3) Gas holder requires painting once or twice a year, depending on the humidity of the location.

(4) Flexible pipe joining the gas holder to the main gas pipe requires maintenance, as it is damaged by ultraviolet rays in the sun. It may be twisted also, with the rotation of the drum for mixing or scum removal.

7.8. Advantages and Disadvantages of Fixed Dome Type Plant

Advantages :

(1) It has low cost compare to floating drum type, as it uses only cement and no steel.

(2) It has no corrosion trouble.

(3) In this type heat insulation is better as construction is beneath the ground. Temperature will be constant.

(4) Cattle and human excreta and long fibrous stalks can be fed.

(5) No maintenance.

Disadvantages :

(1) This type of plant needs the services of skilled masons, who are rather scarce in rural areas.

(2) Gas production per cum of the digester volume is also less.

(3) Scum formation is a problem as no stirring arrangement.

(4) It has variable gas pressure.

7.9. Types of Biogas Plants

As stated earlier there are numerous models of a biogas plant. But they can be grouped under two broad heads—one with the floating gas holder and the other with a fixed dome digester. In floating gas holder plant, the gas holder is separate from the digester. But in the

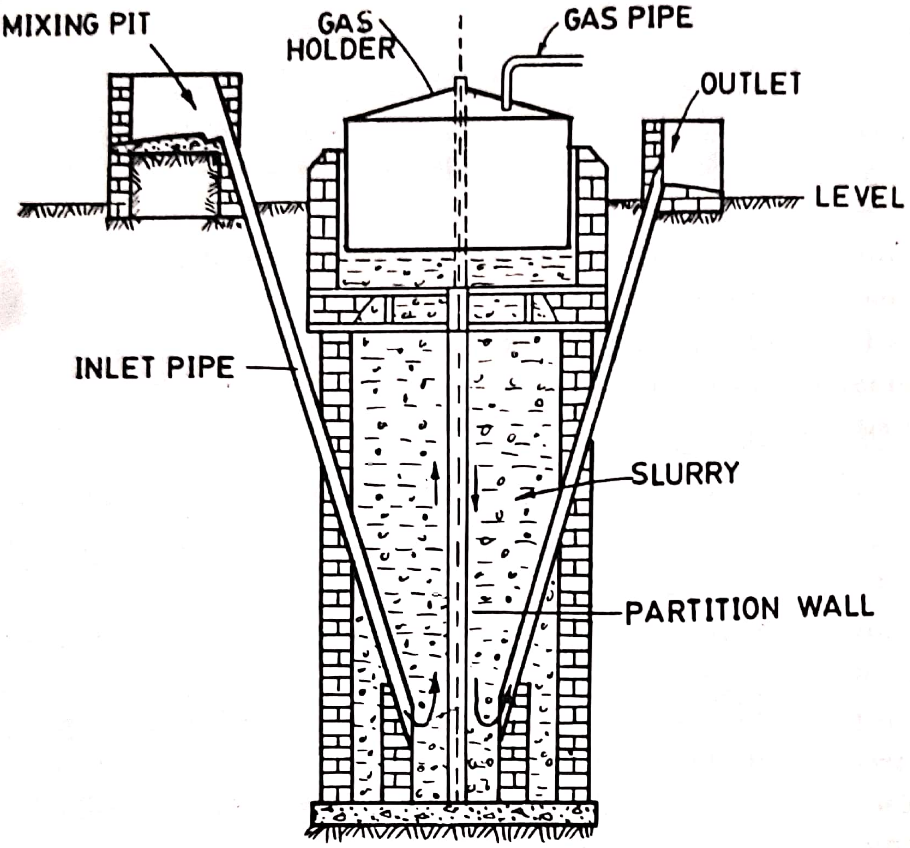

Fig. 7.9.1. Common circular digester with floating gas holder and no water seal (India). (KVIC digester).

