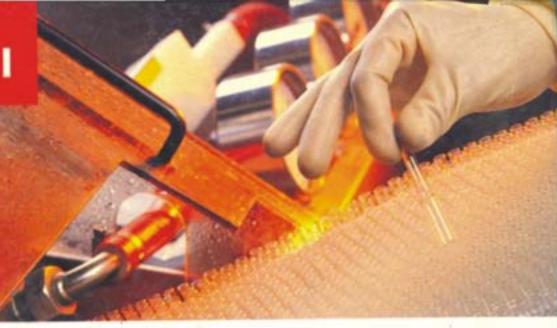
Volume I



Chemical Engineering

D. Sen



Reference Book On Chemical Engineering

THIS PAGE IS BLANK

Reference Book on Chemical Engineering

Volume I

D. Sen

B.Ch.E.

Fellow of the Institution of Engineers (India)
Former Listed IDBI Consultant
and
Retired Chief Engineer (Chem.) of BVFCL, (Formerly HFCL)
Namrup Unit, Assam



NEW AGE INTERNATIONAL (P) LIMITED, PUBLISHERS

New Delhi • Bangalore • Chennai • Cochin • Guwahati • Hyderabad Jalandhar • Kolkata • Lucknow • Mumbai • Ranchi Copyright © 2005 New Age International (P) Ltd., Publishers Published by New Age International (P) Ltd., Publishers

All rights reserved.

No part of this ebook may be reproduced in any form, by photostat, microfilm, xerography, or any other means, or incorporated into any information retrieval system, electronic or mechanical, without the written permission of the publisher. *All inquiries should be emailed to rights@newagepublishers.com*

ISBN (10): 81-224-2331-0

ISBN (13): 978-81-224-2331-0

PUBLISHING FOR ONE WORLD

NEW AGE INTERNATIONAL (P) LIMITED, PUBLISHERS

4835/24, Ansari Road, Daryaganj, New Delhi - <math display="inline">110002

Visit us at www.newagepublishers.com

To My Mother

Who has taken much interest in progress of the book, the book is dedicated

THIS PAGE IS BLANK

PREFACE

A Chemical Engineer needs to know not only the inside changes in a Production Process viz. Chemical, Physical, Thermochemical, Thermodynamics and Kinetics, but also he has to know the basics of other engineering disciplines as well as current developments. During my long service period in Production, Process Design and Projects, I found most of these information are available at different sources and is not always possible to acquire these information always. To meet these gaps, I have given as much information as possible in Volume I and Volume II of this book on various processes, data tables, some unit operations etc. usually required by Professional Chemical Engineers and Chemical Engg. students. In addition, a chapter on Glossary of Terms has also been provided for refreshing the essential information on chemistry and other topics.

In preparation of this "Reference Book on Chemical Engineering" some senior engineers working in chemical industries have extended support in preparation of some chapters; in particular I like to thank K. Das Ex. ED, KRIBHCO, Hazira; D.K. Roy, Ex. GM, Namrup Fertiliser Unit; K.P. Sinha, Sr. Development Engineer, DCL, Professor U.P. Ganguly, Retired, Chem. Engg. Deptt., I.I.T. Kharagpur had reviewed this book. The index for words had been provided. The author also likes to thank Ms. B. Sen for secretarial assistance in preparation of the manuscript.

Kolkata D. SEN

THIS PAGE IS BLANK

CONTENTS

	Preface	(vii)		
1.	Fertilisers	1		
2.	Heat Transfer	25		
3.	Pulp and Paper	37		
4.	Chlor Alkali Industry	45		
5.	Cellulosic Fibres (Rayon)	50		
6.	Selected Process Equipment Design	53		
7.	Petroleum Refinery	70		
8.	Active Carbon	75		
9.	Refrigeration	78		
10.	Coal Tar Chemicals	96		
11.	Refractory Bricks	103		
12.	Explosives and Detonators	107		
13.	Water Treatment	111		
14.	Metal Cleaning Process			
15.	Manganese Dioxide	130		
16.	Wind Turbine for Power Generation	133		
17.	Centrifugal Pumps	135		
18.	Industrial and Town Gases	143		
19.	LNG Production	159		
20.	Products Manufactured from Benzene, Ethyl Benzene,			
	Ethylene, Ethylene Oxide, Ethanol and Others	162		
21.	Synthetic Iron Oxide Pigment	167		
22.	Dyes, Intermediates and Dyeing	170		
23.	Flourescent or Optical Whitening Agent (FWA)	172		
24A.	Flame Retardants, Halons, Fire Alarms/Hydrants and Rubber and Expanded Plastics	174		
24B.	Float Glass, Carbon Black, Electrophoresis, Dry Ice and Technological Development in Iron and Steel Industry and Electrolytic Chlorinator	179		
25	Ceramic Colouring Materials	185		
£ 10 F	CELEBRA CONTROLLED VIOLETTALS	100		

26.	Glass Fibres for Insulation and Other Uses	187
27.	Plastics	190
28.	Flocculation	195
29.	Phosphoric Acid	198
30.	Electroplating Process	207
31.	Cooling Towers	212
32.	Paints and Painting	217
33.	Biogas Plant (Domestic Use)	223
34.	Sugars	225
35.	Phenols for Disinfection	230
36.	Ferrous Alloys	232
37.	High Carbon Charge Chrome	234
38.	Characteristics of Valves Used in Chemical Process Industry	236
39.	Boiler Feed Pumps and Standard Values for Boiler Feed and Circulating Water	237
40.	Crystallizer Classification	240
41.	Brief on Offshore Oil Exploration and Transportation Pipeline	242
42 .	Insecticide or Pesticide	243
43.	Critical Path Method (CPM)	254
44.	Psychrometry	255
45.	Glasses and Textile Glass Fibres	258
46.	Environment and Pollution Air and Water	260
47.	Vegetable Oil Refining	275
48.	Furfural	282
49.	Polyethylene Terephthalate Resin (Bottle Grade)	285
50.	Process Evaluation of a Chemical Plant	288
51 .	Detail Project Cost Estimation	298
52.	Types of Contract	307
53 .	Project Financial Management	309
54.	ISO-9000 Series Quality Assurance System	320
55.	Conversion Factors	328
	Index	336



1. GENERAL INORGANIC FERTILISERS

These are plant nutrients which are grouped as nitrogenous, Phosphatic and mixed fertilisers with or without potassium chloride (muriate of potash, MOP). Among nitrogenous fertilisers, urea containing 46–46.5% (wt) nitrogen is most important because of high nutrient content and is widely produced and used. Di-ammonium Phosphate (DAP) single super phosphate (SSP), mono ammonium phosphate (MAP) and dicalcium phosphate (DCP) are common phosphatic fertilisers. CAN is Ammonium nitrate mixed with lime. Mixed fertilisers are balanced nutrients for plants as they contain nitrogen, phosphorous and potash in various proportions. Fertilisers are generally termed as containing $N: P_2O_5: K_2O$ or simple N: P: K where N stand for % nitrogen, phosphate as % P_2O_5 or simple P and Potassic as % P_2O_5 or simple P0.

Types of Inorganic Fertilisers

Туре	Constituents, % by wt	Remarks
Nitrogenous		Fertilisers use as prills and industrial
Urea, NH ₂ CONH ₂	N = 46–46.5%	Use as crystals or Prills
Ammonium Nitrate,	N = 34.5%	Explosives and fertiliser use
NH ₄ NO ₃		
UAN soln.	$N = 20\%$ or $NH_3 = 23\%$	UAN is urea mixed with ammonium nitrate
Nitrolime or CAN	N = 25%	Mix. of 60% amm. nitrate and 40% lime stone (CaCO ₃)
Ammonium Sulphate, (NH ₄) ₂ SO ₄	N = 21%	Fertiliser use
Phosphatic and Potassic:		
Monoammonium Phosphate MAP (NH ₄ H ₂ PO ₄ H ₂ O)	$N = 11\%, P_2O_5 = 52\%$	Fertiliser use
Diammonium Phosphate, DAP (NH ₄) ₂ HPO ₄ H ₂ O	$N = 18\%, P_2O_5 = 46\%$ or $21\% = N, 53.5\% = P_2O_5$	Fertiliser use

Dicalcium Phosphate, (CaHPO) ₄	$P_2O_5 = 51\%$	Fertiliser use
Single Super Phosphate	$P_2O_5 = 16-18\%$	Fertiliser use
(Mixture of mono calcium		
phosphate and Gypsum)		
Tripple Super Phosphate TSP (mix of tricalcium phosphate and Gypsum)	$P_2O_5 = 46-48\%$	
Liquid spray fertilizer	(i) 24% AqNH ₃ soln.	Fertiliser use
Developed after (1950 in USA)	(<i>ii</i>) Ammonia nitrate or urea aq. soln with liquid NH ₃ upto 50%	
	(iii) Non press. Appln 32% aq. soln of urea and ammon, nitrate	
Mixed Fertilisers		
N P K	15:15:15	Fertiliser use
	12:12:12	
	8:8:8	
N P	18:46	
	16:20	
	20:20	
N P K (other type)	17:17:17	Fertiliser use
	10:22:26	
	14:28:14	
	19:19:19	
N P K (foliar grades)	12:4:6	Foliar spray
	6:12:6	
	5:8:10	
Controlled release	urea aldehyde	Slow release to soil
fertiliser		

2. BY DANGER CRITERIA, THERE ARE FOUR TYPES OF FERTILISER

A type explosive fertilisers, exm. Ammonium nitrate-storage conditions are stringent.

- B type fertilisers are self-sustaining progressive thermal decomposition.
- C and D type fertilisers are not self-sustaining as well as do not subject to progressive thermal decomposition.

Group B fertilizers are more important for storage.

3. RAW MATERIALS FOR FERTILIZERS PRODUCTION

Nitrogenous Fertilisers

For manufacture of nitrogenous fertilizers, ammonia as intermediate product, is manufactured first.

Raw Materials

Natural gas (N.G) containing mainly methane and other higher hydrocarbon stock. (LSHS) is also used where natural gas is not available. Other oil refinery distillation product like Naptha is also used as starting raw material although it is costlier. Even low sulphur and low ash bituminous coal is used in some plant (South Africa) as raw material.

Process Steps

(i) These involve production of raw gas (CO + H₂) with pre or post desulphurisation depending on type of raw material used. For N.G, pre-disulphurisation is carried out first followed by steamair reforming (two stage) using compressed air and compressed natural gas. H.P. steam generation from reformed gas (R.G.), H.T. CO conversion and L.T CO conversion for generation of equivalent H, from CO, CO, gases in the raw gas are absorbed in a CO, absorber using pot. Carbonate with anticorrosion chemicals viz V_2O_5 or $As_2\ O_3$ or using MEA/DEA absorption for CO_2 followed by methanation to convert residual CO and CO2 to methane. CO2 from CO2 absorbing solution is recovered in a desorption tower using heat for regeneration of CO₂. The byproduct CO₂ from CO₂ desorption tower, containing over 96% CO₂, is sent to urea plant for production of urea. The synthesis gas obtained after methanation and having H2 and N2 in 3:1 molor ratio, is used for ammonia synthesis and compressed to 200-250 Kg/Cm²g and synthesized to produce ammonia in the H.P ammonia reactor with recycle in the synthesis loop having synthesis gas compressor with recycle gas circulator, primary and secondary condensation using cooling water and ammonia refrigeration respectively. The ammonia produced as liquid is about 99% (wt) and stored in horton sphere for sending to urea plant for urea production. The conversion of H₂ to NH₃ in synthesis loop is about 14-16% (Vol) and inert gases from synthesis loop is sent to ammonia recovery section. Only make up synthesis gas $(H_2 + N_2)$ is fed to the NH_3 reactor using KM_1 and KM_2 catalyst, to the extent ammonia is produced due to catalytic conversion of H2 and N2 into NH3.

$$3H_2 + N_2 = 2NH_3$$
 $\Delta H = -22400$ Btu/1b mole

The overall energy required per ton of ammonia various from 5–10 Geiga calories/ton depending on patented process of Haldor Topsoe, Texaco, Kellog, etc.

(ii) In case of LSHS, desulphurisation by cold methanol is carried out after raw gas generation in gasifier using oxygen from air separation unit and O_2 compressed to 28 Kg/sq.cm. In the gasifier partial oxidation reaction takes place in the flame with generation of raw gas (H_2 + CO).

When refinery naphtha (boiling range 170° C) is used as raw material, two stage desulphurisation is carried out first prior to gasification in a reactor. The rest of the process like CO conversion, CO_2 absorption using hot Pot. Carbonate soln. with V_2O_5/As_2O_3 as corrosion inhibitor, (As_2O_3) is normally not used now due to pollution) and methanation followed by high pressure ammonia synthesis. By product carbon pellets is obtained when LSHS is used for gasification.

Fuel used in reforming section is same as starting raw material viz N.G. or naptha (Vaporised). Texaco, USA is the licensor for gasification section. Other process licensors are ICI, KELLOG etc.

4. DETAIL PROCESS DESCRIPTION FOR AMMONIA PRODUCTION USING N.G. AS FEED STOCK

Natural gas is compressed to 41 ata and preheated to 400°C in N.G. fired heaters and sent for desulphurisation using comox catalyst (Cobalt – moly and Zinc oxide) catalyst. The type of catalyst required depends on inlet sulphur concentration as H_2S and organic sulphur. The gas is then mixed with H.P. steam at 40 ata and 370°C. The mixed N.G. is then (further) heated in mixed gas heater upto 500°C and fed to primary reformer at 32 Kg/Cm²g containing primary reformer catalyst in nickel tubes of HK-40 material. For 600 MT per day ammonia plant 240 nos. tubes of 6" diameter in vertical row are required. The primary reformer furnace is generally having side fired N.G. burners where N. G. is burnt as fuel (top and side fired burners are also used in primary reformer). The reformer furnace temp. is kept at 1000°C and steam carbon ratio is maintained in the primary reformer tubes between 3–4. The tubes expand upwards and gas flows from top to bottom. Primary reformation of N.G. takes place inside the tubes at 700–800°C in presence of nickel based catalyst. The tube life is around 100,000 hours.

The exit gases from P.R. at 30 Kg/sq.cm and 795°C is further reformed in secondary reformer at 950°C. In the secondary reformer in the presence of catalyst, further reformation takes place at 31 ata when some H_2 burns to produce heat necessary to convert most remaining feed stock to H_2 , CO and CO_2 . Air is fed to S.R so as to provide necessary N_2 in synthesis gas in the molar ratio of 1:3 ($N_2:H_2$). The exit heat from S.R gases is recovered in super heaters, N.G. heaters and air heater and mix gas heater in the reformation section. The hot S.R exit gas, containing 12% CO at 1000°C, is then sent to R.G boiler to generate H.P. steam followed by two stage catalytic CO conversion when equivalent H_2 is produced from CO in raw synthesis gas, (H_2 + CO).

$$CO + H_2O \rightleftharpoons CO_2 + H_2$$

General Reaction in Primary Reformer

C_nH_{2n+2}	+	$nH_2O \rightarrow$	nCo +	$(2n + 1)H_2$	General reaction
CH_4	+	$H_2O \longrightarrow$	CO +	$3H_2$	1
CH_4	+	$2H_2O \rightarrow$	CO_2 +	$4H_2$	2
C_2H_6	+	$4H_2O \rightarrow$	$2CO_2 +$	$7H_2$	3
C_3H_8	+	$6H_2O \rightarrow$	3CO ₂ +	$10H_{2}$	4
C_4H_{10}	+	$8H_2O \rightarrow$	$4CO_2 +$	$13H_{2}$	5
C_5H_{12}	+	$10 \text{H}_2 \text{O} \rightarrow$	5CO ₂ +	$16H_2$	6
C_2H_6	+	$2H_2O \rightarrow$	2CO +	$5H_2$	7
C_3H_8	+	$2H_2O \rightarrow$	2CO +	$7H_2$	8
C_4H_8	+	$2H_2O \rightarrow$	4CO +	$8H_2$	9
C_5H_{10}	+	$5H_2O \rightarrow$	5CO +	$10H_{2}$	10

Reactions 1 to 6 are major reactions. Other reactions possible in varying conditions of pressure and temp. in the primary reformer are:

H.T. CO conversion is carried out at $327^{\circ}\text{C}/427^{\circ}\text{C}$ when CO at exit is around 2–3% and LT CO conversion at $210^{\circ}\text{C}/330^{\circ}\text{C}$. The CO and CO_2 content of L.T. converter is 0.30% and 18.5% respectively. The heat in exit gases from H.T. converter is used to preheat boiler feed water heaters and L.T. converter outlet is used to produce, L.P. steam. The L.T. exit gas is then sent to decarbonation tower to remove CO_2 with either Vetrocoke soln. or Benfield soln. (Pot. Carbonate with V_2O_5). Both the CO_2 removal processes are proprietory items. Now a days Vetrocoke soln. (hot potash with As_2O_3) in not used due to pollution problems. Corrosion in-hibitors As_2O_3/V_2O_5 forms a stable passive oxide film in towers which prevents corrosion; absorption of CO_2 by Pot. Carbonate soln. takes place as per the following reaction:

$$K_2CO_3 + H_2O + CO_2 \longrightarrow 2KHCO_3$$

Regeneration of the bicarbonate is done by heating of the soln. in the desorption tower with reboiler:

$$2KHCO_3 \longrightarrow K_2CO_3 + CO_2 + H_2O$$

Heat supply to reboiler is by steam. The generated CO₂ gas from desorption tower/regenerator top is cooled in a cooler to remove condensate and sent to urea plant.

The decarbonated gas at 60° C and 26 at pressure is preheated by hot methanator outlet gas and partial H.T. CO converter gas upto 315° C and feed to methanator where remaining CO and CO_2 are converter catalytically by iron oxide catalyst to methane.

$$2CO + 5H2O \longrightarrow 2CH3 + 2H2O$$

The heat recovery as well as operating parameters in reformation section to methanator varies according to process licensor scheme. Methanator is often deleted and in its place liquid N_2 wash is carried out in process licensor e.g., C.F. Brown Process.

The hot gas from methanator after heat exchange, cooling and condensate separation is the synthesis gas having H_2 , N_2 ratio within 3 (molar) and $CO + CO_2$ within 5ppm, $CH_4 = 0.75\%$. The synthesis gas is sent to compressor at 45°C and 25 at pressure for compression to 200–250 Kg/sq. cm. The total pressure drop to primary reformer to methanator is designed at 5–6 Kg/cm².

In the synthesis loop, make up pure synthesis gas mixture along with recirculated synthesis gas is compressed and cooled in cold exchanger (Tube side) and in the ammonia cooled condenser and ammonia separated in secondary cold ammonia separator. The gas then enters shell side of cold exchanger and then shell side of hot exchanger and then to ammonia converter packed with KM₁ (often KM₂ also) iron catalyst where NH₃ is formed at a temp. of 425°C–500°C. Reactor temp. is controlled by by-pass gas valve in each of 3 catalyst beds.

H.P. steam is generated in boiler coil inside the NH₃ reactor. The converted exit gas is then cooled in primary water cooled condenser from 70°C to 38°C and then to sec. ammonia cooled condenser. The liquid ammonia condensed is separated in primary separator, sec. separator and unconverted gas is recycled to the recirculator and a small part is purged to ammonia recovery sec. from recycled gas to keep inerts, Argon, CH₃ within limit. Liquid ammonia from primary and two secondary separators is put in let down tank from where it is taken to Horton sphere for storage.

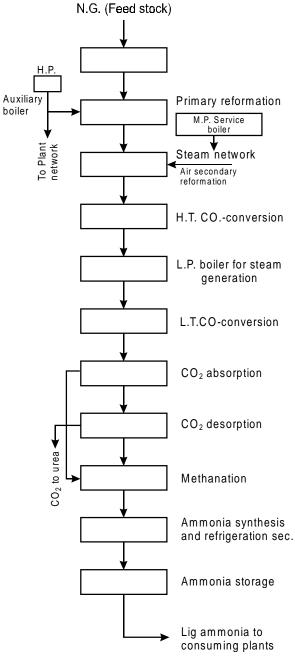


Fig. 1. N.G. steam reformation (HTAS) for ammonia synthesis in (HTAS) process.

The flow scheme of gases in the synthesis section also varies as per process licensor's design depending on the extent of waste heat recovery from syn. converter. Often two syn. converters are required for greater conversion to ammonia as in C.F. Braun's Process as well as some design of Uhde. CO₂ absorption also varies – pressure swing absorption (ICI) and regeneration by flashing and physical absorption using selexol/sepesol and MDEA Process (BSAF) and more common Process of CO₂ removal by DEA and MEA depending on process adopted by process licensor.

5. SYN. GAS (CO + $\rm H_2$) GENERATION BY NONCATALYTIC FUEL OIL/LSHS GASIFICATION

There are two process licensors Texaco and Shell for production of raw syn. gas by non-catalytic gasification of Fuel Oil/LSHS using oxygen by the partial oxidation route. Texaco had, however, developed a gasification process using these feeds stocks with enriched air (with oxygen).

General Formula

$$C_m H_n S_r + m O_2 \longrightarrow m/2 CO + (n/2 - r) H_2 + r H_2 S.$$

Side Reaction

Partial Oxidation of Heavy Fuel Oil (feed stock)

In Case of Full Oxidation

$$C_{15}H_{24}S_2 + 20O_2 \longrightarrow 15CO_2 + 10H_2O + 2H_2S$$

Side Reactions

Process

Oxygen gas from Air Separation Plant is compressed to 52 Ata, mixed with H.P. steam and the mixed gas is led into partial oxidation gun along with preheated heavy fuel oil inside the gasification reactor where flame reaction takes place producing raw syn. gas (H_2 + CO). The nitrogen in fuel oil is converted to molecular N_2 and sulphur to H_2S and small amount of COS. The gases are then quenched with water to remove unreacted fuel oil. The carbon water from quench vessel in then sent to carbon recovery section where carbon is separated and pelletised for use in service boiler and water slurry recirculated with the make up water to quench vessel. The H_2S in raw syn. gas at 51 ata and 48°C is then sent to rectisol section for desulphurisation with cold methanol at -20°C. Due to presence of considerable sulphur compound (H_2S , COS) etc. cold methanol is used in this process (Rectisol) using ammonia refrigeration. Sulphur is reduced to 0.1 ppm.

The gases are then led into HT CO conversion after heating where shift reaction takes place at $327/420^{\circ}$ C and most of CO is converted to H₂.

$$CO + H_2O \longrightarrow CO_2 + H_2$$

The exist gases from HT CO converter contain 0.3% CO and CO₂ gases are absorbed with cold methanol at (-50°C) in Rectisol section where most of CO₂ is physically absorbed in cold

methanol which is then regenerated by heat and flashing. The generated CO_2 , about 96%, is sent to Urea Plant and other consuming plant. The regenerated methanol soln. is sent to CO_2 absorber. The exit gases from absorber still contain some CO and CO_2 along with Methane and Argon. The gases are then first adsorbed in molecular sieve vessel where CO_2 is adsorbed (below 10 ppm) and methane below 50 ppm. The purified gases are then sent to liquid Nitrogen wash tower where CO, CH_4 and Argon are removed and after regeneration of liquid Nitrogen containing CO, CH_4 are Flashed out and stored for use as a fuel. The purified mixture of Hydrogen gas and Nitrogen, in the ratio of CO_2 is then compressed to CO_2 00 mixture of Hydrogen gas and Nitrogen, in the ratio of CO_2 11 is then compressed to CO_2 120 mixture of Hydrogen gas containing unreacted Hydrogen, Nitrogen and some Ammonia is sent to syn. reactor where after preheating enters the catalysts beds in ammonia converter where ammonia is produced at CO_2 130 mixture of CO_2 130 mixture of CO_2 31 mixture of CO_2 31 mixture of CO_2 31 mixture of CO_2 32 mixture of CO_2 33 mixture of CO_2 43 mixture of CO_2 43 mixture of CO_2 44 mixture of CO_2 50 mixture of CO_2 51 mixture of CO_2

$$3H_2 + N_2 = 2NH_3$$
 $\Delta H = -22400$ BTU/1b mole

H.P. Steam is produced in the syn. reactor, flashed in syn. boiler and used in the process.

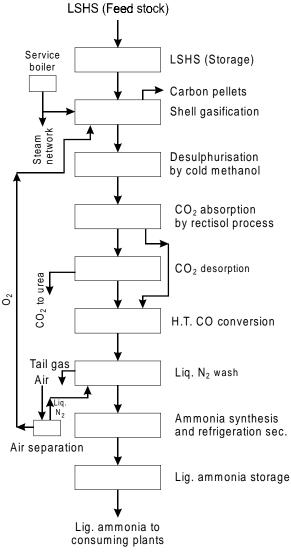


Fig. 2. Shell gasification (partial oxdn.) ammonia synthesis process.

Table 1

CO₂ Removal Process

Plant Supplier	Uhde activated MDEA of BASF	Uhde low heat hot potash U O P
H.P. Boiler FW preheating	31.2%	29.2%
L.P. steam generation	14.9%	_
Heat for CO ₂ removal	31.4%	49.9%
Demineralised → water preheating	22.5%	20.9%
Total heat available	100%	

Table 2

CO₂ Removal Process

Process	MDEA (BASF)	Low heat hot potash (UOP)
Absorber outlet CO ₂	100 ppm	1000 ppm
Kcal/NM ³	368	777
CO ₂ recovered in regenerator, %	96.51	99.52
CO ₂ purity (dry), %	99.75	99.06

Table 3

UHDE Ammonia Synthesis Loop Data

H_2/N_2 ratio	2.95
No. of syn. reactor	One
Mu. syn. gas	27 bar, 6°C
Ammonia separation temperature	−10°C
125 bar steam generation t/t NH ₃	1.17
Waste heat used in H.P. steam raising%	60%
Waste heat removal in cooling water	14.81%
Chiller duty	25.01%
Total heat available	100%

Reformation and syn. –HTAS, CO ₂ shift (Two stage PDIL) and Methanator (PDIL)	HTAS
600 MT/day	1000 MT/day
India	Europe
8.49	7.641 Gcal/Te
78–91% (Vol)	Over 90% (Vol)
1218 SM ³	N.A.
61.20 KWH/Te	28.6 KWH/Te
4.302 M ³ /Te	$4.31 \text{M}^3/\text{Te}$
1.132 Te/Te	N.A.
643 M ³ /Te	210 M ³ (sea water)/Te
13.8 M ³ /Te	N.A.
Benfield	N.A.
10.875	7.02
	CO ₂ shift (Two stage PDIL) and Methanator (PDIL) 600 MT/day India 8.49 78–91% (Vol) 1218 SM ³ 61.20 KWH/Te 4.302 M ³ /Te 1.132 Te/Te 643 M ³ /Te 13.8 M ³ /Te Benfield

Table 4

Energy Consumption for Ammonia Plant (N.G. based)

6. DEVELOPMENT IN AMMONIA PRODUCTION

(1) Raw Syn Gas Generation

G.cal/Te

Most of the fertilizer plants in the world use steam methane reforming process followed by partial oxidation of heavy fuel oil (LSHS) as feed stock. One smaller plant uses coal gasification to produce raw gas. MW Kellog of U.S.A. had developed reforming exchanger system for raw syn. gas generation. The reforming exchanger contains open tube catalyst tubes hanging from exchanger top. Oxygen mixed with air, steam and NG feed (2/3rd) are 1st fed to catalytic adiabatic reformer where certain amount of reforming takes place at a temp. of 954–1010°C. Nearly 1/3rd of balance process feed NG and steam enter the reforming exchanger from top while adiabatic reformer effluent also enters the shell side of reforming exchanger providing recovery of heat for reforming reaction. The outlet gases from reforming exchanger goes to feed/effluent H.E. where mixed gases are preheated and reformed gases then follow the heat recovery system of CO shift converters, CO₂ removal and methanation and compressed prior to entering ammonia synthesis loop.

Table 5

Process Data for Reforming Exchanger (Kellog)

O ₂ in enriched air	Upto 30%
Mixed feed pre heat temp.	$480^{\circ} - 620^{\circ}\text{C}$
Overall, steam/carbon ratio	3.3 - 3.8
Adiabatic reformer exit temp.	925° – 1040°C
Design methane slip	0.5 – 0.7% (vol) dry

^{*}Correspond to full enthalpy of steam and water at 0°C.

However, the reforming exchanger system, where no secondary reformer is used, changes the conventional heat balance system of the process. Most of the high temp. heat, via the heat exchanger reformer is returned to the process and will thus not be available for H.P. steam production and excess of low temp. heat will be available for med. or L.P. steam production which can not be utilized in ammonia plant and H.P. steam must be generated in auxiliary boiler or service boiler for use in H.P. steam turbine drive of syn. gas compressor. The overall energy efficiency will entirely depend upon the efficiency of auxiliary steam generation.

(2) CO2 Removal Process

There are several proprietory processes viz Vetrokoke hot potash system using arsenic oxide, Benfield process using V_2O_5 , Catacarb process, MDEA process of BSAF, Hot Potash process of UOP, low temp. (–50°C) Rectisol process. In addition, MEA and DEA of CO_2 process is also used. In all these processes, absorbed CO_2 rich soln. from packed absorber is regenerated by heating and flashing to low pressure (0.15 Bar). The efficiency depends on heat economy for regeneration of soln. as well as power recovery by soln. turbine in the absorber outlet soln. to recover part of power reqd. for pumping the regenerated soln. to absorber. About 40% recovery is possible. Heat required for regeneration of soln. varies from 370–800 Kcal/NM 3 CO_2 . CO_2 conc. from 96–99% (vol) is recovered CO_2 .

(3) CO Shift Conversion

Generally two stage (HT and LT) shift reactor is used with L.P. steam (3.5 ata) generation at outlet of HT converter. The temp. at HT converter is maintained at 330°–425°C and that of L.T. converter, 210°–330°C.

Shift reaction :
$$CO + H_2O \longrightarrow CO_2 + H_2$$

(4) Methanation

The remaining CO (0.3%) and CO₂ in raw syn. gas after CO₂ removal is removed in catalytic methanator working at $315^{\circ}/220^{\circ}$ C.

Methanation reaction:
$$2CO + 5H_2 \longrightarrow 2CH_3 + 2H_2O$$

 $CO_2 + 3\frac{1}{2}H_2 \longrightarrow CH_3 + 2H_2O$

Instead of methanation often cryogenic separation is used to remove residual CO, CO_2 Methane and Argon and molecular sieve is used for adsorption of CO_2 for plants having air separation unit for oxygen requirement in partial oxidation process.

(5) Ammonia Synthesis

The pure syn. gas with H_2/N_2 ratio of 2.95 CO and CO_2 maxm. 5 to 10 ppm each is compressed in syn. gas compressor to 200–250 Kg/sq. cm pressure and sent to syn. loop for conversion to ammonia in catalytic ammonia converter having 3 beds of KMI and KMII catalyst. The conversion to ammonia is 15–20% and considerable heat is produced which is utilized to generate H.P. steam. The reactor effluent after heat recovery for H.P. steam generation is cooled first by water cooling and separation of ammonia followed by 1–2 steps ammonia cooling when remaining ammonia is separated. The vapour refrigerent ammonia is sent to ammonia compressor where ammonia is compressed, liquefied and sent to synthesis section. The unconverted syn. gas is recycled to reactor via recirculator where it is pre-heated for further conversion along with make up gas. H.P. steam generation, as per modern trend, is to generate H.P. steam at 110–125 ata.

Steam Net Work

A stable steam net work is key to operating stability in ammonia plant; normally H.P. steam is used in syn. gas compressor turbine and part of it is extracted at 38–40 ata for process air compressor and refrigeration compressor drives. L.P. steam from CO conversion is used in condensate stripping and regenerator heat duty in CO₂ recovery section.

Plant Capacity

Modern ammonia plant is constructed as large tonnage plant with capacities ranging from min. 600 Te/day to 1000–3000 Te/day and is mainly based on N.G. or naphtha or LSHS as feed stock. The price of N.G./LSHS/Napfha per million Kcal/BTU is a key factor in economics of ammonia plant and fixes the criteria of plant design basis and economics, of payout time, I.R.R, R.O.I. etc. In Fig. 1 and Fig. 2 block diagrams for ammonia synthesis process based on N.G. and LSHS is given.

7. UREA PLANT

Now a days most urea plants are designed, based on Stamicarbon's CO_2 stripping process or Snadom's ammonia stripping process. Toyo Engg. Corpn's total soln. recycle, ACES process is used in many plants and also Technimont's IDR process which uses both CO_2 and ammonia stripping finds its use in some plants.

Process: Conventional Total Soln. Recycle

Preheated liquid ammonia and CO_2 gases under 190–200 Kg/cm² press are reacted in an adiabatic reactor at 180–190°C in presence of recycled unconverted carbamate soln. The reactor feed ratio of NH₃: CO_2 : H₂O is 3.5–4: 1: 0.5 to 0.6.

Reaction :
$$2NH_3 + CO_2 \longrightarrow NH_4 COONH_2 \Delta H = -38 Kcal/Kgmole NH_4COONH_2 = NH_2CONH_2 + H_2O \Delta H = 5 Kcal/Kgmole Urea$$

Overall reaction:

$$2NH_3 + CO_2 = NH_2CONH_2 + H_2O \Delta H = -33 Kcal/Kgmol$$

A $\rm CO_2$ conversion efficiency of 60–70% is achieved in the reactor and the unconverted ammonium carbamate decomposed in 2/3 stages. The decomposed gases (NH₃, CO₂ and H₂O) are absorbed in corresponding absorbers with rectification for separation of excess ammonia at 2nd stage (16–17) Kg/cm²; recycle soln. from 3rd stage absorber is successibly sent to next higher stages and finally pumped from 1st stage condensor to reactor by H.P. carbamate recycle pump. Excess ammonia vapour recovered from 2nd stage absorber rectification stage at top is condensed and recycled back to reactor by H.P. NH₃ feed pump along with makeup NH₃ duly preheated. Make up $\rm CO_2$ gas is compressed in centrifugal/reciprocating compressor and fed to reactor. The 70–75% dilute urea solution from 3rd stage distiller is concentrated in two stage vacuum concentration to 98.5–99% urea melt and prilled in a I.D. prilling tower having rotating (370–380 rpm) bucket sprayer (1–1.3 mm hole). The specific load in a prilling tower is 0.17– 0.19 tonnes/m² and air rate = 1000 NM³/te with air velocity of about 0.47 m/sec.

Stamicarbon CO₂ Stripping Process

1st developed by Stamicarbon NV in 1965. It is based on Henry's law.

The equation which governs the principle of stripping gases, CO₂/ammonia in decomposition of unconverted carbamate, is given below:

$$2NH_3 + CO_2 \implies NH_4OCONH_2 \Delta H = -38 \text{ Kcal/Kgmol.}$$

Eqn.
$$C_{carb.} = K_{eq.} C_{NH_2^2} C_{CO_2}$$

where $K_{eq.}$ is the equilibrium constant for the above reaction and C_{carb} $C_{NH_3}^2$ C_{CO_2} are the concentrations of carbamate, NH_3 and CO_2 respectively.

If CO_2 gas is passed through the solution containing unconverted carbamate, the above reaction becomes

$$C_{carb} = K_{eq} \times O^2 \times C_{CO_2}$$
 (due to high CO_2 conc. ion, NH_3 concentrate becomes 0 or negligible)
= 0

Therefore, carbamate conc. will be 0 or nearly so when CO₂ is used as a stripping gas. The operating pressure in the syn. loop consisting of reactor, stripper and carbamate condensers is 150 atm and NH₃: CO₂ ratio in reactor is 2.8 and conversion of CO₂ to urea is around 58–60%. The NH₃: CO₂ ratio is the syn. loop is 2 which ensures smaller NH₃ feed pump. The overall CO₂ conversion efficiency is 80-85%. The stripper is having vertical titanium tubes through which reactor effluent descends in a thin film and the tubes are heated outside with steam at 160–180°C. All CO₂ gases at 150 Kg/cm² are passed upwards through the tubes from bottom and the stripped reactor effluent is devoid of 90% CO₂ and NH₃ and hence carbamate. The stripped NH₃ and CO₂ gases along with water vapour are led into carbamate condenser which is also fed with an amount of ammonia through an ejector which draws reactor effluent equivalent to the amount of CO2 introduced into the stripper bottom. The ejector effluent containing make up ammonia and reactor effluent flows to the falling film type carbamate condenser where condensation takes place and the heat evolved is used for waste heat steam generation at low pressure. The outlet stream from HP condenser containing recycle carbamate solution together with NH3 and CO2 gases, flows into the reactor. The stripper exit solution after pressure reduction, is led to rectifying column at low pressure where urea solution is removed of residual carbamate and dilute urea sol. 72-75% is led into two stage vacuum concentrators at prilling top and 99% urea melt from 2nd stage concentrator is prilled using spinning buckets sprayer in prilling tower with induced airflow. There is only one recycle stage after HP syn. loop.

Since the process works on low excess ammonia, corrosion in HP syn. loop is prevented by introducing 2-3% oxygen along with make up CO_2 gas. The better corrosion resistant material (Titanium tubes) in stripper and condensor is used; inert gases are removed from reactor top in inert washing tower and condensed NH_3 and CO_2 is recycled to H.P. condenser.

Condenser. The vapours from rectifying column are condensed in a condenser and remaining NH₃ and CO₂ along with inerts are washed in inert washing column with condensate from vacuum section. A part of condensate from vacuum section is hydrolysed in a urea hydrolyser and ammonia and carbon dioxide vapours are recovered.

The reactor volume is slightly bigger and vapour pocket exits at top. The reactor is provided with sieve trays for better vapour liquid mixing and to prevent back flow. Stamicarbon CO₂ stripping process is being used in a large number of urea plants in the world. The plant is economical as capital cost and variable cost are lower.

Snam Progetti NH₃ Stripping Process

The principle of the process is given by the following equations:

(A)
$$NH_2COONH_4$$
 \longleftrightarrow $CO(NH_2)_2 + H_2O$ ammon. carbamate urea

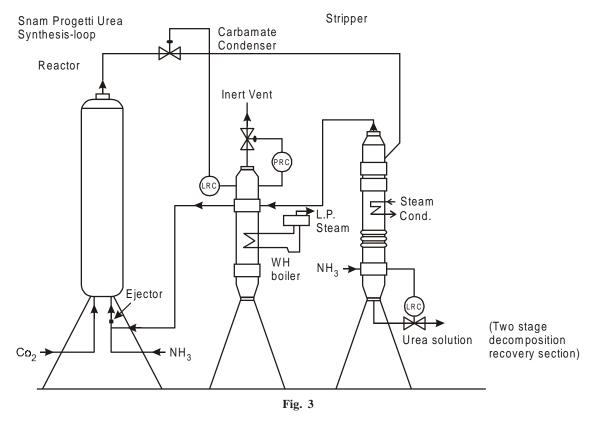
(C)
$$P = \frac{0.53 \text{ Ps}}{3\sqrt{[\text{NH}_3]^2.[\text{CO}_2]}}$$

where P = dissociation Pressure of liquid carbamate.

In this process pressure in the syn. loop using ammonia as stripping agent of reactor, NH_3 stripper (titanium tubes) and H.P. carbamate condenser, is maintained at 150 atm; NH_3 : CO_2 in the reactor is 3:8 and temperature $185^{\circ}C$ with conversion efficiency of 65-67%. Due to high NH_3 : CO_2 ratio, there is high residual NH_3 content in the stripped solution leaving the stripper. The overall CO_2 conversion efficiency in the syn. loop is 85%. Two carbamate decomposition and recovery stages, down stream of syn. loop, and a separate NH_3 recovery unit as pure component have been provided.

Two H.P. condensers have been provided with steam recovery at 4.5 atm and 6 atm respectively. All $\rm CO_2$ with 0.3% oxygen for condensers passivation-with little by pass to stripper (as more heat is produced than required to maintain reactor temp.) to which reactor effluent from top enters. The reactor effluent passes through the stripper against an ascending stream of $\rm NH_3$ vapour from $\rm NH_3$ evaporation section. Steam at 25 atm is passed in the shell side of stripper operating at 170–180°C. The stripper effluent contains only 2% carbamate and followed by two stages of decomposition and recovery at 17 and 3.5 atm and the 75% urea solution obtained is concentrated in 2 stage vacuum concentrator to get 99.5% urea melt which is sprayed from a rotating bucket (300 rpm) in an induced draft prilling tower and prills at 50°C is obtained from bottom. Free fall of urea melt in P/T is 30 m and overall ht. of P.T with vacuum concentrators and dedusting system at top of P.T is about 44 m.

The stripped NH_3 , CO_2 and H_2O gases are condensed in 1st H.P. condenser with steam raising at 6 atm, and outlet condensed carbamate, along with uncondensed vapour, is fed into 2nd H.P. condenser where full condensation of gases occur and then recycled to recover via H.P. ejector operated by H.P. ammonia feed from ammonia pump. The 1st stage recycle solution from H.P. absorber is pumped to no. 1 H.P. condenser and L.P. condenser weak solution is pumped to H.P. condenser. NH_3 and CO_2 is absorbed from vacuum condensate and recycled back to L.P. condenser. Fig. 3.



8. TEC'S ACES (ADVANCED COST AND ENERGY SAVING) PROCESS

The process uses an isobaric syn. loop consisting of reactor with two strippers at 185/187°C and H.P. carbamate condenser working at 175 atm pressure. The reactor temp. is 190°C and NH₃ CO₂ feed ratio is 4.0 and CO₂ conversion efficiency is 68%. Most of CO₂, after compression in a centrifugal compressor, is passed through stripper, having sieve plates at top, and tube bundle through which reactor effluent falls as a failing film layer. In the effluent, NH₃ and CO₂ content is 12 and 14% respectively. The tube bundle is heated by medium pressure steam (25 atm). Most of the unconverted carbamate is decomposed at high partial pressure of CO₂ and the gases move upwards through sieve plates thus reducing moisture in NH₃, CO₂ gases which move into 1st H.P. condensor where it is condensed in presence of carbamate soln. from H.P. scrubber where reactor outlet gases are washed with recycle carbamate from H.P. scrubber. The steam at 5 atm is raised in 1st decomposer. A part of stripper outlet gases is also sent to 2nd H.P. decomposer to the extent heat is required to heat up the stripper outlet solution to decompose residual carbamate.

The urea solution with low carbamate content from shell side of 2nd H.P. decomposer is sent to H.P. decomposer where it is heated by steam in shell side. The solution outlet of H.P. decomposer is then sent to LP decomposer with CO₂ stripping introduced at bottom. It is a packed tower with bubble cap plates at top. The gases from L.P. decomposer top is condensed in shell and tube L.P. absorber and absorbed solution is recycle back to H.P. absorber. The carbamate solution from H.P. absorber is recycled to 2nd H.P. condenser and H.P. scrubber.

The off gases, with inert from air injection in H.P. scrubber are further absorbed in inert washing column after pressure reduction. The dilute urea solution from L.P. decomposer is sent to two stage vacuum concentrators and 99.5% urea melt is sprayed into prilling tower top. The urea prills at the bottom of the tower is cooled in a fluidized bed cooling system. The vacuum condensate from vacuum section is stripped in plate tower and stripped gases are sent to L.P. decomposer. No NH₃ recovery as pure component is considered and all NH₃ is fed to reactor.

9. MONTEDISION'S IDR (ISOBARIC DOUBLE RECYCLE) PROCESS

Here reactor, NH_3 stripper, CO_2 stripper both working at $200^{\circ}C$ and H.P. carbamate condenser and a post condensor operate at 200 atm pressure. The CO_2 conversion efficiency in reactor is 70% and corresponding NH_3 : CO_2 feed ratio is 4.25 with water: CO_2 ratio 0.55. The reactor is divided into two section by a partition plate. The reactants are fed to the bottom of upper section, raised to top and through down comes to the bottom of lower section and flows upwards to outlet to the 1st H.P. CO_2 stripper. The NH_3 , CO_2 stripped vapour flows to reactor upper section where these are condensed and keep reactor temp. at $185-190^{\circ}C$.

The stoichiometric NH_3 feed is arranged at different temperature levels to reactor upper section, to 1st H.P. decomposer and to reactor lower section. The last stream is meant to establish the zone design ratio of NH_3/CO_2 not yet converted.

In the last H.P. NH₃ stripper, most of residual carbamate is decomposed and recycled to the reactor in vapour phase. The heat required is supplied by M.P. stream. The solution from the stripper is conveyed to the 2nd H.P. stripper where whole of make up CO₂ is fed as stripping agent. By supplying heat (M.P. steam), the 2nd stripper outlet contain 40% CO₂ and 14% ammonia is sent to the M.P. stage purification section, working at 23 atm after pressure reduction where it is heated by recovery steam at 157°C. The vapours from 2nd H.P. stripper are sent to H.P. condenser together with most recycle carbamate solution from M.P. carbamate condenser. Steam is generated in M.P. carbamate condenser at 7 bar. The carbamate solution from H.P. carbamate condenser flows by gravity into the reactor. The non condensable gases from H.P. carbamate condenser are cooled and partially condensed in a post carbamate condenser which also flows by gravity into the reactor and unabsorbed gases from post carbamate condenser is sent to inert washing column after pressure reduction. Waste heat from post carbamate condenser is used to generate 3.5 atm steam. The vapour from M.P. condenser is sent to concentrator for heating and concentration of urea solution from L.P. decomposer and carbamate solution at 120°C is recycled to H.P. carbamate condenser and post carbamate condenser. L.P. decomposer is heated by 7 atm steam at 146°C. Urea solution from L.P. decomposer is concentrated to 99.5% concentration in 2 stage vacuum concentrators usually at the top of prilling tower to reduce biuret and prilled in a rotary spinning bucket (holes–1.3 mm). Air is used along with make up CO₂ gas (0.2% oxygen) as well as a small injection of air +H₂O₂ in H.P. stripper is made to passivate stainless steel to prevent corrosion.

10. STORAGE FOR FERTILISER

Silo volume to surface area ratio is kept smaller. Usually RCC parabolic silo is constructed with air conditioning plant to keep R.H. less than humidity of stored fertilizer. Usually critical humidity, around 65–70% in silo, is to be maintained to prevent moisture absorbtion to prevent caking. Air conditioning is required when R.H. is higher than 70–80%. Bagging is usually done in bagging plant.

Process	NH ₃ t/te	CO ₂ t/te	Steam t/te	Export Steam t/te	Process Ele- ctricity kwh/te	Cooling water m³/te
Stamicarbon	0.57	0.75	0.775	_	15	62.5
CO ₂ stripping			25 bar			$\Delta t = 10^{\circ}C$
Snam	0.57	0.74	0.83	-	20	70
Projetti NH ₃			23 bar			$\Delta t = 10^{\circ}C$
Stripping						
TEC-ACES	0.57	0.75	0.70	0.09	30	60
Process			100 bar	6 bar		$\Delta t = 10^{\circ}C$
Montedison	0.568	0.736	0.71	_	18	75
IDR process			105 bar			$\Delta t = 10^{\circ}C$

 ${\bf Table} \ {\bf 7}$ ${\bf CO_2} \ {\bf By \ Product \ Gas \ from \ Ammonia \ Plant}$

Constituents	Values
CO_2	98.5%, saturated at 45°C and 500 mm W.G. Pressure
CO	0.60
H_2	0.65
$N_2 + Ar$	0.1
Sulphur	< 0.5 ppm

Table 8

N.G. Analysis

Constituents	Values
CH ₄	78–91%
C_2H_6	6–10
C_3H_8	5–6
ISO Butane (C ₄ H ₁₀)	1–1.5
N Butane	1.3–1.4
ISO Pentane (C ₅ H ₁₂)	0.3-0.4
N Pentane	0.14-0.25
NCV	10377 Kcal/m ³

 ${\bf Table~9}$ Comparative Statement on Energy Consumption

		Kellog	UHDE	PDIL	MHI-CHIYODA
1.	Ammonia Plant				
(<i>i</i>)	Process route	Kellog's steam reforming	ICI steam reforming	PDIL/HTAS	HTAS
(ii)	CO ₂ removal	Benfield	MEA	Benfield	Catacarb
(iii)	Synthesis	Kellog	UHDE	Ammonia converter (HTAS) rest PDIL	CCC
(iv)	Rated plant capacity	900 MTD	900 MTD	600 MTD	900 MTD
2.	Feed Stock Fuel Energy Mkcal/MT Guaranteed	NG	NG	NG	NG
(<i>i</i>)	Feed + Fuel	10.0569	9.97	10.933	9.59
(ii)	Steam import/export	0.0216	(-) 1.008 (export)	-	1.37
(iii)	Elec. power (excluding C.T.)	0.099	0.12557	0.2185*	0.05
(iv)	Total energy (excluding C.T.)	10.1715	9.0875	11.1515	11.01
3.	Uure Plant	Stami-carbon	Stami-carbon	PDIL conventional	Stami-carbon
(i)	Process route	CO ₂ stripping	CO ₂ stripping	3 stage total solution recylce with steam reco- very in 1st cycle	CO ₂ stripping
(ii)	Rated plant capacity	1620 MTD	1550 MTD	1167 MTD	1600 MTD
4.	Raw Material Consumption (Guaranteed)				
(<i>i</i>)	Liquid NH ₃ MT/ MT urea	0.58	0.58	0.590	0.592
(ii)	CO ₂ MT/MT urea	0.77	0.77	0.77	0.775
5.	Energy, Mkcal/MT				
(<i>i</i>)	Feed ammonia	5.899	5.2707	6.5794	6.517
(ii)	Import steam with pressure and temperature	0.8205 (39 ata, 380°C)	0.7998 (110 ata, 550°C)	1.0376 (45 ata, 360°C)	1.0 (66 ata, 43°C)

Table Contd.

(iii)	Electric power excluding (CT)	0.0215	0.0258	0.3586	0.03
(iv)	Export steam (4 ata. satd.)	Used in deaeration in ammonia plant, 10 Te/hr	Used in desulphurisation for NG preheating, 16.2 Te/hr	Used in 3.5 ata network in urea plant – 4.2 Te/hr	Used in silo dehumidification 10 Te/hr
(v)	Total energy (excluding C.T.)	6.741	6.0963	7.9756	6.7072
6.	Net Process Heat, Kcal/kg Urea	812	722	792	692
7.	C.W., m ³ /MT	106	80	198	100
8.	Turn Down Ratio	70%	70%	65%	70%
9.	Energy for Off-site Facilities mk cal/mt Urea	0.9827	0.8635	1.5	0.9068
10.	Ovarall Energy for the Complex, Mkcal/mt Urea	7.7237	6.9598	8.438	7.614

VAP Pr. Vs TEMP. CURVE OF AMMONIA

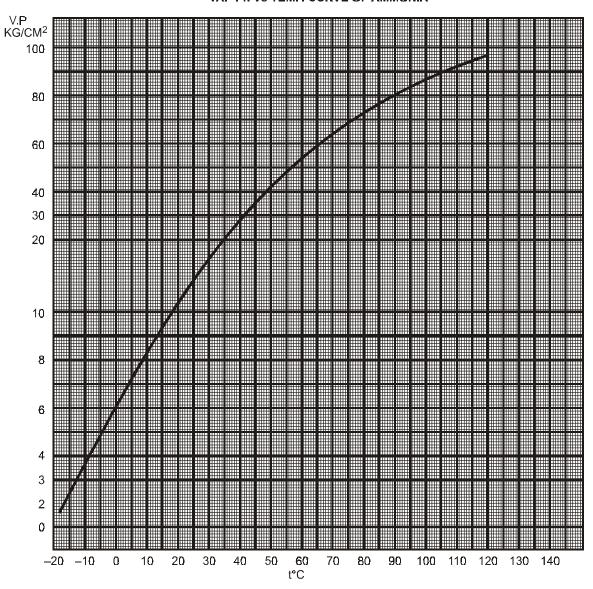


Fig. 4

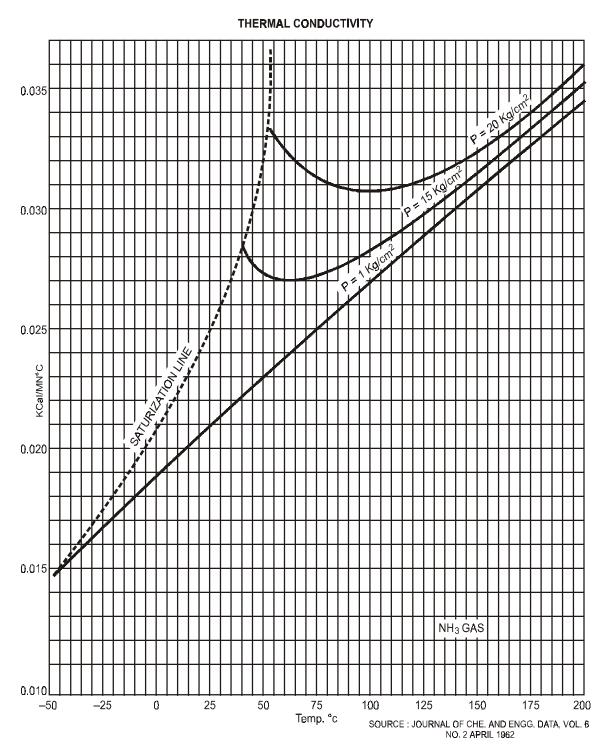
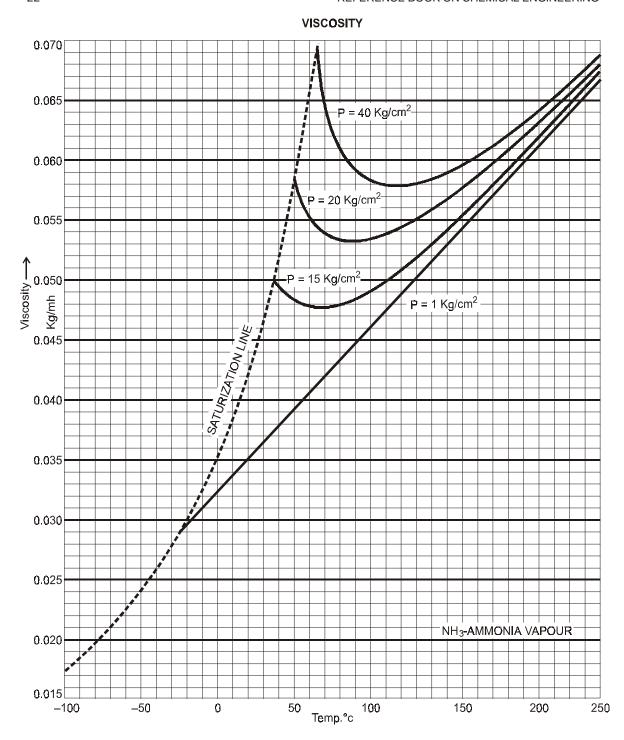


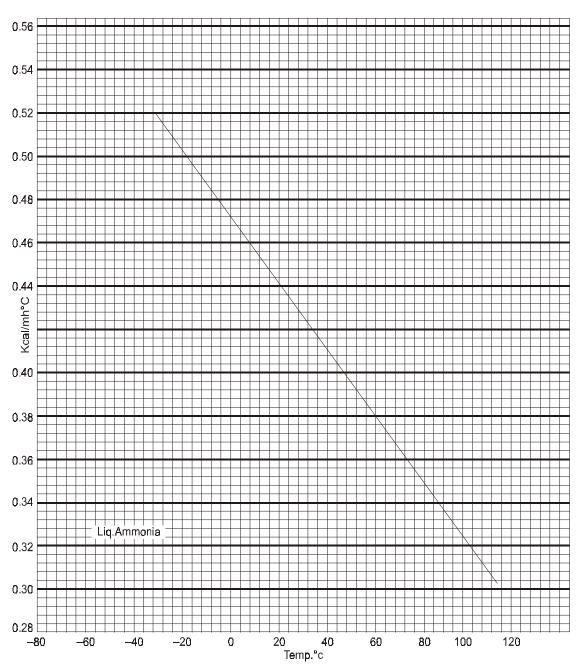
Fig. 5



SOURCE: JOURNAL OF CHE. AND ENGG. DATA, VOL. 6 NO. 2 APRIL 1961

Fig. 6

THERMAL CONDUCTIVITY



SOURCE : CAL. BOOK (AMMONIA)

Fig. 7

o Cristallization point X Experimental data

millipoise

ζpαπ

₹

%

8.99 9.43 9.73 10.40 10.93 112.57 13.54 15.68

1.02 8.13 11.89 15.47 23.12 33.28 38.13 46.18

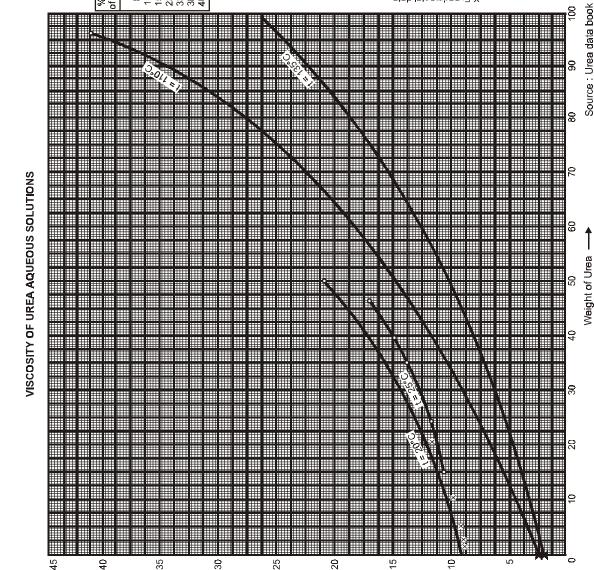


Fig. 8

Viscosity millipoises →



HEAT TRANSFER

1. INTRODUCTION

Heat is transmitted in the direction of the temperature drop by convection (contact), radiation and conduction. In many cases all these types of heat transmission takes place simultaneously. In shell and tube heat exchangers and other types of exchangers, the predominate phenomenon is transmission of heat by contact convection. In furnace and air heaters where gases are burnt to heat a gas or other surface, both radiation and convection are to be considered. Heat conduction is the flow of heat with a material (solid, liquid or gas). In most cases a wall is concerned and the heat is flowing through it from one face to the other face as in a pipe through which a hot fluid is flowing.

Heat transfer considerations are of prime consideration in chemical process industry including waste heat recovery.

1.1 Convective Heat Transfer

In convection (contact) mode of heat transfer is as per Fourier law, the quantity of heat transferred is given by eqn.

 $Q = U.A. \Delta tm$ where U = overall heat transfer co-eff, kcal/hr.m².°C, where A = area of heat transfer, m² based on O.D. of tubes, $\Delta tm = \text{mean/logarithm temperature diff. in °C between heat emitting and heat absorbing media and <math>Q = \text{total quantity of heat transferred in the exchanger, kcal/hr.}$

However, overall heat transfer co-eff. is the sum of reciprocal of undivided film co-eff. is called resistances to heat flow along the conduit (pipe) and resistance of metal wall plus fouling resistances due to foreign material depositing on both tube surfaces (inside and outside). For simplicity, for a single layer wall (tube), the overall heat transfer co-eff. of heat transfer.

$$U = \frac{1}{\frac{1}{u_1} + \frac{t}{\lambda} + \frac{1}{u_2} + \text{ fouling resistance}}$$

$$\frac{1}{U} = \frac{1}{u_1} + \frac{1}{u_2} + \frac{t}{\lambda} + \text{ fouling resistances for inside and outside tubes}}$$

where, U = over-all heat transfer co-eff., Kcal/hr.m²°C

 u_1 = individual film co-eff. on the side of hot fluid

 u_2 = individual film co-eff. on the side of cold fluid

t = wall thickness, m and $\lambda =$ co-eff. of thermal conductivity for

the metal tube material, kcal/hr.m.°C.

or

The coefficient of heat transfer U depends on flow conditions, the type and temperature of heating or cooling medium and configuration of areas of contact.