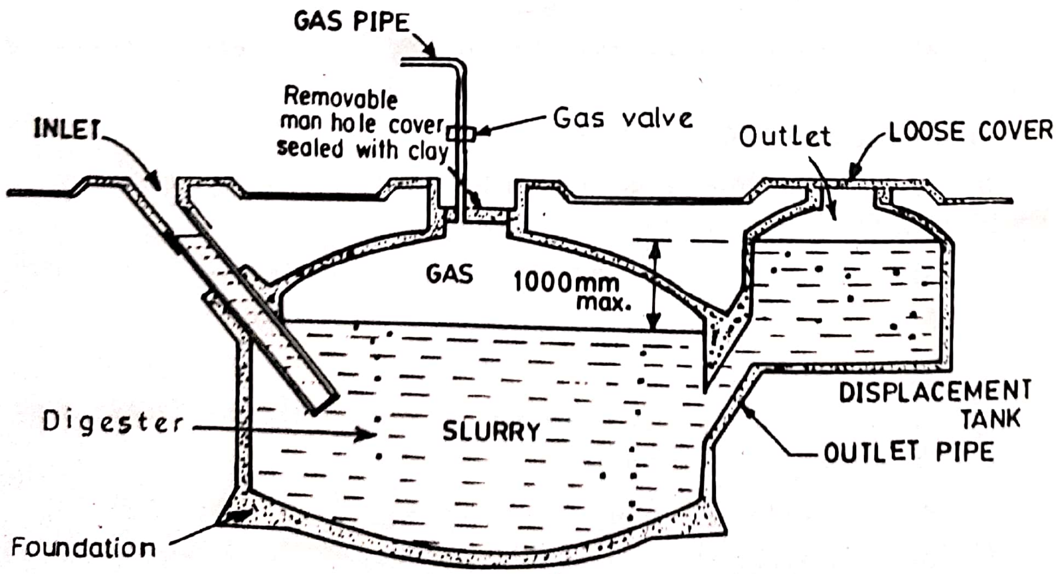

Fig. 7.9.2. Common circular fixed dome digester (China).

fixed dome digester, the gas holder and the digester are combined. The family size biogas plants available today in India are broadly of two types. The Khadi Village Industries Commission (KVIC) model and Janta model which are shown in Figs. (7.9.1) and (7.9.2). The KVIC plant is of steel drum type or floating gas holder design, in which the digestion takes place in a masonry well and the drum floats as the gas collects and is taken out from the top.

The Janta model or fixed dome digester (also called Chinese plant) is a drumless type similar in construction to the KVIC model except that the steel drum is replaced by a fixed dome roof of masonry construction. The floating gas holder digester developed in India is of masonry construction with gas holder made of M.S. plates. The drum in the KVIC model is the costliest component and its life is comparatively less (about 10 years). The dome roof in the Janta model requires specialised design and skilled masonry construction. A poorly constructed roof generally leads to leakage from top and junction of the roof with the digester wall, thereby causing drop in gas yield. The overall cost of both types varies from Rs. 5000 to Rs. 15,000 depending upon the capacity of the biogas plant and subsoil conditions.

In addition to the aforesaid cost and construction material problems, there are constructional problems which the farmers or beneficiaries face. The construction of biogas plants especially in Janta type needs the services of skilled masons who are becoming rather scarce in rural areas. It is observed that plants constructed by unskilled masons or untrained workers have structurally failed or unable to retain dung slurry, gas or even both while the failure of such plants adversely affects plants owners. The prospective plant owners are seldom sure about the correct choice of the plant. Besides the construction of the plant, there are some operational and maintenance problems which almost hinder progress of biomass development.

Fig. (7.9.3) shows a flexible bag digester. The digester is made of plastic material and can be easily installed. The short life of the material due to the effect of ultraviolet rays is a main drawback.

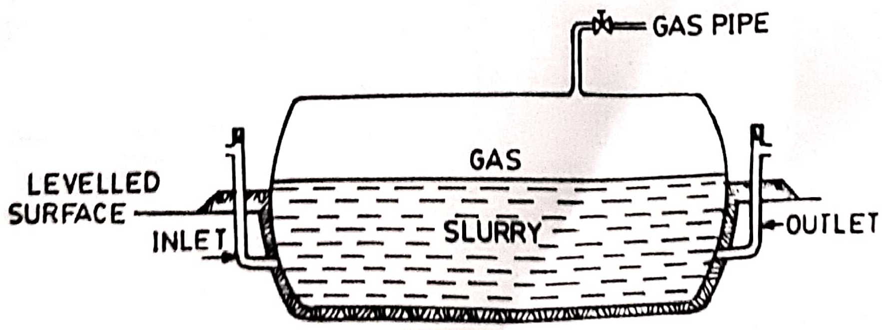

Fig. 7.9.3. Flexible bag type combined digester/gas holder.