Temperature Difference (mean)

The temperature difference between hot and cold fluids is the driving force of heat transfer in a H.E. The flow of fluids (cold and hot) in the H.E. may be either countercurrent or parallel current; usually counter current flow is desirable as the quantity of heat exchanged remains constant. If Δt_1 is the higher temperature difference and Δt_2 is the lower temperature difference at either end of H.E.

then arithmetic mean temperature $\frac{\Delta t_1 + \Delta t_2}{2}$ is to be considered; if the ratio $\frac{\Delta t_1}{\Delta t_2}$ is less than 2 or

2, while log mean temperature difference (LMTD) is to be considered if the ratio of $\frac{\Delta t_1}{\Delta t_2}$ is more than 2

$$\Delta t_m = \text{LMTD} = \frac{\Delta t_1 - \Delta t_2}{2.303 \log \frac{\Delta t_1}{\Delta t_2}}$$

LMTD can be found from nomograph in Fig. 6 and Δt_1 and Δt_2 in Fig. 5.

1.2 Shell Side/Tube Fluid

In H.E. generally the fluid which is more fouling is put in tube side due to ease of cleaning and the other cooling or heating medium is put in shell side. A fluid having moderate to high press and temperature is also passed through tube side to avoid high shell thickness of H.E.; viscous and condensing fluids are passed through shell side.

1.3 Baffle Cut and Baffle Spacing

For making multipasses in shell side for better heat transfer in shell side fluid, 20–30% cut in baffles are made for flow of fluid across tube bundle length. The extent of baffle cut and no. of baffles determine shell side fluid velocity as per design requirement. Increasing velocity in shell side for better heat transfer is by proper spacing of baffles. Baffles may be of annular or segmented cut types. The baffle spacing is usually equally spaced over the length between tube sheets ends. Baffle spacing is usually 1/5th of shell id.

1.4 Tube Pitch

Tubes are laid in tube sheet for triangular pitch or square pitch or diamond pitch as per requirement of shell diameter, tube spacing for heat transfer and fluid properties. The individual tube ends at both sides are sealed with tube sheet by tube expanders. In Fig. 3, layout of tubes for triangular pitch is shown as well as formulae for square pattern layout are stated.

Mech. Design Code

Heat exchangers are generally designed as per TEMA class/ASME code/DIN standard.

Equations for determining heat transfer film co-effs.:-

Reynolds no =
$$\frac{D\nu\rho}{\mu}$$

(i) For turbulent flow (Re no. > 4100 inside a clean tube; usually Dittus–Boltier equation is used to determine surface or film co-effs.

$$u = 0.023 \frac{\lambda}{D} \left[\frac{D \nu \rho}{\mu} \right]^{0.8} \cdot \left[\frac{C p \mu}{\lambda} \right]^{0.4} \text{ (for heating fluid)}$$

$$u = 0.023 \frac{\lambda}{D} \left(\frac{D \nu \rho}{\mu} \right)^{0.8} \cdot \left(\frac{C p \mu}{\lambda} \right)^{0.3} \text{ (for fluid being cooled)}$$

or

N.B. $\frac{Cp\mu}{\lambda}$ is Prandtl no., $\frac{Dv\rho}{\mu}$ is Reynolds no. and $\frac{\mu D}{\lambda}$ is Nusselt no., Nu and Re no. depend on flow conditions and Prandtl no. indicated thermo-physico conditions of fluid.

(ii) For gases in forced convection, perpendicular to banks of staggered tubes:

$$u = 0.13 \quad \frac{\lambda}{D} \cdot \left(\frac{Dv}{\mu}\right)^{0.7}$$

(iii) For condensing vapours in horizontal tube

$$u = 0.73 \left(\lambda^3 \cdot \rho^2 \cdot g\right)^{1/4}$$

And for vertical tubes

$$u = 0.94 \left(\frac{\lambda^3 \cdot \rho^2 \cdot g.K}{L\mu' \Delta t} \right)^{1/4}$$

Where $u = \text{Surface or film co-efficient kcal/hr m}^2 ^{\circ}\text{C}$

 λ = Thermal conductivity of fluid, kcal/m hr°C

v = Velocity, m/sec

D = Tube O.D. or I.D., m

 μ = Absolute viscosity of fluid, kg/m.sec or Pa.S

 C_p = Specific heat of fluid, kcal/kg°C

 ρ = Density of fluid kg/m³

 λ' = Thermal conductivity of metal kcal/m.hr.°C

K = Latent heat of vapour, kcal/kg

L = Length of pipe, m

 Δt = Temperature difference between vapour and metal, °C

g = Accln. due to gravity m/sec²

 μ' = Viscosity of cold film kg/m.sec or Pa.S

1.5 Tube Wall Heat Flow Quantity

$$Q = \frac{T_1 - T_2}{2.303 \log \left(\frac{r_1/r_2}{2\pi L \lambda'}\right)}$$

where Q = Heat Flow, kcal/hr

 T_1 and T_2 = Temp. of inner wall and outer wall, °C

 r_1 and r_2 = Raddii of inner and outer wall, m

L = Length of tube, m

 λ' = Thermal conductivity of metal wall, kcal/m.hr.°C

(i) For multipurpose heat exchangers having tube O.D., and tube I.D. diameter in meter the overall heat transfer co-efficient is given by

$$U = \frac{1}{\frac{1}{u_0} + \frac{d_o}{2\lambda'} \cdot 2.303 \log \frac{d_o}{d_i} + \frac{d_o}{d_i u_i} + \psi_0 + \psi_1 \frac{d_o}{d_i}}$$

where,

 u_o and u_i = outside and inside film co-efficient kcal/hr.m².°C

 d_o and d_i = outside and inside dia. of tube, m

 λ' = thermal conductivity of metal wall, kcal/m.hr.°C and

and ψ_a and ψ_i = fouling factors for outside and inside of tube

(ii) In case of boilers and evaporator heating surface, overall co-efficient is given by

$$U = u_1 + u_s$$

where, u_1 = film co-eff. for hot water side

 $u_{\rm s}$ = film co-eff. for tube metal wall

(iii) For air heaters and super heaters u is given by:

$$u = \frac{u_1 \cdot u_2}{u_1 + u_2} \text{ kcal/hr.m}^2.\text{°C}$$

where u_1 = film co-eff. for hot gas side of tube/coil

 u_2 = film co-eff. for cold gas side of tube/coil

Note : 1. Normally 60% more area is taken over calculated area due to uncertainties of mean data taken for densities, sp. gravity, thermal conductivities, viscosity and sp. heat. Theoretically, R-S-S (root-sum-sq.) system is considered, actual A (area) = $\sqrt{\sum (\Delta A)^2}$

1.6 Fouling Factor

In actual service, addln. resistance to flow of heat from hot side to cold side through metal wall takes place resulting in reduction of respective film co-eff. with reduction of overall co-eff. Therefore, suitable fouling resistances (reciprocal of surface co-eff.) both hot and cold fluids are reqd. to be considered. Fouling resistances for different types of water are as follows:

$$\frac{\text{m}^2\text{hr}\,^\circ\text{C}}{\text{Kcal}}$$

Distilled water = 0.0005

Treated C.W. = 0.0005

Tube well water = 0.0003

Sea-water = 0.004

BFW = 0.001River water = 0.004

Appln. Range:

Temp. $= 115-205^{\circ}\text{C} \text{ range}$

Water vel. = 3'/secWater temp. $= + 52^{\circ}\text{C}$

2. TYPES OF HEAT TRANSFER EQUIPMENT

2.1 Single or Multipurpose H.E

In multipurpose H.Es, pr. Drop of fluid through shell side increases as the fluid moves in restricted space over baffle cuts but overall heat transfer co-eff. increase due to increased velocity of shell side fluid in the shell. Channel covers have reqd. compartments for directing tube side fluid depending on no. of passes. Expansion it, if reqd. it is provided on shell.

2.2 Floating Head H.Es

To prevent unequal expansion of tube bundle resulting in tube leakage failure for fixed channel covers, floating head tube bundle is provided with separate channel cover at floating head end.

2.3 Side/Top Fired Furnace for Indirect Heating of Gases/Water Inside Vertical Tubes

In reformation of hydrocarbon gases, side or top fired furnace heaters are used. In boiler furnace with side fired burners are used for heating of water in tube along vertical wall. The tubes are connected to boiler drum. These furnaces are used in refinery, fertilizers and other plants.

2.4 Evaporators and Re-boilers

These are shell and tube H.Es and located either externally or internally with or without natural or forced circulation. Steam is generally in shell side.

2.5 Condensers

Shell and tube H.Es for condensable vapours or steam is usually kept in shell side. Non-condensable gases are purged from top of vessel or in case of steam, steam ejector is used. In contact condensation, steam is condensed by water spray inside the empty condenser.

2.6 Regenerative H.Es

In a regenerative exchanger, where heat is alternatively stored and removed. The hot and cold fluid passes through same route through the same exchanger. Two exchangers are required as one gets heated up by hot fluid and the other gets cold by fluid which gets heated up. Flows are reversed by auto change-over mechanism which operates inlet and outlet valves of exchangers. They are used mainly for waste heat recovery from furnace fuel gases for primary air heating for furnace heating. Also in air separation, these are used for cooling of air and removal of impurities in inlet air, which gets deposited in cold exchanger and in reverse cycle these impurities are removed by hotter air.

2.7 Finned Tube H.Es

The external heat exchanger surface area in finned tube H.Es are increased considerably by fixing fins arranged either in circular fashion or horizontally along the external diameter of tubes.

2.8 Double Pipe

These are used for cooling of hot liquid by C.W. or cold fluid in annular space of the tubes, which are arranged vertically or horizontally. The fluids flow counter currently.

In Trombone coolers, hairpin type cooling tubes are arranged horizontally and C.W. is a splashed from perforated trough at top and C.W. falls on an open tank below.

2.9 Cascade Coolers for Liquefaction

Treated natural gas, after CO₂ removal, is usually cooled and methane is liquefied by cascade process using 3 refrigerants, propane, ethylene and methane successively. Propane has the highest B.P. (–44.5°C) followed by ethylene, (B.P. = –103.9°C and finally by methane (B.P. = –164°C) which gets liquefied when its temp. falls below critical temp. through 9 stages of cooling. Liquefied propane gets evaporated in propane evaporator by heat from incoming methane gas which evaporates propane (latent heat of evaporation propane is 101.8 Kcal/kg) thereby, cooling methane gas above B.P. of propane *i.e.*, –44.5°C; methane is further cooled to above –103.9°C (B.P. of ethylene) by evaporation of ethylene in ethylene evaporator (latent heat of evaporation of ethylene is 125 Kcal/Kg). Finally methane gets further cooled to below –82.5°C (critical temp.) when it gets liquefied, the pressure being above 47.3 Kg/cm² (critical pressure). The liquid methane gets further cooled to near –164°C (B.P.) by its own refrigeration (latent heat is 121.9 Kcal/Kg) when it is flashed in methane evaporator. The respective refrigerants follow the vapour compression cycle, after coiling process so as to produce cooled liquid methane *i.e.*, LNG.

3. OVERALL HEAT TRANSFER

Overall heat transfer co-eff. for some H.Es have been given in Fig. 1 and 2 for quick estimate of U. However, it is advisable to calculate U based on first principles. Often a U is considered in calculation followed by confirmatory determination of U.

3.1 Tubes Layout

In a heat exchanger tubes can be laid out in triangular diamond and square pitches and no. of tubes in a shell depends on shell dia. and tube pitch. In Fig. 3 calculation for no. of tubes in a Δ pitch and square pitch H.E is given.

4. RADIANT HEAT TRANSFER

The transmission of heat by radiation through space from a surface gas burner to another cooler surface or gas is governed by Stefan-Boltzman law

$$Q = F.C \left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4 \text{ Kcal/hr}$$
$$= F.h (t_1 - t_2) \text{ Kcal/hr.}$$

where, h = Surface (film co-eff. of heat transfer by radiation Kcal/m².hr. °C

 $C = \text{Co-eff. of radiation Kcal/m}^2.\text{hr.}(^{\circ}\text{C})^4$

F = Area of heat transfer, by radiation

 $T_1 = \text{Temp. } ^{\circ}K \text{ of hotter body}$

T₂ = Temp. °K of colder body

 t_1 and t_2 = Temp. °C of hotter and colder body respectively

$$h = \frac{\text{C} \cdot \left[\left(\frac{\text{T}_1}{100} \right)^4 - \left(\frac{\text{T}_2}{100} \right)^4 \right]}{t_1 - t_2}, \text{Kcal/m}^2.\text{hr.}^{\circ}\text{C}$$

and

The eqn. is useful in calculating fired heaters and furnaces where heat (convection) mode of heat transfer is also required to be considered. The heat output from burners is to be considered so as to balance the total heat distribution. Also heat loss through wall is to be taken into consideration.

5. HEAT TRANSFER BY CONDUCTION

Heat transfer by conduction takes place within a material (solid, liquid or gas), in majority of cases a wall is involved and the heat, flowing through it from one face to the other, is given by:

$$Q = A \cdot \frac{\lambda}{S} \cdot (t_1 - t_2), \text{ Kcal/hr.}$$

where, A = Area of heat conduction, m₂

 λ = Co-eff. of thermal conductivity of material Kcal/m.hr.°C

 t_1 , t_2 = Surface temp. of hotter face and colder face in °C, respectively

Q = Quantity of heat flow, Kcal/hr.

S = Wall thickness m

If the wall consists of no. of layers of thickness S_1 and S_2 and co-eff. of thermal conductivities, λ_1 and λ_2 , then the heat flow will be:

$$Q = \frac{1}{\frac{S_1}{\lambda_2} + \frac{S_2}{\lambda_2}} \cdot (t_1 - t_2) \text{ Kcal/hr.}$$

6. DATA REQD. FOR HEAT EXCHANGER CALCULATION: CRITERIA

A large no. of physical data are reqd. for calculation of a H.E. viz fluid properties—density, specific thermal conductivities, fouling resistance etc. The design criteria are to be fixed as per process requirement. If there is uncertainties in these data, then surface area is calculated by considering R-S-S (roof, sum and square) method. In H.E. data sheet often both clean and design over all co-eff. (based on fouling factor consideration) is mentioned and other process and mechanical design data. Apart from shell and tube exchangers, specific equation for film and overall heat transfer co-eff. for other types of heat exchangers should be consulted in heat transmission books and Perry's Hand book. Assumption made should be reasonable. Units of physical properties of fluids to be correctly ascertained in calculation of U.

7. HEAT DUTY

It is found out from process material balances and heat balance. The C.W. temp. rise is the limiting point for heat output of an exchanger. The C.W. quality will also determine the fouling factors to be taken in the determination of individual film co-eff. and overall co-eff. of heat transfer. An example of H.E. calculations is given in Chapter 6.

8. SELECTED PROCESS EQUIPMENT DESIGN

This is given in Chapter 6. For condensing vapors, if sensible heat of vapor is required to, determine Q by multiplying flow by latent heat of vaporization, K.

(i) For conversion of U based on o.d. of tube, multiply U by $\frac{d_i}{d_{\rm avg}}$ for U based on avarage dia. of tube. All tube dia. in mm.

- (ii) For conversion of U based on i.d. of tube, multiply U by $\frac{d_i}{d_o}$ for U based on o.d. of tube.
- (iii) For conversion of U based on i.d. of tube, multiply U by $\frac{d_i}{d_{\rm avg}}$ for U based on avg dia. of tube.

Some Heat Exchanger Types and Average Values for Overall coefficient of heat Transfer, U				
Туре	Exchange conditions	Average K values Kcal/m² h deg. C		
Heat Exchanger with Nested Tubes (a) Straight tube	Gas to gas (low pressures)	10-50		
Internal tube Tubular shell Baffle	Gas to gas at high pressure	100–400		
Number of Passes 1 inner (through the tubes) 1 outer (round the tubes)	Liquid to liquid	200–1000		
(b) U tube	Liquid to gas (low pressures)	20-70		
Number of Passes 2 inner 1 outer	Gas at high pressure (inner) to liquid (outer)	200–1000		

Fig. 1 Source: Borsig pocket book 3rd edn. 1970.

Some Heat Exchanger Types and Average Values f	or Overall coefficient of	heat Transfer, U
Туре	Exchange conditions	Average K values Kcal/m² h deg. C
(c) High-pressure feed water preheater with desuperheating condensation and subcooling zones on the steam side.		
Superheated steam Desuperheating Condensation Zone Zone Subcooling Zone Feed Water	Water (inner) to superheated steam at high pressure (outer)	1500–2500
Number of Passes 2 inner 2 outer	_	
(d) Double-tube heat-exchanger	Gas to gas (low pressure)	10-50
→	Gas to gas (high pressure)	100–400
	Liquid to liquid	300-1200
↑	Gas at high pressure (inner) Liquid (outer)	200–500

Fig. 2

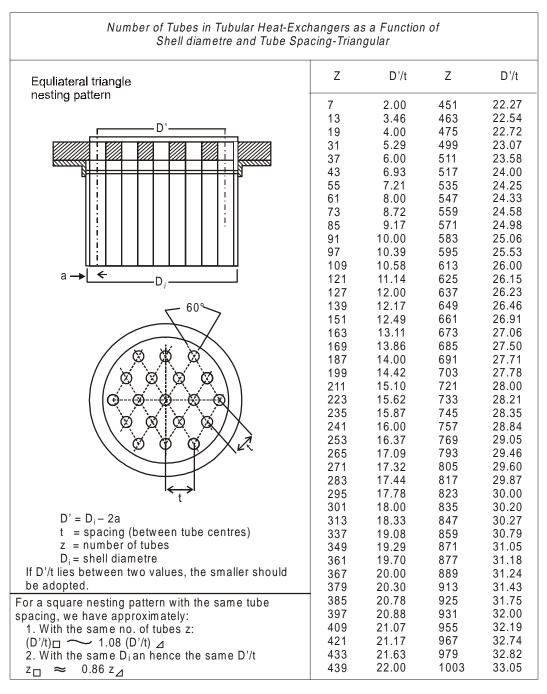
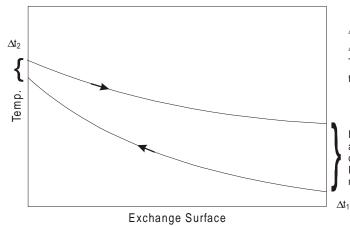


Fig. 3 Source: Borsig pocket book 3rd edn. 1970

Surface in Relation to Heat-Exchanger Length (m^2/m) (referred to external diameter d_a of tube (mm) for the following nominal bores d_i)										
d_i	20	25	32	40	50	di	20	25	32	40
d _a	25	30	38	44.5	57	ďa	25	30	38	44.5
Z						Z				
7	0.55	0.66	0.836	0.98	1.253	451	35.4	42.5	53.9	63.1
13	1.02	1.225	1.552	1.82	2.33	463	36.4	43.6	55.3	64.7
19	1.49	1.79	2.27	2.66	3.40	475	37.3	44.7 47.0	56.7 59.6	66.4
31	2.44 2.91	2.92 3.49	3.70 4.42	4.33 5.17	5.55 6.62	499 511	39.2 40.1	48.2	61.0	69.8 71.5
43	3.38	4.06	5.14	6.01	7.70	517	40.6	48.7	61.8	72.4
55	4.32	5.19	6.57	7.69	9.85	535	42.0	50.4	63.9	74.8
61	4.79	5.75	7.29	8.54	10.92	547	42.9	51.6	65.4	76.5
73	5.74	6.88	8.72	10.21	13.09	559	43.8	52.6	66.7	78.1
85 91	6.68 7.15	8.01 8.58	10.15 10.88	11.89 12.72	15.22 16.30	571 583	44.8 45.7	53.8 54.9	68.3 69.6	79.9 81.5
97	7.13	9.14	11.60	13.57	17.39	595	46.7	56.1	71.0	83.2
109	8.56	10.28	13.02	15.23	19.52	613	48.1	57.7	73.2	85.7
121	9.50	11.40	14.44	16.91	21.7	625	49.1	58.9	74.6	87.4
127	9.97	11.98	15.18	17.74	22.8	637	50.0	60.0	76.1	89.0
139	10.92	13.10	16.60 18.03	19.42 21.1	24.9 27.0	649 661	50.9 51.9	61.1 62.3	77.5 79.0	90.6 92.5
151 163	11.87 12.80	14.23 15.38	19.47	22.8	29.2	673	52.8	63.4	80.4	94.1
169	13.30	15.92	20.2	23.6	30.3	685	53.8	64.5	81.9	95.8
187	14.70	17.62	22.3	26.1	33.5	691	54.3	65.1	82.5	96.7
199	15.65	18.77	23.8	27.8	35.6	703	55.2	66.2	84.0	98.3
211	16.58	19.88	25.2	29.5	37.8	721	56.6	68.0	86.1	101.0
223	17.50 18.45	21.0 22.2	26.6 28.1	31.2 32.8	40.0 42.1	733 745	57.5 58.5	69.0 70.2	87.5 89.0	102.4 104.2
241	18.93	22.7	28.8	33.7	43.1	757	59.4	71.3	90.5	105.9
253	19.88	23.8	30.2	35.4	45.3	769	60.3	72.4	91.8	107.4
265	20.8	25.0	31.6	37.0	47.5	793	62.2	74.7	94.6	110.9
271	21.3	25.6	32.4	37.9	48.5	805	63.1	75.9	96.2	112.8
283 295	22.2 23.2	26.7 27.8	33.8 35.2	39.6 41.2	50.7 52.9	817 823	64.1 64.6	77.0 77.5	97.6 98.3	114.2 115.1
301	23.6	28.4	36.0	42.1	53.9	835	65.6	78.5	99.7	116.9
313	24.6	29.5	37.4	43.7	56.0	847	66.5	79.8	101.2	118.4
337	26.5	31.8	40.3	47.1	60.4	859	67.4	80.9	102.5	120.1
349	27.4	32.9	41.6	48.8	62.5	871	68.4	82.1	104.1	121.9
361	28.4	34.40	43.1 43.8	50.5	64.6 65.7	877 889	68.9 69.7	82.6 83.7	104.8 106.1	122.9 124.2
367 379	28.8 29.8	34.6 35.7	45.0 45.2	51.3 53.0	67.9	913	71.6	86.0	109.0	124.2
385	30.2	36.3	46.0	53.8	69.0	925	72.6	87.1	110.5	129.3
397	31.2	37.4	47.4	55.5	71.1	931	73.1	87.8	111.2	130.2
409	32.1	38.6	48.8	57.2	73.3	955	75.0	90.0	114.0	133.7
421	33.1	39.7	50.3	58.9	75.5	967	76.0 76.8	91.1 92.1	115.5 116.9	135.2 136.9
433 439	34.0 34.40	40.8 41.3	51.7 52.4	60.5 61.4	77.5 78.6	979 1003	78.8	94.6	120.0	140.4

Fig. 4 Source: Borsig pocket book 3rd edn. 1970



 Δt_1 : Large temperature difference Δt_2 : Small temperature difference The nomogram is used for determining the mean logarithmic temperature difference:

$$\Delta t_{m} = \frac{\Delta t_{1} - \Delta t_{2}}{\ln (\Delta t_{1} / \Delta t_{2})}$$

For a parallel or counter flow heat-exchanger Δt_1 and Δt_2 indicate temperature difference in the following media at either end of the heat exchanger. Related values of Δt_1 , Δt_2 , Δt_m are joined on the nomogram by a straight line

Fig. 5

Mean Logarithmic Temperature Difference Δt_m for Parallel and Counter Flow Heat Exchangers

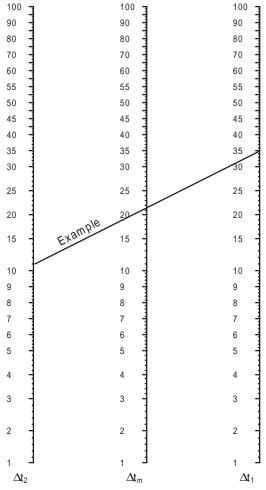


Fig. 6 Source: Borsig pocket book 3rd edn. 1970



PULP AND PAPER

1. GRADES OF PAPER

There are several grades of paper depending on and use, type of pulp, pulp usage and wt. of paper. These are classified as follows:

	Туре	Pulp used	wt. in gms/m²
(i)	Fine Paper	Bleached kraft or sulfite softwood pulps. Some hard wood pulp is also used for opacity.	J
(ii)	News print	High mech. pulp and a small % of chem; pulp.	48.8
(iii)	Bond paper	Bleached chem pulp and cotton fibres water marking possible.	48, 60, 75, 90
(iv)	Uncoated soft wood paper	Kraft or sulfite soft wood pulp with limited amount of mech. pulp or recycled paper.	
(<i>v</i>)	Magazine paper	Coated ground wood pulp	
(VI)	Coated wood free paper	Kraft or sulfite soft wood pulp with coating on both sides. Min 50% mech. pulp	٥.
(vii)	Tissue paper	Bleached chemical soft wood or hard wood pulp with some mechanical pulp.	15–60
(viii)	Wrapping or bag paper	Kraft soft wood pulp	50–134
(ix)	Cast coated paper, machine glazed	MG. Kraft, high glossy paper.	
(x)	Speciality paper	Refined chemical pulp used in electronics, cigarettes, currency making, tea bags etc.	
(xi)	Linear board	Unbleached Kraft soft wood used for corrugation.	205, 220, 330
(xii)	Kraft paper boards	Bleached/unbleached from kraft pulp	
(xiii)	Corrugating medium paper	Unbleached semi chem. pulp and recycled fiber	127
(xiv)	Grease proof	From very refined chem. Pulp	

2. PAPER SIZE STANDARDS

Size	Purpose	Wt.	in gms/m²
24" × 36"	News print		1.6275
17" × 22"	Printing		3.7596
19" × 24"	Blotting		3.0836
20" × 26"	Cover		2.7041
22" × 28"	Card board		2.2827
22.5" × 28.5"	Bristol		2.1928
25" × 38"	Book		1.9801

3. TEST PARAMETERS FOR PAPER

(i) Brightness (0 for black to 100% to MgO standard which has on absolute brightness of 96% by the reflectance of blue light 457 nm from paper)

Burst

Burst index

Stiffness

Flat crush

Tear value

Tear strength

Tensile strength

Toughness index and

Thickness or Caliper (for paper board)

(*ii*) Test parameters for wood = Kappa no (indicated lignin in wood) and determines consumption of oxidation chemical, Pot. permanganate.

4. RAW MATERIALS FOR PAPER MANUFACTURING

- (*i*) **Soft wood:** Fir, Pine, Cedar, Larch, Red wood, Spruce (a type of fir) and some others. Broadly soft wood contains 55–74% holocellulal (α cellulose 38–50%) and 9–11% pentosans (lignin). Soft wood is obtained from coniferous trees.
- (ii) **Hard wood:** Birch, Eucalyptus, Maple, Oak, Poplar and some others. Holocellulal content in hard wood is 70-74% (α cellulose 41-48%) and that of Pentosons is 16-21% (lignin). Hard wood is obtained from deciduous trees.
- (iii) Non wood fibres for pulping: Bamboos, Bagasse, Espartograss, reeds, rice and wheat straws, ramic and papyrus, corn oat stalks and barley stalks.
 - (iv) Textile fibres for pulping: Cotton linters, Flam, Manila hemp (abaca) and sisal.

Soft woods are preferred material for pulping due to its longer cellulose fibres (approx. 3–4 mm long and dia of 25– $30~\mu$). Low lignin content hard woods are used for special paper making where smoothness and softness are desired.

PULP AND PAPER 39

Table 1

Typical analysis of soft wood and hard wood and their pulps.

Constituents	Soft wood % wt.	Hard wood % wt.	Soft wood pulp % wt.	Hard wood pulp % wt.
Cellulose	52	54	85	84
Hemicellulose (Carbohydrates)	17	21	12	14
Lignin	28	22	3	1
Extractives (resins, gums, fats, waxes and colouring matter)	3	3	-	-

5. MANUFACTURING PROCESSES

(i) Pulp manufacturing process principles consists of dissolving cellulosic binding material, lignin by certain chemical and thus releasing the individual fibres. In the process, extractives are also removed.

The four process steps for wood pulping are:

- A. Kraft or Sulfate process at pH 13-14
- B. Sulphite process-it is further subdivided into
 - (a) Commonly used sulfite or bisulfate process at pH 1.5-5.
 - (b) Neutral sulfite or semi-chemical process at pH 7-10.
 - (c) Mechanical pulping process.
 - (d) Chem. Mechanical process using mild action of NaOH or NaHSO₃.

Kraft Process is comparatively new chemical pulping process developed in 1940s while Sulfite Process is the oldest, developed since 1900.

- (ii) Chemical pulping stages broadly consist of
 - (a) Wood preparation
 - (b) Digestion with reqd. process chemicals
 - (c) Washing of pulp
 - (d) Bleaching, washing and screening
 - (e) Pulp beating
 - (f) Paper making
 - (g) Chemical recovery from black or brown spent liquor from digester.

A. Kraft or Sulfate Process

5.1 Wood Pre-treatment

Wetted hard wood or a mix of hard and soft wood are cut into 4' or 8' long logs and fed into the debrarking mill which consists of rotating large horizontal drum of steel bars. Debarked log is removed from the other end of the drum. Modern method consists of using high pressure water jets at 1400 PSI at perpendicular to wooden logs for debarking.

The debarked wooden logs are then cut into chips $(5/8"-7/8"in length \times 1/16"-1/8" thickness and 1/2"-1") width in a chipping machine.$

5.2 Digestion

The chips are then fed into the digester or pressure vessels of capacity 1500-3500 cft and recovered cooking liquor is added. The composition of kraft cooking liquor is as follows:

$$NaOH = 70 \text{ gm } Na_2O/\text{lit}$$

 $Na_2S = 30 \text{ gm } Na_2O/\text{lit}$
 $Na_2CO_3 = 20 \text{ gm } Na_2O/\text{lit}$

The amount of sulfide is defined as "sulfidity" which is Na_2S content divided by sum of NaOH and Na_2S all expressed as Na_2O . Sulfidity is maintained at 25–28%. Na_2CO_3 present acts as an inert material in cooking liquor after recovery of spent black liquor from digester. Make up Sod. Sulfate is added to black liquor from recovery furnace for use as cooking liquor depending on active material conc.; caustic efficiency is determined by ratio of $NaOH/(NaOH + Na_2CO_3)$. In paper mills Sod. sulphate soln. is prepared by melting sulphur with soda ash in air.

$$2Na_2CO_3 + 2S + 3O_2 \longrightarrow 2Na_2SO_4 + 2CO_2 \xrightarrow{H_2O} Sod.$$
 Sulphate soln.

Pressure in autoclave is kept at 13–14 PSI. Solid consistency in autoclave is 24–30%. The digester is heated with steam at 100–115 PSI which gives a cooking temp. at 170–175°C. Digestion time varies between 4–6 hours. The colour of cooking liquor gradually changes to black as cooking progresses. Initially dissolution of carbohydrates (soluble hemi-cellulose) is faster than lignin.

After the digestion is over the autoclave pr. (steam) is reduced to 80 PSI and contents discharged into a tank. Only 1/2 of Na₂S is effectively available.

5.3 Filtering, Washing and Screening of Pulp

From the dumping tank, pulp is separated from spent liquor in cyclindrical washers with washing of pulp. Screening is done in two stages, firstly in common screen (V.K. roller) that removes undigested chips and secondly in screen which removes uncooked fibres. The pulp output is 46–48% of original wood. The colour of Kraft pulp is light greyish brown.

5.4 Bleaching of Pulp

For good quality white paper, the pulp thus obtained, is bleached. Initially chlorine bleaching which was discovered in 1930s is followed by Cl_2O and H_2O_2 bleaching which was introduced a decade later. Oxygenated bleaching agent is used in 1960s. Bleaching is for destruction of chromophore in organic and inorganic compounds remaining in pulp. Bleaching involves oxidation or reduction or both. The oxidative removal of chromosphore is irreversible, whereas reductive bleaching can be reversible in presence of oxygen in air. Bleaching removes residual lignin from pulp and also purifies cellulose. Now a days bleaching process is subdivided into several steps with washing of pulp in between to reduce chemicals. Use of lesser quantities in greater no. of steps reduces danger of cellulose detoriation by bleaching. Initially less selective chemicals are used and finally selective bleaching agents are used.

Bleaching is carried out in several towers with washing drums or displacement (diffusion) washers in between the steps. Kraft pulp is difficult to bleach. For bleaching with Cl_2 gas or soln., pulp consistency reqd. is 3-4%.

PULP AND PAPER 41

Bleaching steps in kraft pulp:

- (a) Cl₂-alkaline extraction-hypo-chlorite-Cl₂O
- (b) Same as in (a) followed by alkaline extraction-Cl₂O
- (c) O₂-Cl₂-alkaline extraction-Cl₂O-H₂O₂-Cl₂O
- (d) O₂-Cl₂-Oxygen/alkaline extraction-Cl₂O
- (e) H₂O₂, Cl₂O

The no. of steps used for bleaching depends on type of product desired. Paper mills produce their hypo-chloride by reacting Cl₂ with NaOH:

$$\begin{aligned} \text{Cl}_2 + 2\text{NaOH} & \longrightarrow & \text{NaOCl} + \text{NaCl} + \text{H}_2\text{O} \\ \\ \text{or} & \text{Cl}_2 + \text{Ca(OH)}_2 & \longrightarrow & \text{CaOCl}_2 + \text{H}_2\text{O} \\ \end{aligned}$$

However, use of lime is decreasing. Hydrogen Peroxide is produced by reacting Sod. Peroxide with water:

$$Na_2O_2 + 2H_2O \longrightarrow H_2O_2 + 2Na^+ + 2OH^-$$

Chlorine dioxide, Cl_2O is an explosive agent. It is gas at STP but explodes spontaneously at partial pressure of > 40 KPa, decomposing to Cl_2 and O_2 . If heated or exposed to light it can exploded even at lower conc. In paper mills it is usually prepared at site from Sod. Chlorate:

$$4\text{NaClO}_3 + 4\text{HCl} \longrightarrow 4\text{ClO}_2 + 2\text{H}_2\text{O} + 4\text{NaCl}$$

 $2\text{NaClO}_2 + \text{Cl}_2 \longrightarrow 2\text{ClO}_2 + 2\text{NaCl}$

Bleaching with H_2O_2 requires stabilishing agent, Sod. Silicate chelating agent (heavy metal ion chelating), dispersants and magnesium salts. Oxygen bleaching is done in NaOH presence.

5.5 Pulp Beating and Filtration

Pulp refiners called beaters are used to treat bleached pulp to improve paper making properties. Originally Jordon/Hollander beaters were used and now replaced by disc refiners. The beater machine lacerate or cut pulp fibres. The disc is made of hardened Ni-white iron. Use of conical disc is subsidising. After wood pulp is diluted to 1.5% congistency and filtered in vacuum filters pulp is obtained. The pulp cake has 10–20% consistency.

5.6 Paper Making through Bleached or Unbleached Pulp

Purified pulp is used in various paper making machines to produce final paper, dried and packed automatically.

After beating operation of the pulp, there is large increase in surface area, sliminess, and good dispersion, increasing in equilibrium moisture/Cu no. and zeta potential.

5.7 Chemical Recovery

The digester spent black liquor pulp and filter washings are treated to recover valuable chemicals, which are reused in digester after addition of make up chemical (Sod. Sulfate). The spent black liquor contg. 10–15% solids (about 40% inorganic, 60% organic) is concentrated to 48–50% solids in a series of counter current evaporates (4–6 stages) with vacuum (8–23 mm Hg) at feed end and Pr. operations (45–15 PSI) at outlet end. Tall oil is separated from 2nd stage outlet. The concentrated

liquor contg. 50% solids is black liquor which is further concentrated to 65–73% solids in a heater and finally sprayed with steam in a recovery boiler using 20% excess air (50% of which is preheated to 150°C). The organic material in atomized spray dries as it falls and burns and salt gets melted and flows to the outlet. Air flow is controlled so that all sulphur compounds are reduced to sulfide. Steam is produced in recovery boiler top steam coils.

Make up Sod. Sulfate is added to feed the stream to recovery boiler so that it also reduces to Sod. Sulfide. The molten chemical is taken out from the furnace and led into a re-circulating water settling tank where it dissolves to form green liquor. The dross, about 0.1%, settles at bottom and is periodically removed. The green liquor is then transferred to causticizing tank where lime is added. The clear liquid from top is sent to digester and settled lime mud is burnt to make Calcium Oxide for reuse.

$$Na_2SO_4 + 4C \longrightarrow Na_2S + 4CO$$
 $NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$
 $Na_2CO_3 + Ca(OH)_2 \longrightarrow 2NaOH + CaCO_3$

Typical data for chemical recovery:

Chemical recovery = 90%

Caustification eff = 85–90%

Reduction of Sulphur Compounds = 90–95%

Steam economy in evaporator 6 stage is possible which will enable 14 lbs of steam at 45 PSI to remove 70 lbs of water from 100 lbs of black liquor containing 15 lbs of solids and 85 lbs of water to a conc. of 30 lbs of solids (50% concentration).

6. SULFITE PROCESS

This process differs from kraft process in digestion procedure, bleaching of pulp and chemicals recovery. Normally soft wood is used.

6.1 Digestion Method and Chemical Recovery

Digester capacity is 3500-12000 cft, chemicals reqd. are sodium sulfite and soda ash. A total of 6.5% SO₂ (free 5.3% and combined 1.2%) is reqd. for digestion to dissolve lignin with the formation of Sulfonate and removal of lignin bonds. Some dolomite is also used. In paper mills Sodium Sulfite is prepared by melting sulphur, absorption of SO₂ in water to form Sulphurous acid followed by reaction with base, NaOH:

An alkaline pH upto 10 is maintained in autoclave heated with steam at 80 PSI. Recovered cooking liquor from chemical recovery section is added into the autoclave after chips are transferred. Cooking time is 7 hrs. Temp. is raised initially to 110°C in 4 hrs. The temp. is again is raised to 135–140°C and kept for 3 hrs. At the end of cooking period, pr. is brought down to 30 PSI and autoclave effluent discharged into a pit. After separation of pulp and washing, the grayish white pulp is sent for bleaching and subsequent operation and the spent brownish liquor is sent for chemical recovery.

PULP AND PAPER 43

6.2 Chemical Recovery

Similar method for kraft process is used where recovery of chemicals upto 50% is achieved. The conc. brown liquor is burnt in a recovery boiler. The make up Sod. Sulfite is added to the conc. brown liquor before it is atomized with steam and burnt in boiler. The melt from boller is put in water tank with re-circulation. The green liquor is transferred to causticizing tank where lime is added. The clarified, filtered clear liquor is then sent to digester for use as cooking liquor. The lime mud is vacuum filtered and cake dried in a rotary kiln to obtain lime, which is reused.

6.3 Bleaching of Sulfite Pulp

Bleaching sequence is as follows: Chlorine alkali extraction hypo-chlorite Chlorine Cl $_2$ O Chlorine H_2 O $_2$ alkali extraction hypo-chlorite Cl $_2$ O Oxygen Chlorine alkali extraction H_2 O $_2$ H_2 O $_2$ H_2 O $_3$ H_3 O $_4$ H_3 O $_5$ H_3 O $_5$ H_3 O $_5$

7. MECHANICAL PULPING PROCESS

Here, a no. of chemicals are used and the process is suitable for Hard wood and light colored soft woods, like spruce, balsam, fir and hemlock.

Wet soft wood is debarked, cut into small pieces and ground in a rotating disc to powder form, followed by pulping and bleaching with $\rm H_2O_2$. The yield of mechanical pulp is 92-96% of wood treated. Paper produced is used for newspaper and magazines; very often 30–40% waste paper is used in this process.

Apart from this process, TMP and CTMP processes are also used.

8. DE-INKING OF WASTE PAPER

Recycling of waste paper is a very necessary step for conservation of forest products and for paper manufacture it is essential that ink and other impurities be removed from recycle paper. There are two processes:

- (i) Wash deinking process.
- (ii) Floatation deinking process.

Both the process involved alkali treatment of waste paper by immersing waste paper baskets in caustic soda solution followed by bleaching with H_2O_2 . Deinked newspaper is used mostly with hard wood pulp for newspaper and magazines.

9. SPECIALITY PAPER

Here unused non-wood based raw materials are used to get good quality chemical pulp due to low lignin content. Leaf cellulose also yields good quality pulp suitable for currency note.

9.1 Bamboo Pulp

Here NaOH and Soda ash is used as chemicals for pulping. After crushing, the bamboo is cut into chips and digested with alkali in a two-stage counter current alkali digestor. High quality pulp is obtained which is better than cereal pulp.

9.2 Bagasse and Corn Stalk Pulp

Here a rod mill is used as a 1st stage digester in series with a 2nd stage digester with alkaline cooking liquor. High-grade pulp is produced which is suitable for light wt. paper making.

9.3 Cereal Pulp

Here rice, wheat, oat and barley straws are used as raw materials. Cooking liquor used is milk of lime (10% CaO) or 13% burnt dolomite. The digester is spherical or rotary. Cooking is carried out at 115°C for 8–10 hrs. using steam at 45 PSI. The pulp is suitable for corrugated paper.

9.4 Details of Pulp Bleaching (Cl₂ alkaline extraction-Hypochlorite-H₂O₂-O₂/Cl₂O)

Normally chlorine bleaching is done with alkali extraction with soda ash at a temperature of 65° C for about an hour and hypo chloride bleaching using Sod. or Cal hypo chlorite at ambient temp. (30°C) for 2–4 hrs. in 2–3 stages with mild alkaline wash in between stages. Subsequent stages of bleaching are with H_2O_2 . Oxygen and Cl_2O are used for better quality paper-making. In all types of bleaching, calculated quantity of bleaching agent is used. The bleachability test or TAPPI permanganate (O.IN) test indicates amount of chlorine in the form of hypo chlorite reqd. to bleach 100 gm. of pulp to standard brightness. Actually it measures the amount of 0.1 N KMnO₄ soln. that reacts with chlorinated soln., consumed by one gm. of pulp under standard condition.

10. PAPER MAKING BY HOLLANDER MACHINE

The bleached pulp is subjected to beating operation in Hollander machine when cellulosic fibres swells (expanded) spilt, bruished and deformed. The machine consists of an oval shaped trough divided in two segments. The bedplate is placed in one section and is made up of projected bars or blades (bronze or steel) of 3/4" dia \times 3" thick. A big roller is placed over the blades and bars fixed on the bedplate. The clearance between the roller blades and those fixed on the bedplate is small and can be adjusted. The roller moves at a peripheral speed of 2000 ft/min. The slurry (5–8% conc.) is circulated around the trough by the padding action of the roller. As the pulp moves through the clearance it is subjected to rubbing, splitting, brushing and deformation along with swelling of the pulp. The clearance is gradually reduced as beating continues. The time of beating varies from 1 hr. to several hrs. depending on the nature of pulp required.

After pulp beating, it is filtered and used for paper making in various automatic machines.

11. Neutral sulfite semi chemical pulping yields black liquor from which acetic acid and formic acid can be extracted.

Paper pulping liquor is a source of hemi cellulose fraction of wood and from which lignin chemicals can be obtained.

Tall oil

It is obtained from Kraft wood pulping process and it is a mixture of resin and a group of fatty acids.



CHLOR ALKALI INDUSTRY

Chlor-alkali industry is one of the key chemicals industry for producing caustic soda (as Pellets, flakes) and chlorine by electrolysis. Pure Hydrogen is produced as a by-products. There are 3 processes. Each process uses different method of keeping the Cl_2 , produced at anode, separate from NaOH and H_2 produced directly or indirectly at cathode. Saturated and purified brine is used at raw material. DC voltage is applied to battery of cells in series.

The cell voltage is kept above the theoretical requirement due to secondary reaction and current leakages.

- (a) Mercury Cell (Castner Kellner Cell-1892)
- (b) Diaphragm Cell (Greshiem Cell-1885)
- (c) Membrane Cell (1970)

Reactions:

$$2NaCl + 2H_2O \longrightarrow Cl_2 + H_2 + 2NaOH$$

Cathode reaction:

$$2Na^{+} + 2OH^{-} \longrightarrow 2NaOH$$

or
$$2\text{NaHg} + 2\text{H}_2\text{O} \longrightarrow 2\text{NaOH} + \text{H}_2(g) + 2\text{Hg}$$

Anodic reaction:

$$2Cl^{-} \longrightarrow 2Cl^{-} + 2e \longrightarrow Cl_{2}$$

Equation for electrolysis:

$$Q = I \times t$$

where Q = coulombs of electricity, I = Current in amps, t = time in seconds.

Theoretically 96544 coulombs of electricity will produce 1 gm equivalent wt, which are 35.45 gms of Cl₂, Hydrogen (1.005) and NaOH (40.01 gm). This output is based on First law of electrolysis (Faraday).

Mercury Cell

Here Sod. amalgam (NaHg) is produced at cathode which is reacted with water in a separate reactor called decomposer to produce NaOH soln. and Hydrogen gas and regeneration of Hg takes

place. Brine is re-circulated and NaCl salt is reqd. for re-saturation. Brine used is purified-first, dechlorinated and then purified by straight precipitation and filtration process. The products obtained are very pure. The Cl₂ along with little oxygen is used to produce HCl by burning chlorine in air. NaOH contg. little chloride leaves the decomposer with as much as 50% (wt.) concentration. This process requires maximum power for electrolysis but no steam is reqd. for conc. of NaOH soln. Hg requirement is maximum and requires environmental facility for treatment of Hg leakages from cell. H₂ gas and chlorine must be freed from Hg.

Liberated hydrogen at cathode is carried through electrically insulated pipe from decomposer or cathode compartment and is cooled in a vessel filled with water seal. If Hg and air mixture is formed due to shut down or breakdown, the seal allows the $\rm H_2$ -air mixture to escape. A demister is put to ensure Hydrogen is free from water droplets or NaOH soln. The hydrogen gas is compressed in roots blower or compressor, cooled in an after cooler and sent to consuming points. Hydrogen is about 99.5% pure. The oxygen in hydrogen can be removed by palladium/platinum catalyst and $\rm Hg$ by spl. catalyst if necessary for end use. Typical $\rm Hg$ content after cooler in Hydrogen gas is $\rm 15~mg/NM^3$ and $\rm O_2$ content is 500 ppm. Cell circuit voltage varies from $\rm 1300{-}2500v$ and applied D.C. voltage in each cell is 3.1 volt and operating voltage $\rm 4{-}4.25$ volts.

Because of very old process with high consumption of utility as well as Hg loss resulting in Hg pollution, this process is obsolete now.

Membrane Cell

In membrane cell, anode and cathode are separated by a cation permeable ion exchange membrane which can be polar or non polar. Here only cations, Na ions and little water pass through membrane brings brine purified by de-chlorination and re-circulated which is required for solid NaOH to saturate the brine. Since the life of membrane depends on purity of brine, brine after precipitation for Mg^{++} and Ca^{++} , ions are removed by sod. carbonate treatment and filtration. A high purity brine is reqd. It is further purified by ion exchange. NaOH soln. produced at cathode is 35% concentrated and is further concentrated by steam in evaporator to 50% conc. or converted to fused NaOH. The consumption of electricity is 25%–40% less than that of mercury cell. The consumption of steam for conc. of NaOH is also less than diaphragm cell. O_2 consumption by electrodes is less. No environmental pollution occurs and the cells are easy to operate. The cells are relatively less costly and insensitive to current density changes. Power consumption is about 2100 Kwh/Te in the membrane cell.

Mercury Cell (Krebs type)

Cathode area = $20.2m^2$

Cathode size = $14.4 \times 1.61 \text{ m}^2$

Slope of cell = 1.8%

Current = 300 A

Maxm. Current density = 13 KA/m^2

Cell D.C. voltage at 10 KA/m 2 = 4.25 V

Stems per anode = 4

Qty. of mercury per cell = 2750 Kg

Energy (DC) reqd. Kwh/Te = 3000

CHLOR ALKALI INDUSTRY 47

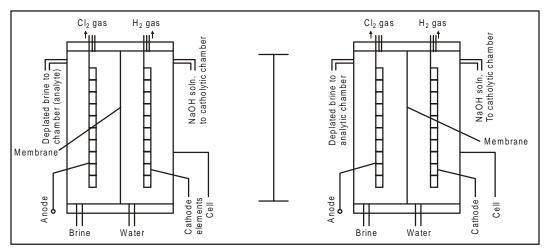


Fig. 1. Membrane cell: Bipolar elements arrangement.

Membrane cell technology came in around 1970. The process is most energy efficient as well as pollution free.

Saturated pure brine soln. (310 GPI) is fed into anode compartment and water in cathode compartment of electrolyser where DC voltage above theoretical limit is passed. Sodium ions with some OH-ions pass through membrane, made of per-fluoro-sulphoric acid or others whose life is about 4 years and forms NaOH soln. in cathode chamber. Water is added to cathode chamber and NaOH soln. from cathodic cell top is sent to catholyte chamber.

 H_2 generated, is a very pure type and sent for compression and use elsewhere. The NaOH soln. (~ 35%) soln. form cathodic chamber is sent for concentration.

Chlorine, generated in anodic compartment with oxygen content 0.5–0.7%, is sent for other uses in the plant of HCl production. Purified brine @ 310 GPI is fed to anode compartment and deplated brine from anode chamber is taken to anolyte chamber from where it is sent to brine purification section for saturation with brine soln.

Mono Polar and Bi-polar Electrolyser

Depending on the mode of DC connection to electrolyser cells, they are classified as bi-polar or mono-polar. Bi-polar cells are having min. voltage drops between cells and electrolysers are connected in parallel. The monopolar cells have simple structure and easy for maintenance. Each cell unit in one electrolyser is connected in parallel and each electrolyser is connected in series of 100 electrolysers. Electrolyser operates as per Faraday's law.

The electrolysers consists of plate type cells. The cathode is made of activated nickel and anode is of Titanium and both have operating life of 8 years each.

Diaphragm Cell

In this process (also called Nelson Process) the cell is U-shaped with graphite anode at center and perforated steel cathode covering the outer surface of asbestos, which acts as diaphragm.

The cell is in an outer casing in which steam is put to heat the cell to reduce the resistance and also to keep the pores of asbestos diaphragm clean.

Purified brine, after causticizing and removal of iron and other metals is kept in the cell at constant level and electrolysis takes place as it percolates through the asbestos diaphragm.

 ${
m Cl}^-$ ion is discharged at anode as ${
m Cl}_2$ and is let off. H⁺ ions are discharged at cathode where Na⁺ and OH⁻ *i.e.*, NaOH accumulation takes place in water which diffuses through porous diaphragm from anode compartment. The NaOH conc. is 10–12% and liquor containing NaCl (14–16%) which is separated by conc. and separates out. The NaOH soln. is further concentrated by evaporation, fused and flaked. No re-circulation of brine takes place. The power consumption is less than mercury cell and product yield contains much NaOH. Actual DC voltage applied in each cell is 3.8 V. Series cells circuit voltage is 800 V.

Brine Purification Steps

The impurities in brine is given in table 1 below:

	Sea salt	Rock salt
Insolubles	0.1-0.3%	≤ 2%
Water	2–6	≤3
Calcium	0.2-0.3	0.1-0.3
Magnesium	0.08-0.3	0.03-0.1
Sulphate	0.3–1.2	≤ 0.8
Potassium	≤ 0.04	0.02-0.12

Table 1

Purification steps for brine depend on type of cells used and impurities in salt (sea or rock).

In membrane and mercury cells HCl is added to brine to lower pH 2-2.23 (Cl₂ = 400-1000 mg/lit). Brine is sprayed in a packed column or brine sprayed in a vacuum, de-chlorination vessel at 50–60 Kpa which reduces the chlorine conc. to 10-30 mg/lit; vacuum is maintained by steam jet ejector or a liq. ring pump. The water from de-chlorinator is condensed in a cooler and further reduction in chlorine is done by either activated carbon or chemical treatment with hydrogen sulphite/hydrogen thiosulphite salts. Conc. of sod. chloride is determined by vibration techniques, radioactive isotopes or density measurement.

Precipitation by adding chemicals

1. With Na₂CO₃:

$$CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3 + 2NaCl$$

 $MgCl_2 + Na_2CO_3 \longrightarrow MgCO_3 + 2NaCl$

2. With NaOH:

$$MgCl_2 + 2NaOH \longrightarrow Mg(OH)_2 + 2NaCl$$

 $FeCl_2 + 2NaOH \longrightarrow 2NaCl + Fe(OH)_2$

3. With Barium Chloride:

$$BaCl_2 + Na_2SO_4 \longrightarrow 2NaCl + BaSO_4$$

CHLOR ALKALI INDUSTRY 49

If Mg++ is high in brine, lime soda process is used for its removal which removes Ca also:

Dilute solns. of the dosing chemicals are added to weak brine soln. followed by adding fresh NaCl salt to bring NaCl soln. to the reqd. level. Brine soln. is further purified by ion exchange resin.



CELLULOSIC FIBRES (RAYON)

Rayon or artificial silk is regenerated cellulose from cellulose xanthate obtained from xanthation of cellulosic raw materials. Natural cellulose is a polysaccharide (carbohydrate) having the empirical formula $C_6H_{10}O_5$.

There are four main processes for the manufacture of cellulosic fibres or rayon:

- (a) Viscose process
- (b) Cupraammonium process
- (c) Cellulose nitrate process
- (d) Cellulose acetate process (non regenerative)

The process at (d) is used in 50% of manufacturing units.

(a) Viscose manufacturing process

Here cotton linters is used as the raw material source for cellulose. The residual cotton left in cotton seeds after the lint or cotton has been removed is used for textile manufacture.

The cellulosic raw material thus obtained is subjected to steeping operation using 18% caustic soda soln. at 18°C for 30–90 mins. Excess caustic soda soln. is drained off and the cellulose is pressed until final wt. is about 3 times the original wt. of cotton linters.

$$\text{Reaction:} \qquad \text{\mathbf{C}_6H}_7\text{\mathbf{O}_2[(OH)}_3]_n \,+\, n \,\, \text{NaOH} \,\, \longrightarrow \,\, \left[\text{\mathbf{C}_6H}_7\text{\mathbf{O}_2(OH)(NaO)}_2 \right]_n \,+\, (n-2)\text{H}_2\text{O}_3}_{n-2}$$

The wet cellulose is then disintegrated in shredders at temp of 20–30°C. Temp. control is important as at higher temp. residual caustic will react with cellulose thereby reducing the length of cellulose chains. The fluffy cellulose material is stored in cans at 25–30°C for 18 hrs., when the length of cellulose is shortened as per desired length. This ageing process controls the viscosity of viscose soln., formed at a later stage, and the final strength of finished viscose fiber. Ageing time and temp. are carefully controlled to achieve desired finished product.

The aged alkali cellulose is then put into revolving drums called barattes each having a capacity of 500–1000 gallons (U.S.) and carbon disulphide is added in the proportion of 50 lbs or less per 100 lb of alkali cellulose and reacted for 2–4 hrs. Alkali cellulose is converted to dithiocarbonate cellulose, granular or jelly like mass and the colour changes to bright orange.

Reaction:

This xanthation reaction is exothermic and the barattes are, therefore cooled to keep the temp. at $25-30^{\circ}$ C. The gases evolved are also removed. The cellulose xanthate is then transferred to water jackated dissolvers or mixers in which dil. caustic soda is added along with a delustering agent (Titanium oxide or White Oil) which reduces the brightness of fiber. The cellulose to caustic soln. ratio is maintained at cellulose = 6-9% and caustic = 4-7%. The temp. of this reaction is controlled at 16.7° C. The orange coloured xanthate soln. thus formed is called viscose.

The viscose soln. is then transferred to evacuated blending tanks and allowed to ripen until it becomes suitable for spinning process for making viscose rayon fibres.

The controlling factors for hydrolysis, carried out in ripening process, are temp., residence time and ripening process is carried out for 48 hrs. at 17–22°C. Increased residence time or higher temp. accelerates the ripening process.

In the next step, cellulose xanthate is regenerated to cellulose in the spinning bath where it is filtered and extruded through cup-shaped spinnerets made of Pt-irridium of Pt-gold alloy having holes (0.002 to 0.006 in dia.). For staple fibers, no. of holes could be several thousands. The spinning bath contains some chemicals also ($H_2SO_4 = 8-12\%$, Sod. sulphate 0.5–2%, zinc sulphate and glucose). The spinning bath is kept at about 43°C. Sod. sulphate helps in co-agulation in fiber formation and liberation of H_2S . Glucose is used to prevent salt formation during precipitation or co-agulation reaction. Sulphuric acid is the regenerating agent which co-agulates the cellulose xanthate and breaks down the xanthate releasing cellulose. Sod. sulphate is formed in the reaction as also free NaOH is always present. Zinc sulphate helps which is formed on the filament and increased the tensile strength in fine filaments.

There are two types of spinning machines—one is pot or bucket type and the other spool or bobbin type. The viscose soln. soon after coming through spinnerets in the form of threads as it passes through the spinning bath where it is co-agulated and formed into cellulose fiber which travels upwards through a guide (in bucket type spinning machine, movement is downwards through a feed wheel and then through glass funnel). The revolving bucket speed is 2000–9000 rpm and it gives twist as the bucket rotates. The spinning operation takes 20–30 mins. After spinning, the yarn is subjected to stretching, washing, de-sulphurising, bleaching, finishing (oiling), drying and twisting operation.

(b) Cuprammonium Process

In cupraammonium process, cotton linters are dissolved in copper hydroxide and ammonium

hydroxide (25° Baume'). The dissolved cellulose soln. is taken to 2nd mixing tank where it is diluted to 4% cellulose with water–filtered in vacuum filter–blended with other charges and de-aerated. The filtered viscose soln. is then pumped to spinning machine where 4% NaOH is used in spinning bath. The yarns are treated with 1-3% H₂SO₄ followed by washing with soft water and drying.

Raw materials reqd. per lb. of rayon = Cotton linters = 0.92 lb Copper sulphate = 0.75 lb Ammonia = 0.5 lb NaOH = 0.80 lb

(c) Cellulose nitrate process

In cellulose nitrate process for yarn making, cotton linters are mixed with ether and alcohol., filtered and subjected to ageing process.

After ageing the cellulose soln. is subjected to dry spinning. The soln., as it comes out of spinnerets of spinning machine, it passes through warm air which evaporates the solvents and helps in coagulation of filament. The individual yarns are combined when a slight twist is given, followed by de-nitration by treating the filament with sod. sulphate or ammonium sulphide soln. The yarn is regenerated into cellulose during de-nitration, washed and bleached.

There is very little use of this process as it is more expensive and dangerous also.

(d) Cellulose acetate process

In this process cellulose is not regenerated but involves the production of cellulose ether. The process consists of acetylation of cotton linters with combined acetic acid (over 50%) followed by hydrolysis with dil. acetic acid under controlled temp. condition. Water reacts with part of acetyl group of triacetate liberating acetic acid. When the combined acetic acid content, by hydrolysis, is reduced to 54.5%, the mass is diluted so as to precipitate secondary acetate when entire cellulose acetate is precipitated. This is washed with water to remove acetic acid. The precipitated cellulose acetate is then dissolved in acetone in large enclosed mixers, filtered with stirrers and agitated for 12–24 hrs. depending on derived viscosity of cellulose soln. The soln. is then blended in blending links when it is mixed with previous value of quality controlled material. The soln. is then filtered under press. in cotton filters. Filtration is carried out several times and the cellulose soln. is stored in evacuated vessels for de-aeration.

The soln. is then sent to spinning machine similar to spinning process for cellulose nitrate yarn. The yarn obtained is bright unless some delustreing agent is added in the spinning bath.

Cellulosic Polymers–Rayon, cellulose acetate, cellulose esters, cellophane and modified cellulose are in stiff competition from petrochemicals.



SELECTED PROCESS EQUIPMENT DESIGN

- 1. Process material balance of the selected process route has to be carried out followed by heat balance of each equipment calculated with available material balance and various physical data and data on heat of reactions for various reactions in the process equipment.
 - A thorough knowledge of reaction kinetics, thermodynamics is essential for designing of a chemical process along with types of equipment required for the process route adopted. Similar available processes are also to be studied while making material and heat balance.
- **2.** Once material balance and heat balance are ready and checked for Hazop-I (Hazards of operations), designing of process equipment starts. Hazop II analysis is to be done after process and equipment design is over and much erection is completed. Hazop III analysis is done with problems faced during commissioning.

3. A FEW SELECTED PROCESS DESIGN PROCEDURES ARE GIVEN BELOW:

3.1 Sizing of Vapour—Liquid Separators

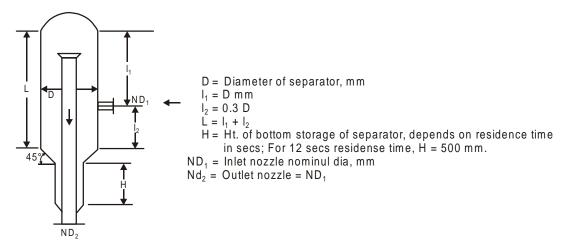


Fig. 1 Impingement type vapour-liquid separator.

These are impingement type separators used to separate a liquid from vapours from preceding process vessels.

Exm: Design a vapour liquid separator for the following gas liquid mixture from the material balance of a plant for urea production.

	Flow Kg/hr	Kg mole/hr
NH_3	4094	240
CO_2	1377	31.3
H_2O	1905	106
	7376*	377.3

The gas Pressure is 3 Kg/Cm² abs at 150°C

Flow of gas
$$Q = 377.3 \times 22.4 \times 1/3 \times \frac{423}{273}$$

$$= 8450 \times 0.515 = 4360 \text{ m}^3/\text{hr}$$

$$= 1.21 \text{ m}^3/\text{sec}$$
 Density of gas,
$$\rho_G = \frac{7376}{4360} = 1.69 \text{ Kg/m}^3$$

Density of liq. soln. $\rho_S = 1100 \text{ Kg/m}^3 \text{ (assumed)}$

The theoretical speed of vapour V_t as per Pastonisi's book, volume-1

$$V_{t} = 0.22 \sqrt{\frac{\rho_{S}}{\rho_{G}} - 1}$$

$$= 0.22 \times \sqrt{\frac{1100}{1.69} - 1} = 0.22 \times 25.4$$

$$= 5.6 \text{ ft/sec} = 1.71 \text{ m/sec.}$$

$$V = 0.4, V_{t} = 0.4 \times 1.71 = 0.684 \text{ m/sec.}$$

Design speed, (40% of V_t)

Free cross-section of the separator assuming 20% oversize:

$$A = Q/V \times 1.20$$
$$= \frac{1.21 \times 1.20}{0.684} = 2.12 \text{ m}^2$$

The separator inside pipe has an o.d equal to

$$406.4 - 2 \times 3.5 = 400 \text{ mm}$$

I.D. of separator is $= \frac{\Pi}{4} [D^2 - (0.4)^2] = 2.12$
 $\frac{\Pi}{4} D^2 = 0.125 + 2.13 = 2.245$
 $D = 1.905 \text{ m} = 1900 \text{ mm}$

^{*} Excluding urea wt.

The lower tank part having level indicators is sized for a residence time of 12 secs. l_1 is assumed to be D and $l_2 = 0.3$ D, and h (assumed) = 500 mm for residence time of 12 secs.

The out following urea soln. from separator, as per material balance is 30904* kg/hr and density is 1100 kg/m³. The volume of tank (lower) is

$$V = 30904 \times \frac{1.2}{1100} \times \frac{12}{3600} = 0.112 \text{ m}^3 \text{ (20\% oversize of tank)}$$

Inside diameter of tank:

$$\frac{\Pi}{4} \left[\phi^2 - (0.4)^2 \right] \times 0.5 = 0.112 \text{ m}^3$$

$$\frac{\Pi}{4} \phi^2 = 0.224 + 0.125 = 0.349$$

$$\phi = 669 \text{ say } 670 \text{ mm}$$

$$l_1 = D = 1900 \text{ mm}$$

$$l_2 = 0.3 \text{ D} = 570 \text{ mm},$$

$$L \text{ (overall length)} = 1900 + 570 = 2470 \text{ mm}$$

3.2 Sizing of a Steam Heater (H.E)

Example: Size up a 13 Kg/cm² abs. steam heater (steam in shell side) shell and tube heat exchanger having S.S tube for decomposition of ammonium carbonate soon in tube side. The heat duty required is 2,600,000 Kcal/hr and soln. flow rate is 38000 Kg/hr which is to be heated up in H.E. from 130°C to 150°C.

Calculations–Flow rates in an hour and overall heat transfer co-efficient assumed is 1000 Kcal/hr.m².°C which has to be verified later.

Heat to be exchanged = 2,600,000 Kcal/hr.

Steam saturated at control valve inlet is 13 Kg/cm² abs. and effective steam pressure in H.E. (shell side) is assumed 7 Kg/cm² abs. having condensation temp of 164.2°C.

(a) Calculation of Δt_m :

$$\Delta t_m = \frac{t_1 - t_2}{2.303 \log (t_1 / t_2)}$$
$$= \frac{34.2 - 14.2}{2.303 \log 2.41} = \frac{20}{0.80} = 22.70$$
°C

(b) Exchanger surface area:

Q = U.A.
$$\Delta t_m$$

A = $\frac{Q}{U \times \Delta t_m}$
= $\frac{2,600,000}{1000 \times 22.7} = 114.5 \text{ m}^2$ Say 116 m²

^{*} Considering urea wt. in ammonium carbonate soln. undecomposed in preceding steam distiller.

$$U = \frac{1000 \text{ Kcal}}{\text{m}^2 \cdot \text{hr.}^{\circ}\text{C}}$$
 (assumed) which will be verified.

Considering 10×1.5 tubes, triangular pitch = 15 mm and Tube length of 6000 mm (commercially available):

No. of tubes =
$$\frac{116}{11.8.5 \times 10^{-3}.6}$$
 = 724 tubes say 730

Total pipe cross sectional area

$$= 730 \times \frac{\Pi}{4} (0.7)^2 = 280 \text{ cm}^2$$

(Considering effective i.d. as 7mm due to fouling.)

Mass velocity in tubes =
$$\frac{\text{Flow of soln wt}}{\text{Sectional area}}$$

= $\frac{38000}{280} = 135.7 \text{ Kg/cm}^2\text{hr}$

No oversizing considered as steam press. in shell is considered as 7 Kg/cm² abs.

(c) Velocity of Soln. in tubes:

Soln. flow rate = 38000 Kg/hr

Density of Soln. = 1100 Kg/m^3 (assumed)

Volumetric flow =
$$\frac{38000}{1100}$$
 = 34.54 m³/hr

Pipe passage area = $280 \text{ cm}^2 = 0.028 \text{ m}^2$

Velocity of Soln. =
$$\frac{34.54}{0.028}$$
 = 1233 m/hr = 0.342 m/sec

(d) Determination of shell inside diameter:

From Table in Borsig Pocket book data in Fig. 3 in Ch-2 we have the eqn. for triangular pitch corresponding to 730 tubes.

$$\frac{D'}{t} = 28.21$$

where D' = C.L. distance of tubes in center line of H.E.

t = tube pitch

$$D' = 28.21 \times 15 = 423.15 \text{ mm}$$

Also
$$D' = D_i - 2a - \text{tube o.d.}$$

where D_i = shell diameter

a = tube o.d.

Then
$$\begin{aligned} \mathbf{D}_i &= \mathbf{D}' + 2a + \text{tube o.d.} \\ &= 423.15 + 2 \times 10 + 10 \\ &= 453.15 \text{ mm} = 460 \text{ mm say.} \end{aligned}$$

(e) Baffles:

Segmental cut baffles are considered,

Min. placement of baffles should be 1/5th of shell i.d.

$$= 1/5 \times 460 = 92 \text{ mm}$$

Actual baffle spacing considered = 300 mm

No. of baffles =
$$\frac{6000}{300} - 1 = 20 - 1 = 19$$
 nos

$$\phi$$
, (shell dia) = 460 mm

No. of pipes in center =
$$\frac{460}{\text{pitch}} = \frac{460}{15} = 30.66 \text{ say } 30$$

Total sectional area of exchanger shell

$$= \frac{\Pi}{4} \times (0.46)^2 = 0.166 \text{ m}^2$$

Area occupied by pipes =
$$\frac{II}{4} \times (10 \times 10^{-3})^2 \cdot 730 = 0.0573 \text{ m}^2$$

Passage area of steam in shell = 0.1087 m^2

Sectional area for steam passage perpendicular to the tubes is

0.30 (0.460 - 30 × 10 × 10⁻³) = 0.30 (0.460 - 0.30)
= 0.30 × 0.16 = 0.048 m²
steam flow =
$$\frac{2,600,00}{\text{Latent heat at 7 Kg/cm}^2}$$

= $\frac{2,600,00}{493.9}$ = 5264 Kg/hr

Sp. Volume of steam a at 13 Kg/cm² abs.

$$= 0.1541 \text{ m}^3/\text{Kg}$$

Volumetric flow of steam = $5264 \times 0.1541 = 811 \text{ m}^3/\text{hr}$ Steam velocity perpendicular to tubes:

$$V = \frac{811}{3600 \times 0.048} = 4.69 \text{ m/sec}$$

(g) Baffle cut (segmental)

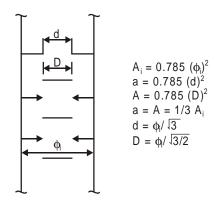
$$A_{T} = 0.048 \times \frac{0.166}{0.1087} = 0.0733 \text{ m}^{2}$$

 $R = 0.230 \text{ m}$

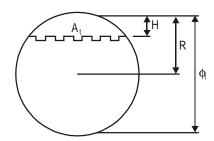
$$R^2 = 0.0529$$

Heat Exchanger Baffles

(i) Annular Type:



(ii) Segmental Cut Type:



Baffle spacing should be min. On shell dia.

No. of Baffles =
$$\frac{\text{Tube Length}}{\text{spacing}} - 1$$

Area occupied by pipes = xi and Area of id of shell = X Free area = X-xi.

Assume H at 25% or 30% cut, Find H/R and $A_{\rm r}/R^2$ Basis: Area of passage of shell side fluid perpendicular to the pipes shall be nearly equal to area of passage of shell side fluid parallel to the pipes.

Fig. 2
$$\frac{A_T}{R^2} = \frac{0.0733}{0.0529} = 1.38$$

$$\frac{H}{R} = 0.7$$

$$\frac{H}{\phi_1} = \frac{0.7R}{0.460} = \frac{0.7 \times 0.23}{0.46} = 0.35$$

$$H = 0.35 \times \phi_1 = 0.35 \times 0.46 = 0.161 \text{ m say } 160 \text{ mm}$$
 % baffle cut = $\frac{160}{460} \times 100 = 34.8\%$ say 35%

Assuming

(h) Verification of overall heat transfer co-eff:

(a) Shell side (steam) film co-eff:

$$u_0 = 0.023 \times \frac{\lambda}{D_0} \times \left(\frac{D\nu\rho}{\mu}\right)^{0.8} \times \left(\frac{C_p\mu}{\lambda}\right)^{0.4}$$
Re. no. = $\frac{D\nu\rho}{\mu}$

$$D_0 = 10 \times 10^{-3} \text{ m}$$

$$\rho = \frac{1}{\text{sp. vol. of steam at 7 kg/cm}^2 \text{ a}}$$
= 3.60 kg/m³
$$\mu = \text{abs. viscosity of steam at 164°C} = 0.015 \text{ cp}$$
= 0.015 × 10⁻³ kg/m.sec.

Re. no. = $\frac{10 \times 10^{-3} \times 4.69 \times 3.60}{0.015 \times 10^{-3}} = 11256$
(11256)^{0.8} = 0.8 log 11256 = 1742

Pr. no. = $\frac{C_p\mu}{\lambda}$

$$\lambda = \text{Thermal conductivity of steam}$$
= 0.0199 B.T.U./hr.ft°F
= 0.0199 × 1.488 Kcal/hr.m°C
$$= 0.0296 \text{ Kcal/hr.m°C}$$
C_P Specific enthalpy of satd. steam at 7 ata
= 659.5 Kcal/kg (considered because the steam is condensing)
Pr. no. = $\frac{659.5 \times 0.015 \times 10^{-3} \times 3600}{0.0296} = 1203$
(1203)^{0.4} = 17.06

Now

here

Now

here

$$\frac{\lambda}{D_0} = \frac{0.0296}{10 \times 10^{-3}} = 2.96$$

$$u_0 = 0.023 \times 2.96 \times 1742 \times 17.06$$

$$= 2023 \text{ Kcal/hr.m}^{2\circ}\text{C}$$

(b) Tube side (carbonate soon) film co-eff:

$$u_1 = 0.023 \times \frac{\lambda}{D_i} \times \left(\frac{D_i \nu \rho}{\mu}\right)^{0.8} \times \left(\frac{C_p \mu}{\lambda}\right)^{0.3}$$

Here
$$D_i = \text{Tube id, m, } 7 \times 10^{-3}$$

v = Vel. of soln. = 0.342 m/sec

 $\rho = 1100 \text{ kg/m}^3$

 μ = 0.8 C_p = 0.8 \times 10^{-3} kg/m.sec

 $C_p = 0.8 \text{ Kcal/kg}^{\circ}\text{C}$

 λ = Thermal conductivity of soln. = 0.45 Kcal/hr.m°C

 $\lambda' = T.C.$ of metal tube

= 14 Kcal/hr.m°C

Re. no. =
$$\frac{D_i \nu \rho}{\mu}$$

= $\frac{7 \times 10^{-3} \times 0.342 \times 1100}{0.8 \times 10^{-3}} = 3282$

(Re. no.)^{0.8} =
$$(3282)^{0.8}$$
 = 650
Pr. no. = $\frac{C_P \mu}{\lambda}$
= $\frac{0.8 \times 0.8 \times 10^{-3} \times 3600}{0.45}$ = 5.12

$$\frac{(C_{\rm p}\mu)^{0.3}}{\lambda} = (5.12)^{0.3} = 1.63$$

 $\frac{\lambda}{D_{\odot}} = \frac{0.45}{7 \times 10^{-3}} = 64.28$

 $u_i = 0.023 \times 64.28 \times 650 \times 1.63 = 1565 \text{ Kcal/m}^2\text{hr}^\circ\text{C}$

Also,

(c) Wall resistance,

$$\frac{t}{\lambda'} = \frac{1.5 \times 10^{-3}}{14} = 0.1071 \times 10^{-3} \text{ m}^2\text{hr}^\circ\text{C/Kcal}$$

where

t = tube thickness, mm

 $\lambda' = \text{T.C.}$ of metal wall

(d) Fouling resistance:

$$Total\ considered\ =\ 0.0003\ \ \frac{m^2.\ hr\ .\ ^\circ C}{Kcal}$$

Overall co-eff of heat transfer U,

$$\frac{1}{U} = \frac{1}{U_0} + \frac{1}{U_i} + \frac{t}{\lambda'} + \text{total fouling resistance}$$

$$= \frac{1}{2023} + \frac{1}{1565} + 0.1071 \times 10^{-3} + 0.0003$$

=
$$0.00049 + 0.00064 + 0.00010 + 0.0003$$

= 0.00153
U = $\frac{1}{0.00153}$ = 653.6 Kcal/hr.m².°C

Remarks: Another trial needed with rev. thermal conductivity of steam at 7 ata. Eqns. for annular baffles, if considered:

No. of annular baffles reqd. =
$$\frac{6000}{750} = 8 - 1 = 7$$

Baffle spacing considered = 750 mm

We have,

$$A_i = \text{ area of shell}$$

$$= \frac{\Pi}{4} \times 0.460^2 = 0.1697 \text{ m}^2$$

$$a = \text{area of annulas} = \frac{\Pi}{4} \times d^2$$

$$A = area of disc = \frac{\Pi}{4} \times D^2$$

Also

$$a = A = \frac{1}{3} A_i = \frac{1}{3} \times 0.1697 = 0.0565 \text{ m}^2$$

$$d = \frac{\phi_i}{\sqrt{3}} = \frac{0.460}{1.732} = 0.265 \text{ m}^2$$

$$D = \frac{\phi_i}{\sqrt{3/2}} = \frac{0.460}{1.2249} = 0.375 \text{ m}^2$$

For symbols see Fig. 2

- (e) Nozzles of H.E
- (i) Soln. inlet 38000 Kg/hr

Velocity = 1.3 m/sec

Flow =
$$\frac{38000}{1050}$$
 = 36.2 m³ / hr (den. = 1050 Kg/m³)

Nozzle size = DN 100

(ii) Soln. outlet flow as per material balance

$$= 4360 + \frac{30.9}{1.1} = 4388 \text{ m}^3/\text{hr}$$

Velocity = 18 m/sec

Nozzle size = DN 300

(iii) Steam inlet

(iv) Condensate outlet

Flow =
$$5.264 \text{ m}^3/\text{hr}$$

Nozzle size = DN 150
Velocity = 0.78 m/sec .

3.3 Combustion Calculation for NG Fired Boiler Furnace:

Problem–120 ton/hr. steam generation at 90 kg/cm². Pressure 350°C with NG (mainly CH_4) having NCV = 9001 Kcal/Nm³. Calculate the NG flow rate, gas composition and flow rates for fan and chimney ratings. Consider 80% combustion efficiency.

Enthalpy of steam =
$$706.9 \text{ Kcal/Kg}$$

Total heat in steam = $120 \times 10^3 \times 706.9 = 84.83 \times 10^6 \text{ Kcal/hr}$.
NG flow reqd. = $\frac{84.3 \times 10^6}{0.8 \times 9001} = 11.78 \times 10^3 \text{ Nm}^3/\text{hr}$
 $\frac{11.78 \times 10^3}{1.000} = \frac{11.78 \times 10^3}{1.000} = \frac{11.$

Kg moles of NG burned =
$$\frac{11.78 \times 10^3}{22.4}$$
 = 525.9 Kg moles

Products flow and composition

Reaction:
$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

1 mole 2 moles 1 mole 2 moles

Reactants	Calculation	Moles	Product	s Calculations	Moles	% Dry
CH ₄	-	525.9	CO ₂	-	525.9	11.11
O ₂ (5%	$525.9 \times 2 \times 1.05$	1104.4	H_2O	2 × 525.9	1051.8	-
excess air)						
N ₂	525.9 × 2 × 1.05 × 79/21	4154.6	O_2	$2 \times 525.9 \times 0.05$	52.59	1.11
			N_2	-	4154.6	87.78
		Tota	moles	(dry)	4733.09	
		Tota	moles	(wt.)	5784.89	

Expected flue gas composition (dry):

$$CO_2 = 11.11\% \text{ vol.}$$
 $O_2 = 1.11$
 $N_2 = 87.78$

Fan and chimmey flow rates considering temp. 25°C:

Methane flow =
$$525.9 \times 22.4 \times \frac{273 + 25}{273 + 0}$$

= $12859 \text{ m}^3/\text{hr}$ at 1.033 Kg/cm^2 and 0°C

Air flow rate

$$525.9 \times 2 \times 22.4 \times \frac{100}{21} \times \frac{298}{273} = 122466 \text{ m}^3/\text{hr at } 1.033 \text{ Kg/cm}^2 \text{ and } 0^{\circ}\text{C}$$

flue gas (wet) flow rate =
$$5784.89 \times 22.4 \times \frac{273 + 210}{273 + 10}$$

$$= 229259 \text{ m}^3/\text{hr} \text{ at } 1.033 \text{ Kg/cm}^2 \text{ and } 210^{\circ}\text{C}$$

Fans and blowers need to be sized as above with safety margins.

Dew pt. of waste flue gas:

Partial pressure of water in fuel gas

$$= \frac{1051.8}{5784.89} \times 1.033 = 0.1878 \text{ Kg/cm}^2 \text{ a}$$

Corresponding to partial pressure of 0.1878 Kg/cm² a, Dew point from steam table is 58.5°C.

3.4 Run-off Rate of Rain Water in cft/sec

Ramser formula:

$$Q = G.C.A.$$

where

G = rainfall in inches/hr

$$C = run-off co-eff = \frac{run off rate}{rain fall rate}$$

(1 in 5 or 5 in 10 slope and agri. land, the co-eff is approx. 0.50 or 0.60)

A = area of rainfall acres

Q = Run-off rate, cft/sec

3.5 Bubble Cap Plate Tower

Formula for gas velocity per cap

For triangular slots:

$$V = 0.001068 \left(\frac{B}{2A}\right)^{NC} \sqrt{\frac{2g}{\rho} \times h_0^{5/2}}$$

where

V = Gas volume per cap, cft/sec

N = No. of slots per cap

C = orifice co-eff (0.51)

W = width of slot, in

A = ht. of triangular slot, in

B = Base of triangular slot, in

$$\rho=\frac{\rho_G}{(\rho_L-\rho_G)}$$
 where ρ_G and ρ_L are densities of gas and liquid/ft³ $g=32.2$ ft/sec² $h_0=$ slot ht., in

Ref: Cross and Dryder (1952)

3.6 Bernoulli's Theorem for Determination of Pumping Head Reqd. in Fluid Flow

The theorem is based on the principle of conservation of energy as applied to flow of fluids, between points 1 and 2; the theorem gives the overall equation as:

Static head + velocity head + Pressure head + Friction head

= work input by the pump + external heat input

or,
$$H_2 - H_1 + \frac{V_2^2 - V_1^2}{2g} + P_2 - P_1 + F = W + Q$$

where, H_2 and H_1 = static head in ft from an arbitrary horizontal datum

 V_2 , V_1 = linear velocity, ft/sec

 P_2 , P_1 = Pressure of fluids. lbs/ft²

F = Friction drop, ft of fluid

and W = Work input, ft-lb/lb

Q = External heat input Btu/lb

3.7 Friction Drop is Usually Calculated from Fanning Eqn.

In a circular cross section of pipe at isothermal condition. The determination of fanning friction factor, f depends on Reynolds no.

We have.

$$F = \frac{2fLV^2}{g_c D} = \frac{2fLG^2}{g_c D\rho^2} = \frac{4fLH_V}{D}$$

The Reynolds no. $\frac{DV\rho}{\mu}$ or $\left(\frac{DG}{\mu}\right)$ is determined so as to ascertain whether the flow is turbulent (Reynolds no. > 4100) or the flow is in streamline zone (Reynolds no. < 2100 or in the transition zone, Reynolds no. in between 2100 – 4100). The friction factor, f is determined from Fanning friction factor chart in Perry's Chemical Engg. Handbook.

The nomenclature of above equation is as follows:

F = Pipe friction loss, ft of fluid

f = Fanning friction factor as per Reynolds no. from Chart in Perry

L = Length of pipe, ft

V = Linear velocity of fluid, ft/sec

G = Mass velocity of fluid lb/sec.ft²

 g_c = gravitational constant, 32.2 ft/sec²

 H_v = velocity head, ft

 μ = viscosity of fluid at pumping temp. CP/1488 lb/ft.sec

D = pipe dia., ft, ρ = Fluid density, lb/ft³

An alternate simplied formula has been given in Perry's handbook when Reynold is > 4100 as:

$$f = 0.0014 + 0.090 \left(\frac{\mu}{\text{DG}}\right)^{0.27}$$
 consideration of velocity, roughness factor is reqd.

Often two unknown quantities, viz. pipe dia. and F are involved when a trail and error method is to be adopted by assuming the pipe dia and then calculation of the F; pipe dia. can be assumed from chart for economic pipe dia. chart. The standard equivalent length tables, should be used for fittings.

3.8 Estimation of H.E areas and volume of a vessel when these figures are known for a certain plant capacity for area/volume at some other capacity of an identical new plant by the rule of three.

We have the equation,

$$A_2 = A_1 \times \frac{S_2}{S_1}$$

Where, A_2 = Area or volume in metric units for new plant of capacity S_2

 A_1 = Area or volume in metric units for known plant capacity, S_1

 S_2 = New plant capacity/annum or day

 $S_1 = Known plant capacity/annum or day$

3.9 Estimation of nozzles of equipment of a plant: when plant capacity and nozzle diameter, are known,

We have the equation,

$$d_2 = d_1 \sqrt{\frac{S_2}{S_1}}$$

Where, d_1 = Nozzle size in mm or inch for known plant capacity, S_1

 d_2 = Nozzle size in mm or inch for a new identical plant capacity

 S_1 = Known plant capacity or nozzle size

 S_2 = New plant capacity or nozzle size

3.10 Six Tenth Rule

By this rule approximate estimated cost of a new plant or equipment can be determined based on FOR/FOB costs when cost of an identical plant or equipment is known.

We have the equation,

$$C_2 = \left(\frac{S_2}{S_1}\right)^{0.6} \times C_1$$

Where, $C_1 = \text{Cost of plant or equipment (known capacity or volume) of a known plant or equipment is available$

 C_2 = Cost of plant for a new plant or equipment for an identical plant.

 S_1 = Known plant capacity or equipment size

 S_2 = New plant capacity or equipment size.

3.11 Determination of Steam Jacket Pressure of a Crystallization Recirculation Line

We have,

$$Pcr = \frac{E.t^3(n^2 - 1)}{12r^3(1 - v^2)}$$

where, Pcr = Limited ext. steam pr. Kg/cm² a

v = Poisson ratio = 1/3

r = Radius of pipe, cm

 $E = Young's modulus, 2.1.10^6 Kg/cm^2 (steel)$

t = Wall thk. of pipe, cm

 $n = \text{Internal pr of circulating line, } (\text{Kg/cm}^2 \text{ a})$

Chimney Draught

Static draught $h_{st} = H(\gamma_L - \gamma_G)$ mm water column (kp/m²)

where H = Chimney height . m

 γ_{L} = density of air . kg/m³ at t_{L} °C

 $\gamma_G = density \ of \ flue-gas. \ kp/m^3 \ at \ an \ average \ flue-gas \ temperature \ t_{GM}^{\ \circ}C$ in chimney

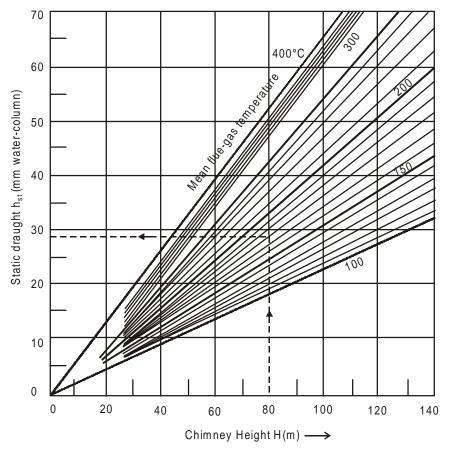
The curves are valid for flue-gases produced by bituminous coal and having a density of

$$\gamma_{OG} = 1.34 \text{ kg/nm}^3$$

The cooling of flue-gases in brick chimneys may be assumed to be at the rate of 0.2 °C per metre of chimney height.

For flue-gases produced by brown coal, wood and peat the values shown in the diagram Fig. 3 should be multipled by 1.04

GRAPH FOR CHIMNEY HT



Example: Chimney height H = 80 m

Average flue-gas temperature t Gm = 160°C

Static draught h_{st} = 29 mm water-column (kp/m²)

Source: Borsig pocket book 3rd edn.

Fig. 3

Vapour Pressure of Paraffin Hydrocarbons

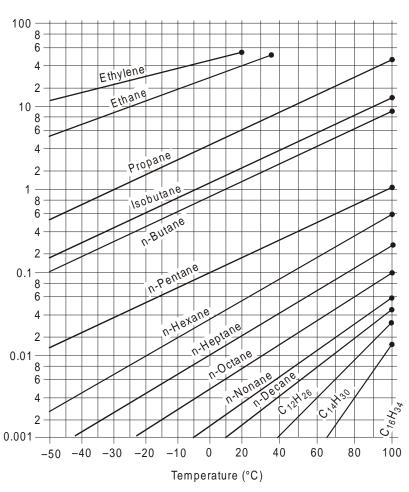
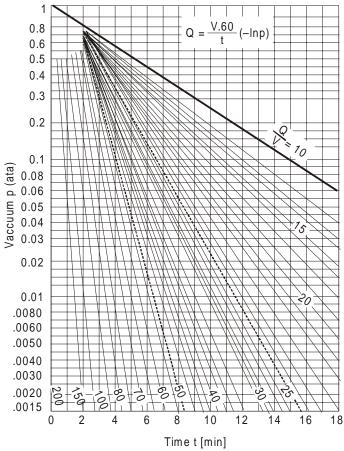


Fig. 4

Evacuation of a Vessel as a Function of Time



Q = Effective capacity of a vacuum pump, m³/hr.

V = cubic capacity of vessel . m³

t = times. minutes

D = required final pressure . ata (note : ata-atm abs)

Example : A vessel of capacity $V = 20 \text{ m}^3$ is required to be evacuated in 12 min to a 99.5% vaccum = 0.00516 ata. What must the hourly suction volume of the vaccum pump be ?

Pressure and time lines interest at Q/V = 26.4

Required suction volume Q = $26.4.20 = 528 \text{ m}^3/\text{h}$

Source: Borsig pocket book 3rd edn.

Fig. 5



PETROLEUM REFINERY

- 1. Crude oil, a mix of Paraffinic, naphthenic, aromatic and asphaltic hydrocarbons.
- 2. The grades are called asphaltic base 60%, paraffinic base 75%, naphthenic base 75% and aromatic base 60% or mixed base according to residue obtained. Other impurities present are Sulphur 0.5–3%, Nitrogen 0.1–0.5% and Oxygen compound 0.1–2% as hydrocarbons derivatives.
- **3.** Asphalt or Bitumen is found in crudes, rich in aromatic hydrocarbons.
- **4.** Crudes are also called wax base (>5%), asphalt base (2–5%) and mixed base (<2%).
- **5.** Products from crude oil:
- (i) N.G. casing head gas (mix of lighter hydrocarbons upto butane with N_2 , CO, H_2S and higher hydrocarbons.
 - (ii) LPG mixture of liquefied Propane and butane $(C_3 C_4)$
 - (iii) Natural gasoline (from N.G. by stripping of heavier constituents.
- (*iv*) Straight run gasoline The yield is for Aromatics crude (6–22%) Naphthenic crude (20-50%), Paraffinic crude (50–70%).
 - (v) Kerosine 8–15% C_4 – C_{12}
 - (vi) Gas oil (Diesel oil) C_{15} – C_{25}
 - (vii) Paraffinic base C₅–C₃₀

Lube oil - Deficient in hydrogen of fused ring type.

- (viii) Fuel oil or heavy fuel oil.
- (ix) Asphalt or Bitumen.

6. BRIEF CRUDE OIL REFINING PROCESS STEPS

Various products are separated for production of LPG, Gasoline, Kerosine, Gas oil by primary fractionation of crude oil which is carried out in two stages called stabilization in which crude is distilled under 3-5 atm pressure to get a top product of $\rm C_4$, $\rm C_5$ and a lighter hydrocarbons responsible for giving high V.P and a bottom product. The bottom product is subjected to atm. pressure secondary fractionation to get light gasoline (B.P. 170°C) as top product and naphthas (med. and heavy) (B.P. 220°C) as side stream product and a bottom reduced crude product which is again distilled under vacuum (sometimes with steam) to get gas oil and a residue contg. wax cut, lube oil, fuel oil and pitch.

PETROLEUM REFINERY 71

This residue is further distilled under high vacuum to separate wax, lube oil, fuel oil and pitch/bitumen.

The top product consisting of hydrocarbons upto C_5 obtained in stabilization operation is further fractionated into individual hydrocarbons (Methane, ethane, propane, N-butane, isobutene, n-pentane and isopentane.)

The intermediate products in secondary fractionation are subjected to further refinery operation to get purer products or new compounds.

7. CHEMICAL ENGINEERING OPERATION

System		Physical treatment
1. Liq. Vapour system	_	Distillation
2. Liq. stream	_	Extraction
3. Cracking and Reforming thermal and catalytic	_	Heat treatment and new compound formation
4. Plat forming	_	"
5. Hydroforming	_	"
6. Catalytic desulphurisation	_	,,
7. Alkylation and polymerization	_	"
8 Isomerisation	_	,,

The fuels in conversion process above (3 to 6) may vary from gaseous streams to residual fuel oil. The type of intermediate products obtained will vary depending on crude-viz a paraffinic base crude will give a wax residue containing lube oil and an asphaltic base crude will give asphalt residue.

Cracking and reforming operations are main steps carried out either in vapour or liquid stage thermal or catalytic cracking.

8. REFINERY CATEGORY

(a) Simple (b) Complex (c) Integrated types

Simple refinery consists of crude distillation unit, catalytic reforming units and subsequent treatment plants. The products are mainly LPG gasoline, kerosene and ATF, diesel oils. Kerosine is a mix of light gas oil and heavy naptha.

Complex refinery contains in addition to units in simple refinery, vacuum distillation unit for lube oils, catalytic cracking accessories units for converting cracked gases to get improved gasoline and ATF by alkylation and polymerization or utilization of cracked gases for manufacture of various petrochemical and products. The feed gas is naphtha or surplus fuel oil. Bitumen manufacture is also practiced. Integrated refinery—it is integrated to produce all types of petroleum products. These contain elaborate vacuum fractionation units for different lube oils and followed by treatment plant, deashphalting units, solvent (furfural) extraction and dewaxing unit. In addition, it contains all units in complex refinery.

9. REFORMING PROCESS

Naphthas are subjected to catalytic reforming to improve antiknocking property so as to produce higher octane value in petrol. Process involves heating naphtha under controlled condition

in presence of hydrogen (to reduce coke formation) and a catalyst is used. The process routes available are (1) non-regenerative platinum catalyst (0.3–0.7%) platinum on silica-Alumina in H.P. fixed bed multiple reactors. (2) Regenerative non-platinum catalyst (10% moly, or 30% Chromium) in fluidized bed reactors and (3) using cyclic regenerative Pt. Catalyst at moderate pressure (200–300 PSI) in fixed bed multiple reactors.

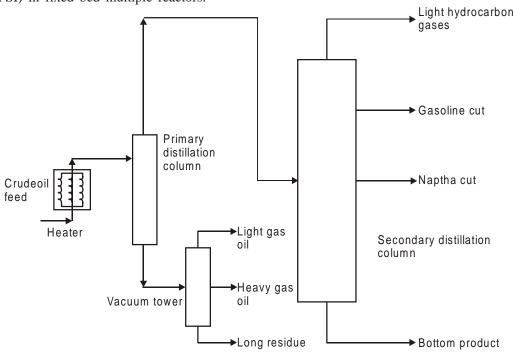


Fig. 1. Flowsheet for Primary Crude Distillation.

Catalytic Reforming Reaction

Feed naphthas are mixture of paraffins and naphthas

$$nC_7H_{16} = C_6H_6CH_3 + 4H_2 \qquad \Delta H + ve$$

Paraffins also under go isomerisation, hydrocracking and to a small extent dehydration.

n.C
$$_6H_{14}$$
 = Methyl Pentane isomerisation ΔH – ve
$$C_{10}H_{12}+H_2=C_6H_{14}+C_4H_{10}\qquad \Delta H$$
 – ve
$$C_8H_{18}=C_8H_{16}+H_2$$

C₆ naphthenes are converted to corresponding aromatics:

$$C_6H_{12}CH_3 = C_6H_6CH_3 + 3H_2$$

desulphurisation also occurs

$$C_6H_6CH_3 + 4H_2 = C_5H_{12} + H_2S$$

Fluid hydroforming process is also used.

Non regenerative platinum reforming process is widely used. Thermal reforming process is used for high octane no. Gasoline. Cracking of gas oils and fuels oils either thermally or catalytically yields gasoline of higher octane no. using catalytic route; often thermal cracking is also done using steam.

PETROLEUM REFINERY 73

Coking Process

The coking process is performed under extreme conditions to manufacture gas, naphtha heating oil (mazor products) and coke from pitch and tar is used as feed stock. Coke particles and steam are used as fluidising agent. Steam is passed at bottom of reactor to fluidise the bed. Pitch top fed at 260–370°C in the form of a spray from top into the fluidized bed at 480–1270°C. The feed partly vaporizes and partly collects on the coke particles. The hot pitch on the coke surfaces cracks and vaporizes leaving a non-soluble residue, which forms coke. The vapour coke stream is passed in cycles at the top of the reactor where entrained coke is removed. The cracked vapour is then cooled and fractionated when a top product, containing gas, and naphtha, is obtained. The bottom product from fluidiser containing heavy tar mixed with residual coke particles is recycled to the coking reactor.

The stripping and fluidisation steam displaces products vapour from coke surfaces and stripped coke, then flows to the burner at 590–650°C temp. at 5–25 Psi pressure by burning part of product coke. There remaining coke is then returned to the reactor. The flue gases are discharged to the atmosphere after separation of coke particles in a cyclone.

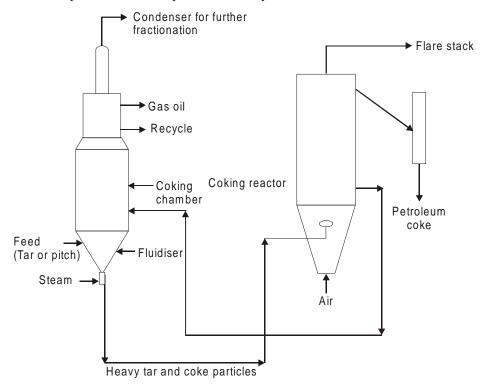


Fig. 2. Flowsheet for Coking Process.

10. DESULPHURISATION

Sulphur is removed from low boiling distillates upto 200°C and middle distillates, 250–400°C are stripped of sulphur by catalytic hydrodesulphurisation process by hydrogen from catalytic reforming process or hydrogen generated in the process itself by dehydrogeneration reaction.

Alkylation is done to obtain high octane gasoline from paraffins or olefines.

Lubricating Oils

The long residue after primary distillation of crude oil is subjected to high vacuum distillation when a short residue is obtained. The long residue constituted asphalt wax, aromatics, naphthenic acid, dark constituents and chemically unstable compound, Good quality lube oil is made by refining so as to remove these undesireable materials from short residue. The deasphalting step is carried out using propane. The aromatics and resins are removed by liquid extraction. MEK/Benzene dewaxing process or propane dewaxing process are also used.

Sweating process manufactures petroleum wax. Lubrication grease and soap grease are also manufactured.

Bitumen soluble in CS₂ is obtained from residue from asphaltic and mix base crude when used for refining. The primary distillation of heavy long residue is heated to 300°C at atm. pressure.



ACTIVE CARBON

1. INTRODUCTION

Active carbon has turbostratic carbon structure and a large porous structure with pore diameter ranging from 1–0.8 nm (less than 2 nanometer) and specific vol. = 0.25-0.4 cm³/gm. It has microcystallites—only a few layers in thickness and less than 1000 in width. The surface area is 1000 m²/gm due to high porosity, which gives it excellent adsorption capacity. All types of active carbon has small amount of bound oxygen and H₂ in the form of Carbonyl group, Carboxyl, Phenol etc. derived from raw materials. It also contains 20% mineral salts. Convential raw materials give active carbon a pore size 0.8–1 nm; active carbon from coke gives pore size of 0.5–0.7 nm and molecular sieve active carbon is made from anthracite and it is having pore size of 0.2–0.3 nm. Adsorption capacity of active carbon is determined by microscope.

2. MANUFACTURE

It involves charring of raw materials by burning depending on nature of active Carbon desired. Low carbon raw materials used are coconut shells, saw dust, wood charcoal, bone charcoal, paper mill waste liquor. High carbon raw materials are calcined coke/H.T. Coke and anthracite (used for molecular sieves).

When low carbon raw materials are used, it is first charred and formed into briquettes and then activated. High carbon raw materials, coal anthracite, are directly activated.

- (a) Charring Process It is partial oxidation of low carbon containing raw materials during heating at temp. 600–1000°C. The carbon contents is increased to 90%. After charring, the material is formed into briquettes for activation.
- (b) Coking Process The high carbon raw materials are sized as per requirement and heated in a furnace in inert atmosphere (oxygen free) using CO_2 gas at a high temp. $\geq 1000^{\circ}C$ to drive off all non carbon components of carbonaceous materials using bound oxygen for self oxidation.

3. OXIDATION PROCESS

The carbon materials are then subjected to high gas phase exposure to oxidation atmosphere (O_2, CO_2) at about 200°C or alternatively the carbon materials are then treated with conventional oxidizing agent solution.

4. ACTIVATION PROCESS

There are two processes viz.

- (a) Gas activation and
- (b) Chemical activation

There are three variables in activation process:

- (i) Nature of starting materials
- (ii) Composition of activation atmosphere
- (iii) Time and temp. of activation process

Item (ii) and (iii) affect surface chemistry and adsorption by active carbon for various uses and item (i) will give the nature of active carbon product.

Gas Activation Process

The carbon after coking or charring is subjected to heating at $800-1000^{\circ}$ C in super heated steam CO_2 atmosphere or both. This results in some loss of active carbon. Before heating, usually 5% caustic potash or Pot. Carbonate is used to moisten the active carbon charge. This addition accelerates activation process.

Side reactions
$$H_2O + C = CO + H_2\Delta H = 117 \text{ KJ}$$
 $2H_2O + C = CO_2 + 2H_2 \Delta H = 75 \text{ KJ}$ $CO_2 + C = 2CO \Delta H = 159 \text{ KJ}$

A high degree of activation gives 20% yield of active carbon whereas a lower degree of activation gives 60% yield.

Chemical Activation

It is done by dehydrating chemicals-starting materials phosphoric acid or ZnCl₂-the latter is used usually for chemical activation of mostly uncarbonised viz. finely divided saw dust and pit coal mixed with phosphoric acid solution when a pulp is formed. This is then heated in a rotary furnace to 400–600°C; the excess H₃PO₄ is removed by extraction, neutralized with phosphate salt and dried up. Activation with stream and phosphoric acid also can be done. The dried up active carbon is then coked or charred. This process is popular and economy depends on recovery or phosphoric acid.

For pharmaceutical use of active carbon low ash content active carbon is made by washing the activated carbon with water or HCl/H₂SO₄. Lignite or coal base active carbon when activated by precise thermal and chemical treatment can prduce carbon with specific pore system.

5. PROPERTIES OF ACTIVE CARBON

Apart from large pore size distribution and surface area, chemical reactivity of surface area is important. For many applications of active carbon it does not require to reactivate the spent active carbon but it is necessary to remove adsorbed material in order to bring carbon to its virgin form.

Adsorption from solution does not involve multilayer formation and depends on chemical activity of surface. Adsorption for gas phase purification involves multilayer formation and capillary condensation in pores of the active carbon. Physical properties of various active carbons are given in (Vol.-II A).

Regeneration of spent active carbon-It is done by passing super heated steam or inert gas through active carbon base, which takes out the adsorbed gases from intergranular spaces. Exhausted active carbon from gas purification is heated to red heat for regeneration by decomposing the adsorbed gases and thus desorbing the masses.

ACTIVE CARBON 77

6. USES OF ACTIVE CARBON

1. For liquid and gas purification process-active carbon is used in granular or pelletised form.

- 2. For molecular sieve, active carbon in proper size is made form anthracite.
- 3. For water purification and decolourisation, grounded active carbon is used.
- 4. For food processing, pelletised active carbon is used.
- 5. Catalyst preparation.
- 6. Active carbon of high ignition temp. and high resistance to abrasion is suitable for industrial use for removing sulphur and nitrogen oxides from flue gases from power plant, separation of mixer of gases and in solvent recovery.
 - 7. In gold purification.
- 8. Active carbon is used in the manufacture of sucrose, glucose, maltose, lactose, soft drinks, edible oils, paraffin wax, phosphoric acid, plasticizers, glycerol, gelatin, pectin, caffeine, quinine, vitamin C, lactic acids etc. Also used in Fruit juices, wine and alcohol manufacture.
- 9. Powdered active carbon is also used in liquid phase reaction. Grains of active carbon are also used in gas phase reaction.
 - 10. For odour removal.



There are two types of refrigeration principles used in industry and domestic services:

- A. Vapour compression type
- B. Absorption type

A. VAPOUR COMPRESSION TYPE

In vapour compression, the refrigeration cycle works on reverse Rankine (or carnot) cycle. The refrigerant vapour is compressed by a compressor which increases the pressure so that the compressed vapour attains temp. higher than the cooling water or air and the vapour gives out heat to cooling water/air thereby the vapour condenses to liquid in the condenser as the saturation temp. is reached due to cooling.

The condensed liquid then flows through an expansion valve where partial flashing of liquid takes place, thus cooling the remaining liquid to below the temp. of product to be cooled. The temp difference facilitates heat to be transferred from product to refrigerant, which causes the cooling of product and the refrigerant to evaporate. The hotter products give out heat for evaporation of refrigerant thereby cooling the product in refrigerated space. Heat of evaporation of refrigerant is the key factor. For refrigerators, compressor with motor is inside a sealed unit, condensation by aircooling and refrigerant liquid flashes in freezer body tubes. The vapour of refrigerant is removed by compressor suction which causes the flow of liquid to maintain and also maintain low pressure in evaporator. The simple circuit given in Fig. 1 and layout in Fig. 2.

Refrigerants

Three types—halogenated hydro-carbons, hydro-carbons and inorganic compounds. These are generally substances having higher latent heats and low specific heats with the objective of reducing quantity of refrigerant in circulation and minimizing losses, which occur in expansion valve and other fittings. The boiling point of refrigerant establishes the refrigeration temp. at which it could be used in the particular refrigeration system. Normally refrigerants are non-inflammable or slightly inflammable and non toxic or slightly toxic.

Coefficient of performance of a refrigerant

It is the ratio of

$$\frac{\text{refrigeration effect}}{\text{Works expended}} = \frac{Q_0}{Q_k - Q_o} = 5.75$$

where Q_0 = net heat extracted per unit mass, and $Q_k - Q_o$ = work of compression per unit mass

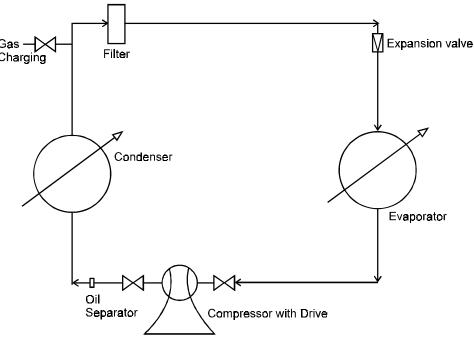


Fig. 1. Vapour compression refrigeration circuit.

This ratio indicates efficiency under certain conditions of the refrigerant selected. It is often given at standard conditions *i.e.*, -15°C (5°F) evaporation and +30°C (86°F) condensation. The maximum value is 5.75, which is obtained on working with a, reverse Rankine cycle (or Carnot cycle) and is independent of refrigeration. For vapour compression machine, the coefficient is of the order of three, for air cycle refrigeration application one and for vapour absorption systems, it is well below one.

$$\frac{\text{H.P.}}{\text{TR}} = \frac{4.71}{\mu e} \text{ (Imp H.P.)}$$

$$\frac{\text{H.P.}}{\text{TR}} = \frac{4.78}{\mu e} \text{ (metric H.P.)}$$

and

Refrigerant Number R

In a numerical cooling system which defines the molecular structure of refrigerant as per designation ABCD (applicable to halo and hydrocarbons refrigerants only where A, number of double bonds: B, number of carbon atoms less one, C, the number of hydrogen atoms + one and D, the number of fluorine atoms.

Example : For R-12, A = 0, B = 1 - 1 = 0, C = 0 + 1 and D = 2.

Therefore the refrigerant number becomes R-12 (Dichloro Difluoro methane.)

Inorganic refrigerants are designated differently. They are given digits number, the first is 7 and following two numbers gives its molecular number.

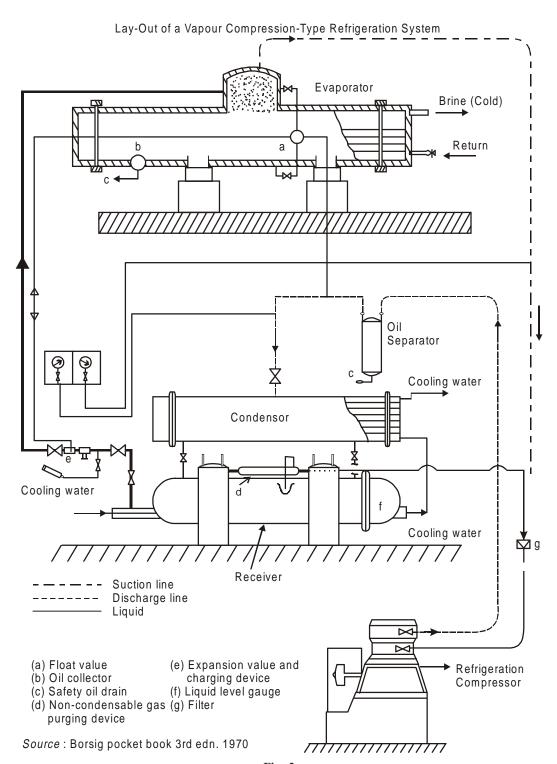


Fig. 2

Example: Ammonia-R 717

US's ASHRAC standard 34–94 (2) classify refrigerants in 6 groups:

Group A_1 = non inflammable and non toxic.

Group B_1 = non inflammable but slightly toxic.

Group B_2 = same as above but moderately toxic.

Group A_3 = highly inflammable but non toxic.

Group B_3 = highly inflammable and highly toxic.

Ozone Depletion

Both CFC and HFCs contribute ozone depletion in stratosphere and as a result, ozone hole was detected in Antarctica. Ozone depletion potential (ODP) has been fixed as 1.0 for CFC-1 and all other CFCs and HFCs are grouped accordingly.

The production of such ozone depletion compounds was decided to be phased out in 1987 as per Montreal protocol as per the following schedule:

CFCs phase out by 1.1.96 (Developed countries)

HFCs phase out by 1.1.2020 (Developed countries).

However, developing countries were given further extension of 10-15 years from above dates. In view of the above stipulations developed countries are on the look out for alternate CFCs and HFCs. Some HFC refrigerants like R 134 a, hydro-carbons, propane (R-290) and ethane (R-170) are reportedly found better replacements for CFCs and HFCs.

Table 1

Name	Code	Range	Volume refrigerant Effect
Hydro fluoro- Carbons	R-134 a	-15°C evaporation and 30°C condensation	1062 (KJ/m³)
Ethane	R-170	-15°C evaporation and 30°C condensation	1811 (KJ/m³)
Propane	R-290	-15°C evaporation and 30°C condensation	2238 (KJ/m ³)

Normally mineral oil is used as a lubricant in compressor, which is miscible with refrigerant and return back to compressor for lubrication. About 2–3% lubricating oil is reqd. Details given in Table-5.

However, R-134a requires a synthetic oil, called polyster oil, which is miscible with refrigerant. DIN 51503 gives refrigeration oil specification. For applications of various refrigerants see Table 126 in Vol. IIA.

Table 2

Refrigerant	TLV. ppm	ODP**	GWP* 100 yr.	Atmospheric Life yr.
CFC-11	1000	1	4000	60
CFC-12	1000	1	8400	130
CFC-13	1000	_	11700	400
HCFC-22	1000	_	1500	15

(Contd.)

(Table Contd.)

Refrigerant	TLV. ppm	ODP**	GWP* 100 yr.	Atmospheric Life yr.
HCFC-23	1000	0	_	310
HCF-134a	1000	0	1200	16
HFC-152a	1000	0	140	2
Propane (R-290)	_	0	3	4
Ammonia (R-717)	25	0	1	1

^{*}Global warming potential

Units of Refrigeration

It varies from country to country. Care should be taken as to know the type of refrigeration unit followed in the country.

A few are as follows:

1 US ton of refrigeration, TR = 200 BTU/min or 12000 BTU/hr

= 3024 Kcal/hr

1 U.K. ton of refrigeration, TR = 220 BTU/min

= 3340 Kcal/hr

1 lb/hr TR = 9 kg/hr per 1000 Kcal/hr 1 lb/min TR = 0.15 kg/min per 1000 Kcal/hr

1 BTU/min TR = 5 Kcal/hr per 10000 Kcal/hr

1 TR (Euorpe) = 211 kg/min

B. ABSORPTION REFRIGERATION

The system works on continuous basis using ammonia liquor as refrigerant. Separated ammonia after generator and condenser is taken into expansion coils and dissolved in the absorption vessel having water when the pressure falls. The refrigerant is separated by applying heat to refrigerator and its water content is reduced by rectification, and then liquefied by ammonia condenser using cooling water and collected in storage tank. The liquid ammonia is passed through expansion coils when its pressure falls and partial flashing of liquid occurs with the fall of temp. The flashed refrigerant cools the cooling media (brine solution) flowing in a coil in the brine cooler. The cold brine is circulated in the storage through coils for lowering the temp, of stored products in storage bunkers/ice plant. The vapour ammonia refrigerant, which absorbs heat from brine solution is then absorbed in the absorber and the heat is removed by cooling water. The aq. ammonia is pumped to exchanger and finally the strong aq. ammonia is sent to rectifier for separation of ammonia from water. The heat required in the aq. ammonia exchanger is supplied by circulating weak aq. ammonia from generator. The process is elaborate and generally finds use in cold storages for vegetables and other products. In place of brine solution, calcium chloride solution is used in some process. For evaporating temps. of secondary cooling fluids, see Table 127 Vol. IIA for properties of secondary cooling media, Brine soln. (NaCl) and CaCl2 soln; ethylene glycol soln. etc. in vol-IIA. see Fig. 3.

N.B. (i) Safety Precaution-ISO-1662 gives safety precautions to be taken in refrigeration systems.

^{**}Ozone depletion potential

(ii) A heat pump (refrigeration) using a refrigerant having maximum COP in a vapour compression circuit, pumps out 35 Kw of heat from (say) 7°C to 55°C, will consume 15 Kw of electrical energy and gives 50 Kw of heat output.

TLRV Brine Solution NH₃ Liquid NH₃ Strong Solution Weak Solution ☐ Cooling Water

Lay out of an Absorption-type Refrigeration system

- Α Generator Heating Surface
- В Analyzer with Rectifier
- С Condenser
- Liquid Ammonia Receiver D
- E Ammonia Subcooler
 - (Liquid to Gas Heat Exchanger)
- F Vapour Dome
- Evaporator G
- Η Solution Collector
- I Absorber
- Heating steam admission a
- Condensate Outlet b
- Two-cham condensate trap С
- d Liquid Level gauge
- e Flowmeter for liquid ammonia

Source: Borsig pocket book 3rd edn. 1970.

- Fig. 3
 - Κ Solution Receiver
 - Solution Pumps
 - M Rectifier
 - Ν Solution Heat Exchanger
 - \mathbf{O} Solution Preheater
 - P Solution Reservoir
 - R **Auxiliary Solution Pump**
 - RV Expansion valve
 - LRV Solution Expansion valve
 - Flowmeter for liquid ammonia
 - Drain valve for evaporator g
 - Screen h
 - Non-return valve

Table 3
Working and Test Pressures (above atmospheric)¹)
as per DIN (Ed of May 1967)

		Maximum A Working P		Test Pr for Ind Compo with v	ividual onents	Test of Installati Air or Rei	ion with	
Groups	Refrigerant	High Pressure Side Kp/cm²	Low Pressure Side Kp/cm ²	High Pressure Side Kp/cm²	Low Pressure Side Kp/cm ²	High Pressure Side Kp/cm ²	Low Pressure Side Kp/cm ²	Test Pressure with Liquids per AD Pamphlets ²
	Carbon dioxide Trichloro-mon- ofluro Methane R11 Dichloro-	95 1	67 1	142 1.5	100 1.5			
	difluoro Meth- ane R12							
1	Chloro-trifluoro Methane R13	53	40	80	60			
	Difluoro mono- chlor Methane R22	16 22 ³)	13	24 33 ³)	20			
	Trichloro-trifl- uoro ethane R113	1	1	1.5	1.5			
	Dichloro Tetrafluoro ethane R114	4.4	2.6	7	4			
	Ammonia	16 22 ³)	13	24 33 ³)	20	Same max.	Same max.	1.3 times max.
2	Methyl chlo- ride	12 ′	8	18	12	admissible working	admissible working	admissible working
	Sulphur dioxide	9	5.4	13.5	8	Pressure	Pressure	Pressure
3	Ethane Ethylene Propane Isobutane	67 80 19 7	50 67 12 4.6	100 120 29 10.5	75 100 18 7			
	Butane	5.4	3.4	8	5			

⁽¹⁾ Lower working and test pressure are possible in low-temperature installations, provided that the whole plant is so designed and protected by safety that there is no risk of the specified pressure being exceeded.

⁽²⁾ The pressure ratings and test pressure shown in DIN 2401 apply to pipes and fittings. Calculation of wall thickness as per DIN 2413.

⁽³⁾ Permitted in high-pressure side under arduous working conditions.

Table 4
Physical Properties of Common Refrigerants

Refri- gerant	Ethane (R170)	R 13	Carbon Dioxide	Propane	R 22	Ammo- nia	R 12	Methyl Chloride	R 114	R 11	R113
goran	(11170)		(R744)	(R290)		(R717)		(R40)			
Chemical Formula	C ₂ H ₆	CF ₃ Cl	CO ₂	C ₃ H ₈	CH ₂ CI	NH ₃	CF ₂ Cl ₂	CH₃CI	C ₂ F ₄ Cl ₂	CFCl ₃	C ₂ F ₃ Cl ₃
Molecular Mass	30.06	104.47	44.01	44.09	86.47	17.03	120.92	50.49	170.93	137.38	187.39
Gas consta- nt Kpm/kg°K	28.22	8.12	19.26	19.23	9.81	49.79	7.01	16.80	4.96	6.17	4.525
Boiling temp °C at 760 Torr	-88.6	- 81.5	- 78.5	-42.5	-40.8	-33.4	-29.8	-24.0	+4.1	+23.7	+47.6
Soldification Point °C	-183.6	-181	-58.6	-189.9	-160	-77.9	-155	- 91.5	-94	-111	-36.5
Critical temp ℃	32.1	28.8	31.0	96.9	96.0	132.4	112.0	143.1	146	198	214.1
Critical pres- sure ata**	50.3	39.5	75.2	43.4	50.3	115.2	40.9	68.1	33.3	44.6	34.8
$X = C_p/C_v$ at 0°C Heat of evapora-	1.202	1.15	1.30	1.153	1.19	1.312	1.148	1.27	1.106*	1.124	1.075*
tion kcal/ Kg at–15°C Specific vol. of saturated	83.1	25.08	65.3	95.1	52.0	313.5	38.6	100.4	33.88	46.66	38.9
Vapour m³/kg	0.033	0.012	0.017	0.156	0.078	0.509	0.093	0.279	0.263	0.772	1.649
Density of Liquid kg/ at 0°C	0.412	1.12	0.925	0.53	1.285	0.639	1.39	0.96	1.54	0.652	1.62
Volumetric Refrigerating capacity Kcal/ m³ at –15°C Evap. Temp. and + 25°C upstream of expansion											
valve	1443	1000	2434	458	519	529	319	307	89.4	51.2	18.3

From "Rules for Refrigeration Machines", 5th Edition 1958, Veriag C.F. Muller. Karisruhe

N.B. For vapour press.-temp. relation of refrigerants see curves in Fig. 7.

^{*}at +25°C **ata = atm.abs.

Discharge	remp	eratui	62 11	ı əmg	ie-Sta	ge co	mpre:	551011	WILLI	Allilli	ioilia	Com	pressor
Evaporation Temperatu (Suction G Reading)	re					Conden Discharg		ige [°] Re)			
°C	10	12.5	15	17.5	20	22.5	25	17.5	30	32.5	35	37.5	40
+10	10	16	22	28	35	41	47	53	58	64	70	76	82
+5	17.5	24	30	36	43	49	56	62	67	72	79	84	91
+0	26	32	39	45	52	59	65	71	76	82	88	94	100
- 5	35	42	48	55	61	68	75	81	86	91	98	105	111
-7.5	40	47	53	60	66	73	80	86	91	96	103	110	117
-10	45	52	58	65	71	78	85	91	96	102	108	114	123
-12.5	50	57	64	70	77	84	91	96	102	108	114	121	129
-15	55	62	69	76	82	89	96	102	108	114	121	127	135
-20	66	73	80	87	94	101	108	115	121	126	127		
-25	78	85	92	99	107	113	121	126	132	140			
-30	90	97	104	112	120	127	133	140					

Table 5 Discharge Temperatures in Single-Stage Compression with Ammonia Compressor

116 124 133 Source: Borsig Pocket Book, 3rd edition 1970.

Power Requirement for Refrigeration Plant using Reciprocating Compressor

Diagram 1 of Fig 4 shows the effective power requirement as a function of the refrigerating capacity of single and two-stage ammonia-compressors on the basis of the following reference conditions:

(a) Single-stage compressors:

Evaporation temperature -10°C, condensing temperature +25°C;

140

(b) Two-stage compressors:

Evaporation temperature -40°C, condensing temperature +30°C.

These are average value and apply approximately to other refrigerants also.

Example 1.

-40

Given: Refrigerating capacity $Q_0 = 600,000$ kcal/hr

Evaporation temperature = -10° C corresponding to reference

Condensing temperature = +25°C} conditions for Diagram 1 and 2

Required: Effective power requirement:

 $N_e = N_c - 10 = 140 \text{ KW}$ From Diagram 1 we have

Example 2.

Given: Refrigerating capacity $Q_0 = 600,000 \text{ kcal/h}$

Evaporation temperature = 0° C

Condensing temperature = +32.5°C

Required: Effective power requirement:

From Diagram 1 we obtain the effective power requirement N_e (-10) = 140 KW From Diagram 2 we find for $\pm 0/32.5$ °C

Refrigerating capacity = 150%, effective power requirement = 130% as compared with the reference values -10%, +25%. Therefore effective power requirement

$$N_e = \frac{140 \cdot 1.3}{1.5} \approx 122 \,\text{KW}$$

Power Requirement For Reciprocating Compressors for Refrigeration Plant.

Diagram 1 shows the effective power requirement as a function of the refrigerating capacity of single and two stage ammonia compressors on the basis of the following reference conditions:

(a) Single stage compressors:

Evaporation temperature -10°C, condensing temperature +25°C;

(b) Two-stage compressors:

Evaporation temperature -40°C, condesing temperature +30°C;

There are average values and apply approximately to other refrigerants also

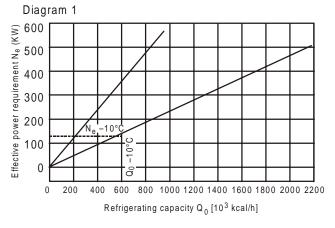


Fig. 4

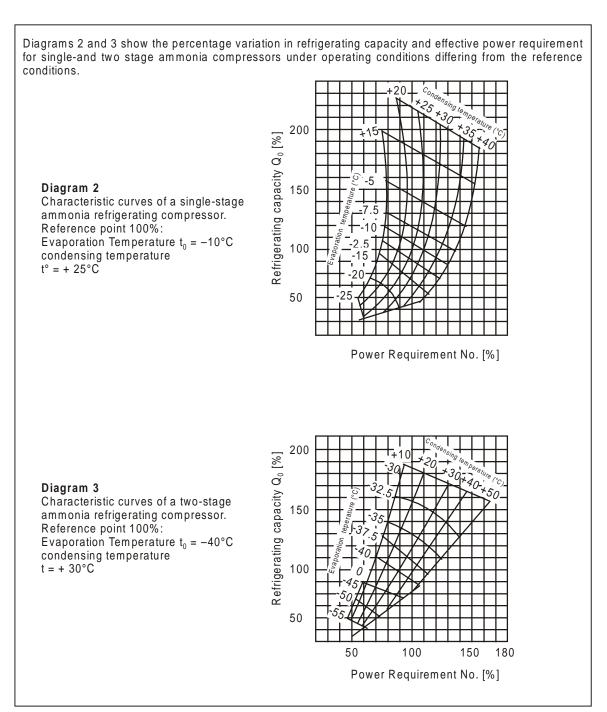
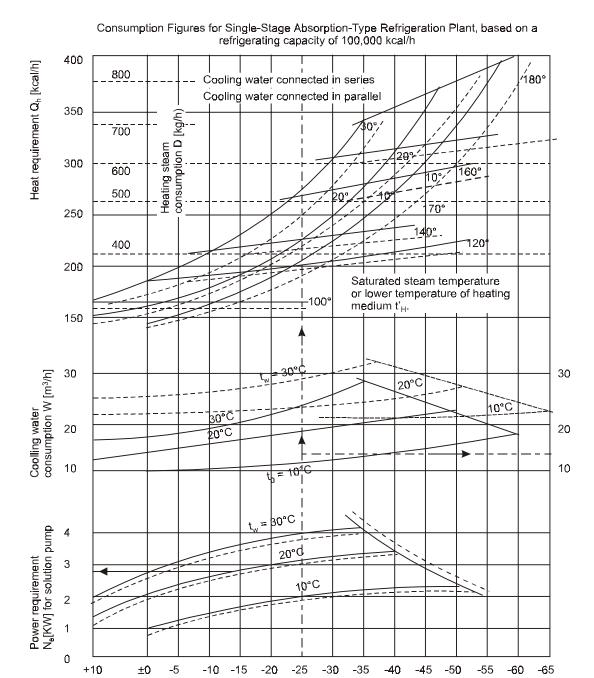
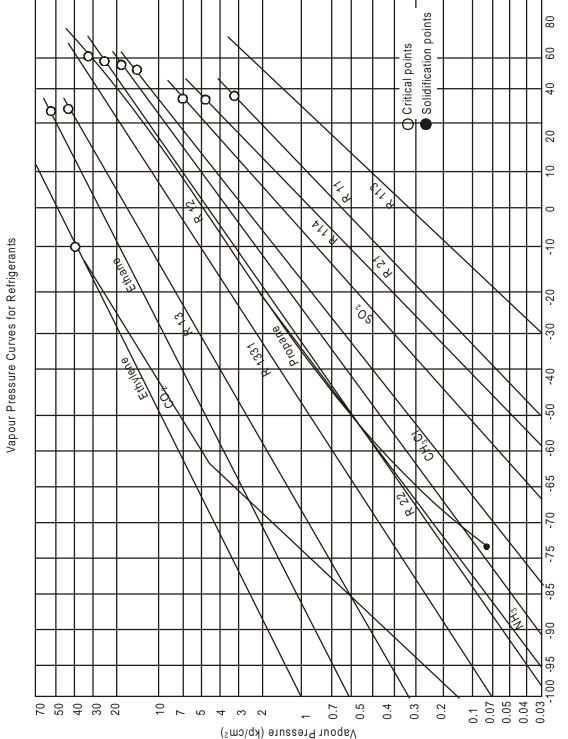


Fig. 5. Gives diagram 2 and 3 which shows % variation of refrigeration capacity and effective power consumption.



Source: Borsig pocket book 3rd edn. 1970.



Temperature (°C) Fig. 7.

100

				J		
Type of refrige-	Type of	W	hen Cool	ing	When freezing	Tolerance
rating Capacity	Condenser	Liquid	Cold rooms	Air or Gas Streams	ice etc.	
	As desired	1	1	1	1	±6%
					9	±7%
Overall Refrigera-	Water-cooled	2	2	2		±5%
ting Capacity	without evapo- rative effect	3	3	3		±8%
	Water-cooled with Evaporative Effect	e 3	3	3		±8%

Table 6
Procedures for Measuring Refrigerating Capacity

Different procedures are employed for measuring refrigerating capacity, depending on the type of condenser and the material to be cooled.

7

±10%

±6%

±5%

By definition, distinction between:

As disired

Useful

Capcity

Refrigerating

- (a) The overall refrigerating capacity, as the product of the refrigerant flow and the enthalpy difference between compressor intake and condenser liquid outlet: and
- (b) The useful refrigerating capacity, as the product of the flow-rate (of the refrigerant, cooling medium, etc.) and its enthalpy difference at two points in the refrigerating plant defined in the Contract, at which the cold is utilized.

The individual measuring procedures, together with the tolerances permitted, are shown in the table 6 above:

1. Measurement of the overall refrigerating capacity Q_0 as the product of the refrigerant flow $G_{\bf k}$ and the enthalpy difference;

$$Q_0 = G_k \cdot (i_1 - i_3)$$

In this case the refrigerant flow G_k is measured by means of an orifice plate nozzle, meter, etc. Where measurement is made on the gas side, the vapour must be superheated and as free as possible from oil; pulsating flow is avoided. When measurement is made on the liquid side, injection must be continuous and no displacement of the refrigerant charge must occur.

2. Determination of refrigerant flow from the condenser duty Q_c , this being calculated from the cooling water flow G_w and the cooling water temperature at the inlet and outlet $(t_{w1}$ and $t_{w2})$:

$${\bf Q}_c \ = \ {\bf G}_k \ (i_2 - \ i_3) \ = \ {\bf G}_w {\bf C}_w \ . \ (t_{w2} - \ t_{w1}) \ \pm \ {\bf Q}_u$$

Using the refrigerant flow G_k thus obtained, the overall refrigerating capacity can be then calculated by procedure (1).

The term $Q_u = k.F$ ($t_m - t_R$) is a correction which may be positive or negative depending on the ambient temperature t_R , although as a rule it amounts to only a few percent; for this reason, the mean condenser-wall temperature t_m , needed on an average, be taken as K = 7 kcal/m²h deg C.

3. Determination of refrigerant flow from the subcooler duty Q_{NK} :

$$Q_{NK} = G_k (i_3 - i_4) = G_w \cdot C_w (t_{w2} - t_{w1}) \pm Q_u$$

The water through flow should be taken as small as possible in order to obtain a minimum temperature difference of 3°C.

4. Measurement of the flow of cooled liquid G_s and its cooling under steady-state conditions:

$$Q_0 = G_s \cdot C_s (t_{s1} - t_{s2})$$

Measurement of the liquid flow is made by weighing or by flow-metering. At the end of the test all temperatures should agree as closely as possible with the initial temperatures. Otherwise correction must be made using the water equivalent of all components situated within the measuring section: variations in the temperature difference should, however, not exceed $\pm 5\%$ of the mean value.

5. Measurement under steady-state conditions of the heat required in the cooled liquid to cancel the refrigerating capacity:

Using steam heating, it is most convenient to weigh the condensate yield G_c per hour. The condition I_D of the steam as it enters and that of the condensate as it leaves (I_c) must be known accurately.

$$Q_0 = G_c (I_D - I_c)$$

Using heating by means of water, having an inlet temperature of t_{h1} and an outlet temperature of t_{h2} , we have:

$$Q_0 = G_h \cdot C_w (t_{h1} - t_{h2})$$

If the refrigerating capacity is cancelled by means of electrical energy, the current I and voltage U are measured. For direct current, we then have:

$$Q_0 = 0.86 \text{ U.I.}$$

6. Determination of the useful refrigerating capacity by heating the cooled space and measuring the heat required under steady-state conditions:

Stable conditions must be accurately maintained for a sufficiently long period and the cold losses must be known. This method is thus suitable for refrigerators but not recommended for large cold-rooms.

7. Determination of the useful refrigerating capacity by measuring the air or gas flow G_L and the cooling and drying obtained under steady-state conditions.

$$Q_0 = G_L (i_{1,1} - i_{1,2}) - G_L (X_{1,1} - X_{1,2}) i_w$$

where

 i_{L1} , i_{L2} are the enthalpy of the air at the inlet and outlet, and

 i_{w} that of the precipitated, moisture

 X_{L1} , X_{L2} are the water-vapour content at the inlet and outlet.

This method is acceptable only if the conditions, specified in the "Regulations for Refrigerating Machines", are observed carefully; no great accuracy should be expected.

8. Ice-production test to determine the useful refrigerating capacity:

$$Q_0 = G_E (t_1 + 80 - 0.5 t_{sm}/2)$$

where

 t_1 is the mean temperature of water when placed in the ice cans.

 $t_{\rm sm}$ is the mean brine temperature.

The quantity of ice G_E produced per hour is obtained from the weight of the resulting ice-cubes immediately after removal from the can, not less than 10% of the cubes being weighed on each occasion. Strict attention must be paid for the maintenance of steady-state conditions; the brine temperature at the end must agree exactly with that at the start.

9. If it is desired to determine the overall refrigerating capacity from the ice-product test, proceed as under (8), In addition allowance must be made for the incidence of heat from environment and for the heat equivalent of the work of the stirrer. The quantity of ice produced per hour is, in this case, determined by measuring the quantity of water introduced.

Note:

The subscripts relating to enthalpy values in the refrigerant circuit are designated as follows (as per standard rating cycle):

The subscript 1 is used for the entry of water, brine, air, etc. and the subscript 2 for their exit. Source: "Rules for Refrigerating Machines", 5th Edition 1958

Table 7 Oils for Refrigeration Machinery as per DIN 51 503

1. FIELD OF APPLICATION

This Standard applies to oils suitable for use with evaporation temperatures down to -30° C. Where even lower evaporation temperatures are involved, special agreements should be made between manufacturer and user and these will often cover testing procedures in addition to maximum and minimum values.

2. TERMINOLOGY

Refrigeration-type oils are lubricating oils used in refrigeration machinery and therefore exposed to the influence of the liquid and gaseous refrigerant.

Note:

Oils for lubricating the running gear of open-type refrigeration machinery need not satisfy this Standard provided that it is impossible for them to enter the refrigerant circuit. Such oils are covered by DIN 51 501 and DIN 51 504.

3. CLASSIFICATION

Refrigeration oils are divided into two groups to some extent differentiated by the relevant maximum and minimum values:

Group A

Oil for refrigeration machinery using:

Refrigerant NH₃ to DIN 8960

Refrigerant CO2 to DIN 8960

Group B is obsolete, refrigerant SO₂ being no longer used

Gruop C

Oils for refrigeration machinery using fluorinated and/or chlorinated hydro-carbons as the refrigerant, e.g.,

Refrigerant R 11 to DIN 8960

Refrigerant R 12 to DIN 8960

Refrigerant R 21 (dichloro-monofluoro methane, CHFCl₂) to DIN 8960

Refrigerant R 22 to DIN 8960

Refrigerant R 40 to DIN 8960

Refrigerant R 114 to DIN 8960

4. **DESIGNATION**

Designation of a Group A refrigeration-type oil:

Refrigeration-type Oil A DIN 51 503

5. PROPERTIES

Requirement	Group A	Group C	Test as per:		
Appearance	(Clear	-		
Flash point °C min.		160	Din 51 584		
Neutralisation number		0.08			
Nz, mg KOH/g oil, max.	(free of miner	al acid and alkali)	DIN 51 558		
Saponification number Vz, mg KOH/g oil, max.		0.20	DIN 51 559		
Ash, weight % max.		0.01	DIN 51 575		
Able to flow in U-tube at or below °C	For refrigeration machinery with evaporation temp. betweeen -20°C and -30°C -30				
	For refrigeration machinery with evaporation temperature above -20°C -20	–25	DIN 51 568		
Water content in as- delivered condition	Oils delivered in tan content no settled w the tank contents ha	ater after 101 of			
		Oil supplied in drums should contain no settled water at room temperature			
	Oil in small water vashould not contain rof water p.kg.				
Resistance to refrigerants (using R12) hrs. minimum	-	96	DIN 51 593		

Matter insoluble in Freon-12 weight %, max.	-	0.05	DIN 51	590
Kinematic Viscosity, cSt minimum		76 at 20°C	DIN	51 561
	•	on machinery with mperatures above –	DIN	51 562



COAL TAR CHEMICALS

Coal tar obtained from coal carbonization for production of coke, is a source of various aromatic chemicals and pitch (residue). Coke oven tar is rich in naphthalene and anthracine. The coal gases from coke oven battery or retorts, containing tar and other chemicals are separated in stages. The yields of tar and other coals chemicals depends on type of coal use, mode of coal carbonisation method via continuous coke oven battery, retorts as well as type of carbonisation whether high temperature (1200°C).

Carbonisation or low temperature carbonization ($600-800^{\circ}$ C) is used. Atmospheric distillation of H.T. coke oven tars yields 50–60% pitch. CVR tar gives 40–50% pitch and tars from L.T. carbonization yields 26–30%

Table 1
Composition of crude tars

Item	H.T. Coke oven	L.T. Coke oven	CVR
Yield, Lit/Mt Carbonisation temperature °C	26–33 1200	75–130 600–800	70.9
Density at 20°C gm/cc	1.169–1.175	1.029	1.074
Water, wt%	2.5-4.9	2.2	4.0
Carbon, wt%	90.3-91.4	84	86
H ₂ , wt%	5.25-5.5	8.3	7.5
N ₂ ,wt%	0.86-0.95	1.08	1.21
Sulphur, wt%	0.75-0.84	0.74	0.9
Ash. wt%	1.15-1.24	0.10	0.09
Toluene insoluble wt%	5.5–6.7	1.2	3.1

The chief constituent chemicals from coal tar fractionation are benzene and its homologues, phenols, cresols, naphthalene, or carbolic oil, cresols and their homologues and anthracine from heavy oil (green oil). Tars also contain aniline, pyridine, quinoline and thiophne. Cresols—a pale brown yellowish liquid-become darker with age on exposure to light, contains ortho, meta and para cresols. O-cresols-colourless Deliquescent solid become yellow on exposure to light: m.p. 30°C: m cresols colourless or yellow liquid: m.p. 10°C. Para cresols-crystalline solid m.p. 30°C. It is a disinfectant fluid.

Table 2 Fractions in continuous H.T. coke oven tar distillation

Item	B.P. range °C	wt% of crude tar (dry)
Crude Benzol/light oil	99–180	0.5–1.0
Phenolic/Carbolic oil	180–205	3–4
Naphthalene Oil	200-230	10–12
Wash oil (Benzole absorbing oil/light creosote oil)	240–290	6–8
Light Anthracine oil	260-310	12–15
Anthracine oil (heavy green oil)	323–372	95
Residue-medium soft pitch	-	53–58
Liquor losses	_	4.5

Light oil contains benzene 65% toluene, 3%, ethyl benzene and xylene 8% and remainders are balance items.

Primary distillation of crude tar upto 150°C yields crude benzole or light oil. Further distillation of crude benzene will yield crude benzene, toluene and xylenes together with some higher aromatic hydrocarbons, paraffin, naphthalene, phenol and sulphur and nitrogen compounds. Crude benzene is further subjected to hydro refining.

Second product, naphtha and light oil from primary distillation in B.P. range of 150–200°C gives the important products viz. pyridine bases, naphtha and coumarene resins and creosote oil residue.

Third product naphthalene oil of primary distillation in B.P. range of 200–230°C gives phenols and naphthalene.

Fourth product wash oil of primary distillation in B.P. range of 240–290°C yields wash oil or benzene absorbing oil.

Fifth product anthracine oil of primary distillation in B.P. ranges 260–350°C gives light anthracine oil and heavy creosote oil.

The last fraction, heavy oil is distilled at B.P. range of 323–373°C. The residue is medium soft pitch, having softening point (Ring and Ball method) of 60–75°C.

Pitch is a complex heterogeneous mixture of H resins 2.8–14% and M resins 3.8–28.2%.

Table 3

Type of pitch	Softening point °C
Refined/base tar	below 50°C
Medium soft pitch	60–75°C
Soft pitch	50-60°C
Medium hard pitch	75–110°C
Hard pitch	above 140–150°C

Medium hard pitch is made by air blowing of medium soft pitch containing heavy tar oil.

Road tar: BS-1964 specifies two types of tar.

Type A for surface dressing and Type B for tar macadam. Heavy tar oil bitumen (medium soft pitch mixture is used as a binder for stone chips in road construction and the viscosity of tar bitumen

should be 50 secs by standard tar viscometer. The disadvantage of road tar is that the temperature difference between R and B (Ring and Ball) method of softening point and brittle point is only 46°C due to which tar tends to flow in hot weather and suffer from brittleness in winter. Its internal cohesive strength is low. The disadvantage of high temperature coefficient of viscosity can be over come by blending with petroleum bitumen (pitch). Such medium soft pitch-petroleum bitumen blends along with 1–2% PVC or certain synthetic rubber are used in advance countries for road making.

Pitch for Electrode Binder used in Al Smelter

A paste of 70% petroleum coke or pitch coke and 30% medium hard coke oven pitch was used as electrode binder earlier. Now a days, the electrodes after binder appln. is baked at specified temperature.

Refined tar products constitute about 10–12% of crude tar distilled. The bulk product is pitch and creosote oil and blends of pitch and creosote oil *i.e.*, road tar and coal tar fuels.

Table 4
Yields of Refined products from tar distillation fractions

Refined Product	H.T. Coke Oven	L.T. Coke Oven	CVR
Wt% dry tar			
Benzene	0.25-0.42	0.01	0.22
Toluene	0.22-0.3	0.12	0.22
O Xylene	0.04	0.05	0.06
m Xylene	0.11-0.2	0.10	0.13
p Xylene	0.04	0.04	0.05
Ethyl benzene	0.02	0.02	0.03
Styrene	0.04	0.01	0.02
Phenol	0.5-0.57	1.44	0.99
o Cresol	0.2-0.32	1.48	1.38
m Cresol	0.4-0.45	0.98	1.01
p Cresol	0.2-0.28	0.87	0.86
Xylenols	0.48	6.3	3.08
Tar acids (High boiling)	0.91	12.8	8.09
Naphtha	1.18	3.6	3.21
Naphthalene	9-10	0.65	3.18
α Methyl Naphthalene	0.5-0.72	0.23	0.54
β Methyl Naphthalene	1.32-1.5	0.19	0.68
Fluorine	0.88-2.0	0.13	0.51
Diphenylene Oxide	1.4–1.5	0.19	0.68
Anthracene	1–1.8	0.06	0.26
Phenanthrone	5.7-6.3	1.60	1.75
Carbazole	1.23-1.5	1.29	0.89
Tar bases	0.99-2.00	2.09	2.09
Med. soft pitch	54–60	26.0	43.7

COAL TAR CHEMICALS 99

Tar Distillation Processes

Smaller size tar distillation plants of capacity 30–70 MT/batch with fractionation column (wt. 10–30 MT) are used in small works while continuous stills of capacity 100–700 MT/day are better to install.

Crude tar containing NH_3 liquor and suspended solids, is first filtered to remove large solid particle. The liquor is taken into tanks fitted with screen. Some light oil separates by gravity. It is then heated in a pipe still having a brick lined rectangular chamber divided into a combustion chamber and a convection chamber. In the combustion process, coke oven gas or heavy tar oil or fuel oil is burnt through burners. Hot flue gases are extracted by a blower through apertures in the partition wall and heat pipe in the chamber, carrying tar.

The exhausted gases are released through the chimney. The heating tar tubes are arranged horizontally and parallel to the furnace walls. Normally, heating tubes consist of two separates coils—a waste heat coil and a longer main coil. The waste heat coil is used to heat the tar upto a temperature to vaporize moisture and light tar oils. The main heating coils may be mostly in convection chamber or partly both in combustion and convection chamber. The tar is finally heated to 360°C when moisture and volatile matters get separated from nonvolatile pitch. The separated tar oil is fed to a fractionating column where distillation products of increasing B.P. range are separated by fractional distillation followed by condensation. Instead of one distillation column a series of column is also used. The distillation column has bubble cap type trays, 10-15" apart.

Precaution for Overheating in Pipe Still

Since tar on over heating will deposit coke due to decomposition on tube surface resulting in blockage of flow, the tar is pumped at a back pressure of 10 Kg/sq. cm. The tubes are either screened from radiant heat or use twin tube coils to reduce flux. Flow gas recirculation is also used to reduce fluegas temperature. Hot pitch can also be circulated with dehydrated tar to reduce vaporization and increase flow rate through tubes for better heat transfer.

Corrosion: Free ammonia salt decomposes to HCl after dehydration and decomposition products of phenol attack carbon steel resulting in corrosion. Use 10% sod. carbonate soln. in crude tar fed to minimize corrosion.

Latest designers for tar distillation plant. 1. Clairton refinery of U.S. Steel Corporation and 2. Teer Verwertung, Germany (Koppers design).

Types of Tar Distillation Plants

Major differences in plants lie in furnace design in which crude tar is heated, either single pass with a flash vessel or multiple pass with flash vessel, and using or no using recirculation of residue tar and in the no. of fractionating column and their efficiencies. The processes employing the above techniques are called pro-abid, GFT Koppers and Wilton process.

Pro-abid process: In this process, crude tar is screened in a wire mesh, treated with caustic soda soln. and pumped through a series of heat exchangers in the furnace and through waste heat heaters in the convection chamber. The temperature of tar increased to 150–160°C at which the tar is fed into hydrator flash vessel where water and light oils are flashed off which are cooled, condensed and water is decanted off from light oil in a decanter. The light oils are then returned to dehydrator or in some cases, to distillation column as reflux. The dehydrated tar is heat exchanged with hot pitch and sent through main furnace coil by a pump and heated to 350–400°C at 2–3 Kg/cm² pressure and led to a flash vessel. The super heated steam is injected into base of flash chamber.

Remaining volatile oil is degassed from tar. The mixture of steam and volatile oil is fed into fractionating column from which various fractions are taken off and products separated out after cooling and condensation.

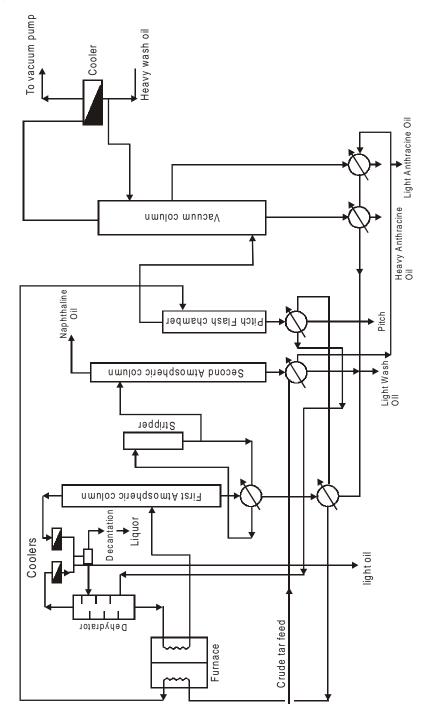


Fig. 1. Flow for Kopper's Tar Distillation unit.

COAL TAR CHEMICALS 101

Refined Products from Tar Distillation

1. Primary distillation upto 150°C gives coal tar light oil or crude benzene. Further distillation of light oil will give benzene, toluene, xylenes together with some higher aromatic hydrocarbon, paraffin, naphthalene and sulphur and nitrogen compounds.

The first stage of refining of benzene or light oil is a defronting process in which steam distillation is carried out to remove compounds boiling below benzene *i.e.*, forerunnings containing CS₂ and some low boiling unsaturated hydrocarbons and paraffins. However, in coal gas works light oil is less suitable for production of pure benzene or toluene and is used as motor benzol with petrol in some countries where it is allowed. Mild treatment of benzol with sulphuric acid is carried out to reduce sulphur to 0.4% and unsaturated compounds and waste with alkali water before fractioning column

The defronted benzol is fractionated to produce BTX fractions and heavy fractions and further fractionation gives pure benzene and toluene. The fraction is combined with that from first distillation to form zylole/naphtha fraction which is then further fractionated to give various xyloles and naphtha.

However, instead of $\rm H_2SO_4$ treatment of benzene, catalytic disulphurisation is also used in some plant, benzene and toluene fractions are made thiophene free and benzene refined to 5–9°C freezing point.

- 2. Primary fraction, distilling in the range of 150–200°C, after further refining gives Pyridine bases, naphtha and coumarene resins.
- (a) For Pyridine bases, the distillate is freed from phenols by washing with 10% Na₂CO₃ soln. The dephenolated oil is treated with 25–35% aq. H₂SO₄ which reacts with bases to form Pyridine base sulphate layer separated from waste oil and allowed to stand when resinous matter floats to the surface. Steaming or boiling removes coextracted neutral oils. The soln. is then cracked by additional NaOH, soda ash or ammonia when sodium or ammon. sulphate is formed in which pyridine bases are substantially insoluble. The crude basis are separated either by adding solid NaOH or by azeotropic distillation with benzene and dried.

The dried bases are then fractionated in a column, batch or continuous when various yields are obtained (1) small quantity of pyridine water azeotrope which is returned to drying (2) Pyridine (3) Picoline (4) mix of ρ and γ picoline fraction, and 2,6 lubidine (termed as 90/140) bases) and (5) higher boiling mixture 99/160 and 90/180 bases—the figure 90 indicates 90% distils upto 140°C, 160°C and 180°C respectively.

 β picoline can be separated by azeotropic distillation with water. The other tar bases occurring in high boiling fractions upto 250°C viz. quinoline, isoquinoline and quinaldin. The quinoline is separated by fractionation.

 β coumarene resin- coal tar naphtha is fractionated to give a narrow boilling range fraction (170–180°C) which is concentrated to coumarene and indene. This is treated with strong H_2SO_4 to remove unsaturated compounds—washed with water and redistilled. The distillate is heated with a catalyst, usually boron fluoride to polymerize indene and part of coumarene content. Unpolymerised oil is drained off. The coumarene resin thus obtained varies in colour from pale amber to dark brown and used in paints, polished and flooring colours. The product can also be called indene resins.

Primary distillation range 200–250°C produces fractions of phenol and naphthalene. Here 1st phenols are removed from distillate and then the dephenolated oils are treated for naphthalene recovery.

(b) Phenol Recovery

The oil is treated with some excess of 8–10% aq. soda soln. at a temperature just high enough to prevent naphthalene from crystallising out. The phenols react with NaOH to give crude sod. phenate, phenolate or carbolate. The crude phenolates are separated and the extracted oil, dephenolated is steam distilled or washed with a solvent to remove neutral oils (1%) and bases (upto 0.5%). The purified phenate is decomposed or "sprung" in a tall lower, packed with coke or steel R/Ring, operating counter current to a gas containing 10-24% CO_2 or a gas containing 30-37% CO_2 , specially produced by calcining mix of coke and limestone in a kiln.

The product from bottom of packed tower is separated in a separating tank into two layersan aq. soln. bottom layer of sod. carbonate and an upper layer of crude tar acid layer. The bottom layer is drained off.

The crude tar is further refined. Sod. carbonate/bicarbonate is then added to bottom layer from separating tank and passed to a recausticizing tank where treatment with quick lime or slaked lime converts sod. carbonate to caustic soda and precipated CaCO₃. The regenerated caustic is recycled for extraction of crude tar acid from fresh oil.

Subsequent refining of crude tar fraction is done in depitching column which separates oil in the over head product containing phenol and water and residue of phenolic pitch. The overhead product is subjected to vacuum distillation using two or more efficient columns and finally distilled in batch still. The products obtained are pure phenol, pure orthocresol and cresylic acids (mix of cresols and xylelols).

However, manufacturing phenol synthetically is cheaper.

(c) Naphthalene Recovery

The dephenolated naphthalene oil contains 85–95% of total naphthalene. There are two processes for recovery of naphthalene:

- (i) Old Process: The naphthalene oil is cooled slowly in open pans to ambient temperature when crude naphthalene crystallizes and mother liquor is allowed to drain by gravity. The naphthalene crystals are then centrifuged and then further separated from mother liquor in a hot filter pressure at 400 atm. pressure and temperature of 60°C. This gives a naphthalene of 96% purity having crystallization pt. 79–78.5°C. Impurities present are thionaphthlenes which cannot be separated by distillation or crystallisation and chemical process is used for pure naphthalene.
- (ii) New Process: Naphthalene oil, having paraffines substantially removed, is fed to a dehydrating column where it is mixed with some overhead product from 2nd front column. The dehydrated naphthalene from dehydrator column is passed to front column near top and fitted with bubble cap plates. Components boiling below naphthalene are removed as overhead products, part of which is sent to dehydrating column. Residue from front column goes to middle of naphthalene fractionating column. The top naphthalene product is of hot process quality. The bottom product together with reminder of overheads from front column is allowed to cool in pans. The crude naphthalene crystals are drained off from pans and recycled with fresh feed.
- (iii) Pure naphthalene by chemical process: The liquid naphthalene (96%) is agitated with 10% of 94–95% $\rm H_2SO_4$ and washed with water and alkali and further distilled in a naphthalene column when 99% naphthalene is obtained which is cooled, crystallised and filter pressed to get solid pure naphthalene having crystallisation point of 79–80°C.



REFRACTORY BRICKS

There are various types of refractory bricks:

- 1. Silica bricks
- 2. Dolomite bricks
- 3. Chromite bricks
- 4. Chrome-Magnesite bricks
- 5. Alumina-Silicate bricks
- 6. Sillimanite bricks
- 7. High alumina bricks (70%)
- 8. Low alumina bricks (42%) or fire bricks
- 9. Magnesite bricks
- 10. 54% silica fire clay bricks

Properties, uses and raw materials for refractory bricks:

(i) Silica Bricks

Bulk density = 1.73-1.78 gm/cc

Porosity = 22-25%

Temperature = 1710° C

Uses: O.H.F. roof lining

Molasses or sulphite lye is added to ground raw materials before moulding of bricks to increase green strength. Sulphite lye is from paper making sulphite process.

(ii) Dolomite Bricks CaMg (CO₃)₂

Dolomite is a mixture of Ca and Mg oxides, 25% CaO and 21% MgO. On heating the reaction

is:
$$CaMg(CO_3)_2 \xrightarrow{heat} CaO + MgO + 2CO_2$$

Properties of dolomite bricks:

Bulk density = 2.52-2.58 gm/cc

Temperature = 1300° C

Uses: In cupola and rotary kiln.

(iii) Chromite Bricks

Avg. composition of Indian chrome ores,

$$SiO_2 = 1.27\%$$
 $CaO = 0.57$
 $Al_2O_3 = 12.75\%$ $MnO = 13.51$
 $TiO_2 = 0.37\%$ $Cr_2O_3 = 45.33$
 $FeO = 7.12\%$ $CO_2 = 0.22$
 $Fe_2O_3 = 15.97\%$ $H_2O = 2.67$

Properties of chromite bricks:

Temperature = $< 1250^{\circ}$ C

Uses: Steel, O.H. (non ferrous), Cu converter

(iv) Chrome-Magnesite Bricks

Properties of chrome-magnesite bricks (> 50% chrome):

Uses. Open hearth furnace, re-heating furnace hearth and soak pits.

(v) Alumino-Silicate Bricks (38.1% Alumina and 57.8% SiO₂)

Raw materials, bauxite and fire clay

Properties of alumino – silicate bricks:

Temperature = 1580° C

(vi) Sillimanite (Al₂O₃, SiO₂) Bricks

Properties of sillimanite bricks:

Bulk density = 2.4–2.47 (
$$A_{10}$$
) and 2.5–2.58 gm/cc
 Porosity = 9–13% (ASTM – A_{10}) and 12–16% (ASTM A_{11})
 Temperature = 1980°C

Sillimanite mineral is found in Khasi hills of Meghalaya in India.

Uses: Glass melting tank lining.

(vii) High Alumina Bricks (70%)

Raw materials, 98% Bauxite and clay

Properties of high alumina bricks:

Bulk denisty = 2.9-2.96 gm/cc

REFRACTORY BRICKS 105

Porosity =
$$14 - 18\%$$
 (ASTM C_4)

Temperature = 1700° C

Uses: Steel plant

(viii) Alumina Bricks (42%) or Fire Bricks

Properties of alumina bricks:

Bulk density = 1.97 (BSI code C_4) gm/cc

Porosity = 19 - 22.1%

Temperature = 1575° C

Uses. In acid Bessemer tuyers, non ferrous and glass melting furnaces and coke ovens etc.

(ix) Magnesite Bricks

Properties of magnesite bricks:

Bulk density = 2.86 gm/cc

Porosity = 14.5 - 19.8%

Temperature = >1730°C

Uses. Mostly used where resistance to strongly basic slags is required, under hearth and lining of O.H.F. and re-heating furnace.

(x) Fire Clay Bricks (54% SiO₂)

Properties of fire clay bricks

Bulk density = 2.16 gm/cc

Pprosity = 16.5%

Temperature = 1680° C

Uses: Excellent general purpose bricks for re-heating furnaces, furnace doors, boiler soaking pit etc.

(xi) Mullite Bricks (65 - 75% Al_2O_3)

Properties of mullite bricks:

Bulk density = 2.55 gm/cc

Porosity = 17 - 23%

Temperature = 1750° C

Table 1
Thermal Expansion of refractory bricks

Type of bricks	% Thermal expansion (200 – 1000°C)	Clearance expansion in laying
Fire Clay bricks	0.5 - 0.7	1/16" - 3/32" per ft.
Chrome bricks	0.8 - 0.9	5/32" per ft.
Chrome-Magnesite bricks	0.8 - 0.9	3/16" per ft.
Dolomite bricks	1.3	-
Silica bricks	1.2 - 1.4	1/8" - 3/16" per ft.

Shapes of Refractory Bricks

Various sizes and shapes – One size is $L = 9^{"}$, $W = 4.5^{"}$ and thickness = $3^{"}$

GLOSSARY

Flux – A chemical, which lowers the fusion point of a refractory material.

Grog – Non plastic materials, usually prefired and added to bricks to reduce drying and firing shrinkages or to obtain special properties *i.e.*, high thermal shock resistance.

Porocity – Ratio of volume of pores in a refractory body to the volume of entire body and expressed in percentage.

Plasticity – It is the property of a material by virtue of which it can be shaped (moulded) into any form and which can be retained when the pressure of moulding is released.

Green strength - The strength of ceramic body in moulded but unfired state.

Modulus of rupture - Transfer strength of material.

Eqn. $M = \frac{3 \text{ wl}}{2 \text{ bd}^2}$

where w = total load, lb.

l = distance between supports, inches

b =width of test pieces inches

d =thikness of test piece, in

M = MOR, lb/in^2 .



EXPLOSIVES AND DETONATORS

An explosion is a violent noisy outburst accompanied with sudden build up of high pressure and release of pressure associated with a chemical change liberating heat and light.

GASEOUS EXPLOSION

A gaseous explosion is generally non-detonation type which takes place (i) when the flammable or explosive mixture is within the flammable limits i.e., in between lower and upper limits of explosion in air and (ii) a source of ignition in the form of (a) hot surface or (b) electric spark or (c) spark due to friction (d) naked light or (e) ignition by shock waves.

Lower the explosive limit, greater is the explosive energy release. At near higher explosive or flammable limit, the mixture burns with long flame. The ignition temperature of a flammable vapour or gas depends on pressure of the gas itself. The ignition temperature decreases as the pressure of gas/vapour increases.

EXPLOSION DUE TO PRESSURE VESSEL RUPTURE

It is a mechanical failure of vessel under pressure due to excessive pressure or corrosion, resulting in thinning out of vessel wall/heads and the metal is unable to bear the tensile strength required to withstand the internal pressure of the vessel. Since it is a physical explosion, no chemical changes occurs and release of heat and light do not occur. However, for a chemical plant, the fluids handled in many cases are flammable, which may cause generation of sparks due to friction of flying metal objects from the ruptured vessel and its supports, hitting other objects in vicinity, causing sparks and ignition of gases, if flammable.

DETONATION

It is caused by mere impact or detonation shock waves or electric sparks. Powerful explosives or explosive gases having lower limit of flammability producing shock waves having very high detonation speed, sometimes as high as MACH 10 (10 times speed of sound), due to violent changes. The speed of shock wave is above 330 m/sec or so. In the case of ethane-air mixture, the flame velocity is 63 cm/sec and detonation wave speed is 1734 m/sec. In detonation, shock wave initiates chemical reaction which propagates through the explosives charge. Detonation is carried forward on the peak of a shock wave. Gaseous detonation is dependent on pressure, volume, energy and velocity and also the time taken for detonation. For an explosion to occur, the reaction must be exothermic. A fraction of chemical energy is used to propagate a shock wave.

DETONATORS

where

These are devises viz. a small amount of very sensitive primary explosive charge is embedded in a high explosive material and mechanical or electrical devices used to set off the main high secondary explosive. Often fuse wire is used for detonation, which consists of a train of black gun powder wrapped in tube of tissue paper or a woven waxed fabric. In mining, high explosive fuse wire is used. Often the blasting cap of a detonator usually contains a small charge of PETN to transmit a powerful shock wave, ignited by fuse wire and serves to touch off the primary explosive.

Gas detonation velocity is calculated from the following formula:

Det. Velocity = $V_1 \sqrt{\tan \theta}$ V_1 = volume of detonating gas

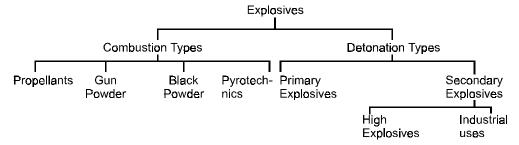
 $tan\theta$ = angle of tangent to equilibrium line with no reaction curve for detonating as per Hogoniot curve for the particular detonating gas.

Gasoline has a detonation velocity of $1/10^6$ meter/sec, for high explosive it is 6000–8000 m/sec and solid propellant $1/10^2$ m/sec. The detonation pressure may rise upto 200,000 atm. in case of high explosives.

Table 1

Gases and other	Calculated detonation velocity, m/sec	Actual detonation velocity, m/sec
2H ₂ + O ₂	2806	2819
$2H_2 + O_2 + 5N_2$	1810	1822
$C_2H_2 + O_2$	2960	2920
Nitroglycerine (liquid)	81	80
TNT (solid)	6480	6700

CATEGORY OF EXPLOSIVES



EXPLOSIVES FOR INDUSTRIAL USES

Blasting gelatine – 8% nitrocellulose in nitroglycerine (mining)

Other explosives

TNT - Trinitro toluene; Amatol-Ammon. nitrate and TNT

ANFO – Ammon. Nitrate – fuel oil mixture (IED), Nitroglycerine [C₅H₅O₀N₃ (Liq)]

RDX - Research and Development explosive, Hexogen or cyclonite

PETN – Pentaerythritol tetranitrate

HMX - Cyclotetra methylene tetra nitramine

HMS – Hexa nitrostilbene

TATB - 1, 3, 5 triammino -2, 4, 6 trinitrobenzene

TNP - Trinitro phenol

 $Tetryl - (NO_2)_3 C_6H_2N(NO_2)CH_3$ also known as Tetralite

N.B. RDX is used with wax or TNT due to high sensitive nature. Chemical name of RDX is cyclo trimethylene trinitramine.

Table 2 Properties of Explosives

Name	M.P. O°C	V.P. P _a	Crystal density gm/cc	Detonation velocity m/sec	Lead block test 10gm, sm ³
Nitroglycerine	13.5	1	1.591(liq.)	7700	520
RDX	204	0.05 at 110°C	1.82	8850	480
TNT	80.8	6	1.654	6960	300
PETN	141.3	0.1	1.77	8340	520
HMX	283	-	1.907	9100	520
TATB	7550 (decom.)	_	1.94	7970	-
TNP	122.5	1	1.767	7500	315
Tetryl	129.4	_	1.73	7570	_

Some Primary Explosives

Mercury fulminate

Lead azide

DDNP (Diazodinitro phenol)

Ammonium nitrate

 Table 3

 Impact Sensitivity of Secondary Explosives

Insensitive	Value
TATB	72.5
TNT	1
Moderately Sensitive	
TNP	0.7 - 0.9
Tetryl	0.4
HMS	0.6

(Contd.)

(Contd.)

Sensitive - high explosive	
HMX, RDX	0.3
PETN	0.15 - 0.2
Nitroglycerine	0.1

Functional groups in explosives

- (a) Nitro gr. Salts of HNO₃, derivatives etc.
- (b) O nitroderivatives nitroesters (RONO₂) PETN
- (c) C nitroderivatives aliphatic and cryclodiphelic nitrocresols
- (d) N nitroderivatives RDX and HMX

TREND IN THE USE OF BLASTING EXPLOSIVES

Both nitrocellulose and nitroglycerine are mixed in tankers and pumped to boreholes in open cast mines and detonated using fuse wires.

Riot Chemicals – These are CN (chloroacetophenone), CS (ortho chlorobenzol metanitrite) and DM (Diphenyl amino chloroarsine) – the latter being more effective than CN or CS. Riot chemicals cause skin irritation. Tear gas contains lacrimating compounds (watering of eyes) viz Bromo acetone, benzyl chloro acetone, ethyl iodoacetate etc. usually put in explosive shell which on firing gives out aerosol of lacrimating compounds.

Plastic Explosive – A combination of petroleum jelly, latex and RDX, designated as C-C4 and containing 88.3 to 91% RDX and plasticiser varies from 11.7% to 20%, 22% and 9% (C2 to C4).

Gelatin Dynamite – It contains mainly gell like mass of nitroglycerine with sodium nitrate, meal, cotton and sodium carbonate. This high explosive can be detonated by fuse wire or a timer or wireless signal.

Chemicals of Mass Destruction (CMDs) – SARIN, a nerve gas consists, mainly methyl phosphonofluoridic acid and ethyl ester. Mustard gas is a blister gas, which acts as a cell irritant and cell poison. CMDs are banned by international treaty.



1. GENERAL

Water occurs abundantly in nature as rain water (from evaporation of water) surface water (lake, river and sea), underground water and spring water. However, water has great solvent property and as such it cannot be used unless suitably treated for use as potable water or process water or boiler feed water. Pure water ionizes to a small extent and its conductivity at 18° C is $0.044 \, \mu s/cm$. Rain water, after first showers is very pure like distilled water. Underground water, which occurs in sandy layer is clear and free from organic impurities and nitrogen compounds which are oxidized by soil bacteria. Spring water contains some special constituents.

2. IMPURITIES

Water, depending on source, contains floating objects, fine silica (silt) which impart turbidity, dissolved salts of Ca, Mg, Iron and often Manganese. These salts are present as bicarbonates, Ca(HCO₃)₂, Mg(HCO₃)₂, Fe(HCO₃)₂ ferrous bicarbonates, as sulphates, CaSO₄ and MgSO₄; as chlorides CaCl₂ and MgCl₂ or as nitrates Ca(NO₃)₂ and Mg(NO₃)₂. Presence of bicarbonates gives carbonate hardness called temporary hardness, where as hardness due to chlorides and sulphates of Ca, Mg and other compounds is known as non-carbonate hardness or permanent hardness. If no Barium and Strontium salts are dissolved in the water the sum of temporary and permanent hardness gives the total hardness. Typical impurities in raw water is given in table 1:

Table 1

Cationic	Anionic	Nonionic	Gases
Minerals	Alkalinity due to		
Ca ⁺⁺	Bicarbonate	Turbidity	CO ₂
Mg ⁺⁺	Carbonate and	silt/mud	H ₂ S
Na ⁺⁺	Hydroxide	dirt colour	O_2
K++	SO ₄ =	organic matter	Chlorine
NH ₄ ⁺	Cl-	colloidal silica	NH ₃
Fe ⁺⁺	Nitrate	Micro organism and	
Mn++	SiO ₂	Bacteria, Oil	
	Organic matter	algae, suspended	
	colour	vegetation	

For converting to equivalent CaCO₃ divide the Fig. for ions by its equivalent wt. of ions and then multiply by 50 (e.g., wt. of CaCO₃)

Example: (i) for 40 ppm as Ca⁺⁺ ion conc., equivalent CaCO₃

$$= 40 \times \frac{50}{20} = 100 \text{ ppm as CaCO}_3$$

(ii) 40 ppm Ca as Ca⁺⁺, divided by 20 to obtain 2 meq/lit

(meq = millieqivalent) calcium expressed as meq.

2.1 pH Value

It is hydrogen ion concentration index and indicates whether a water sample is acidic, neutral or alkaline (basic) and how many litres, as a power 10, of a soln. contain 1 gm of hydrogen ion. pH value of neutral water is 7 i.e., 10^7 lit of water contain 1 gm ion (1.008 gm) of Hydrogen ion. The total of pH and pOH values at 23°C are always 14.

pH = 7 neutral reaction (pH and pOH conc. are same)

pH < 7 acid reaction

pH > 7 alkaline or basic reaction

pH value is temperature dependent and for neutral pure water its values are :

Water temp°C	pH value
0	7.49
23	7.0
50	6.63
100	6.13
200	5.69
300	5.59
370	5.63

3. ALKALINITY

Alkalinity denotes the presence of bicarbonate of calcium, sodium, magnesium and iron, that of soda ash (Na_2CO_3) , potassium carbonate (K_2CO_3) or hydroxides $(NaOH \text{ or } KOH \text{ or } NH_4OH$, hydrazine (N_2H_2) and other substances. It is measured by determining p and m values by titration of water; p value is given by (use of phenolphthalein indicator) on a 100 c.c. water sample treated with the quantity in c.c. of 0.1 N HCl at colour change and as of m value is obtained from the quantity in c.c. of 0.1 N HCL using methyl orange indicator at colour change. This is given in T2.

4. DETAILED PROFORMA

Detailed analysis of water, for ascertaining treatment method for process/boiler/potability, is required to be carried out. Following detailed analysis are required for this purpose.

Physical

Colour temperature index - APHA unit

Turbidity - Jackson or APHA unit

pН

Conductivity - µs/cm

Table 2 Alkalinity of water as mg CaCO₃//

Titration result, ml/c.c	Bicarbonates	- Water contains- Carbonates	Hydroxides
p = 0, M > 0	M	nil	nil
$p < \frac{1}{2} M (2p < M)$	M - 2p	2 <i>p</i>	nil
$p = \frac{1}{2}M \ (2p = M)$	nil	2 <i>p</i>	nil
$p > \frac{1}{2}M (2p > M)$	nil	2(M-p)	2 <i>p</i> –m
p = M	nil	nil	M

Note: p and M in ml/c.c.

Physical (contd.)

Total suspended solids, mg/lit and size range, mm

Hardness: Ca hardness as CaCO₃ mg/l

Mg hardness

Temporary hardness as CaCO₃, mg/lit

Permanent hardness

Total hardness

Non-carbonate hardness, as CaCO₃, mg/lit

Carbonate hardness, as CaCO₃, mg/lit

Nitrous nitrogen

Nitrate nitrogen

as N, mg/lit

Ammoniacal nitrogen

Alkalinity - in p value or M value as CaCO3 mg/lit

Total dissolved solids, mg/lit

Permanaganate value

(4 hrs at 26.6°C)

C.O.D (Chemical Oxygen Demand), mg/lit

Sulphates as CaCO₃ mg/lit

Chlorides as CaCO3 mg/lit

Fluorides as CaCO3 mg/lit

Post chlorination, Cl₂ content in water.

Minerals

Sodium as Na mg/lit

Magnesium as Mg mg/lit

Iron as Fe mg/lit

Copper as Cu mg/lit

Zinc as Zn mg/lit Arsenic as As mg/lit Lead as Pb mg/lit

Bacteriological

B.O.D₅, mg/lit

(5 days at 20°C)

Total colliform as M P N/100 ml

Fecal coliform as M P N/100 ml

Note. Permanganate value gives the organic matter present in water, which is also removed by chlorination.

Raw water having high BOD value, (over 4–6), total/MPN colliform, (10,000), fecal colliform more than 200, higher pH (over 10), chlorides (over 600), fluorides (over 1.5), along with arsenic, lead and zinc are not desirable for chemical treatment and to be rejected. Turbidity above 14,000 ppm is also difficult to remove and requires presettling ponds.

5. WATER SOFTENING

A. Chemical Treatment

(i) For removing temporary hardness due to presence of bicarbonates of calcium and magnesium, quicklime, CaO or slaked lime (hydrated lime), Ca(OH)₂ is used in calculated quantities with excess amount due to impurity. The bicarbonates react with lime (or its solution, milk of lime).

$$\begin{split} &\text{Ca(HCO}_3)_2 + \text{Ca(OH)}_2 = 2\text{CaCO}_3 + 2\text{H}_2\text{O} \\ &\text{Mg(HCO}_3)_2 + \text{Ca(OH)}_2 = \text{MgCO}_3 + \text{CaCO}_3 + 2\text{H}_2\text{O} \\ &2\text{NaHCO}_3 + \text{Ca(OH)}_2 = \text{CaCO}_3 + \text{Na}_2\text{CO}_3 + 2\text{H}_2\text{O} \\ &\text{CO}_2 + \text{Ca(OH)}_2 = \text{CaCO}_3 + \text{H}_2\text{O} \end{split}$$

(ii) Quantity of quick lime required for softening

If A is the temporary hardness due to calcium and B is due to magnesium expressed in equivalent $CaCO_3$ in mg/lit unit, then pure quick lime required for above reactions is $(A+B) \times 0.74$ gm per m³ of raw water.

The purity of quicklime is considered to arrive at actual quantity required. Addl. quantity of quick lime is required if alkalinity due to NaHCO₃, is present. Mg alkalinity removal by slaked lime dosing, the following reaction is also possible:

$$Mg(HCO_3)_2 + 2Ca(OH)_2 = Mg(OH)_2 + 2CaCO_3 + 2H_2O$$

In the above case pure quicklime required is 0.765 gm pre m³ of raw water for each mg for Mg hardness as CaCO₃ (mg/lit). Temporary hardness is removed by boiling when insoluble CaCO₃ or MgCO₃ precipitates:

$$Ca(HCO_3)_2 \xrightarrow{heat} CaCO_3 + CO_2 + H_2O$$

$$Mg(HCO_3)_2 \xrightarrow{heat} MgCO_3 + CO_2 + H_2O$$

(iii) Permanent hardness is determined by difference between total hardness and temporary hardness. Permanent hardness in water is due to presence of sulphates, chlorides and nitrates of calcium and magnasium. It is removed by dosing soda ash along with slaked lime. Dual use of slaked lime and sodium carbonate is useful to remove sulphates and chlorides of magnesium.

Calcium bicarbonate also reacts with soda ash:

$$Ca(HCO_3)_2 + Na_2CO_3 \longrightarrow CaCO_3 + 2NaHCO_3$$

(iv) Quantity of pure sodium carbonate required if C is the permanent hardness due to sulphates, chlorides and nitrates of Ca, Mg expressed as equivalent $CaCO_3$ in $mg/lit = C \times 1.06$ gms per m^3 of water.

B. Sedimentation of Precipitates from Chemical Dosing

Ferric alum containing Aluminium sulphate and ferric sulphate is used as coagulating agent in the clarification of water, which hastens sedimentation process of reaction products from reaction of slaked lime and sodium carbonate. In the flocculation chamber of the clarifier, floc. formation occurs in presence of coagulating agent, ferric aluminium. Aluminium sulphate completely hydrolyses in water to form insoluble aluminium hydroxide, which is colloidal in nature having negative charge.

$$Al_2(SO_4)_3 + 6H_2O \longrightarrow 2Al(OH)_3 + 3H_2SO_4$$

The precipitates from dosing reactions as above bear positive charge which attract jelly like precipitate of Al(OH)₃ to form bigger particles which settle in the clarification zone of clarifier along with sediments present in the raw water.

Part of aluminium sulphate reacts with the calcium and magnasium in water forming Al. Carbonate which immediately hydrolyses to Al(OH)₃.

$$Al_2(SO_4)_3 + 3CaCO_3 = Al_2(CO_3)_3 + 3CaSO_4$$

 $Al_2(CO_3)_3 + 6H_2O = 2Al(OH)_3 + 3H_2CO_3$

The alum floc produced by coagulation being much heavier settles to the bottom of clarifier from which it is periodically removed during blow down.

Calcium precipitate sludge, sp. gr. = 1.2 settles at 3 times faster than alum floc.

Al(OH)₃ floc is formed according to alkalinity present in water after chemical dosing.

Normal alum dose required = 5 - 10 mg/lit. The min. dose is 5 mg/lit. Extent of alum dose required is determined by jar test.

Quality of treated water: In lime soda process, total alkalinity must exceed the residual total hardness. Carbonate alkalinity must exceed magnesium and Ca hardness. Caustic alkalinity can be increased by increase of lime feed and carbonate alkalinity by increasing soda feed.

Table 3
Settling velocity of particles in water

Sattling	velocity.	m/sac
Settiina	velocity.	III/Sec

Diameter of particles mm	Sand Sp. gr. 2.65 at 20°C	Alum floc Sp. gr. 1.05 at 20°C
1	12	0.1
0.5	7.8	_
0.1	1.04	_
0.05	0.2	_
0.01	0.013	-

New poly electrolytes have been developed as a coagulant in mid 70's. Though its cost is much more than ferric alum, but quantity required is less (dose = 0.1 mg/lit or 0.1 gm/m^3). It can be used with min. alum dose and put into intake channel to flocculator after alum is added and flocculation is started.

C. Lime Softening Process by Clariflocculator

Usually a sludge blanket type of flocculator is used for water softening. Required quantities of lime and alum solutions were prepared based on raw water analysis and mixed with water in flash chamber from where it is sent to central flocculator section of clarifier. This section is provided with four paddle agitators rotating in opposite directions. Here, chemical reactions between bicarbonates of Ca and Mg and milk of lime take place and carbonates of these salts precipitate out. The precipitated carbonates form flocks with Al hydroxide, formed due to hydrolysis of alum become bigger and flows to outer clarification section. The heavier flocks settle to the bottom conical portion where the sludge blanket is formed which do not allow any flocks to leave the clarifier clear water trickles from holes in top periphery of clarifier and is stored in storage tank.

The bottom scraper, which moves very slowly scrapes the heavy sludge, swept in towards central sludge water discharge valve and the valve is opened usually once in a shift for sludge drain. The success of this process depends on proper floc. formation, which depends on alkalinity present in water after dosing of chemicals. Total sludge formation is 2.8 - 3.6 times the wt. of lime added. The treated water is then subjected to sand gravity filtration to remove any carry over smalls of flocks/suspended matter. Then chlorination is done in pump discharge line from filtered water storage tank. Chlorination from large cylinder is usually done through dosing instrument. Often pre-chlorination is required if organic matter is high.

Removal of Iron and Manganese Salts in Water

Both iron and manganese salt can be removed by aeration. Ferrous salts get oxidized to ferric state and precipitated out:

$$4Fe(HCO3)2 + O2 + H2O \longrightarrow 4Fe(OH)3 + 8CO2$$
$$4FeSO4 + O2 + 10H2O \longrightarrow 4Fe(OH)3 + 2H2SO4$$

In case of high carbonate hardness, the liberated sulphuric acid is decomposed as below:

$$H_2SO_4 + Mg(HCO_3)_2 \longrightarrow MgSO_4 + 2H_2O + 2CO_2$$

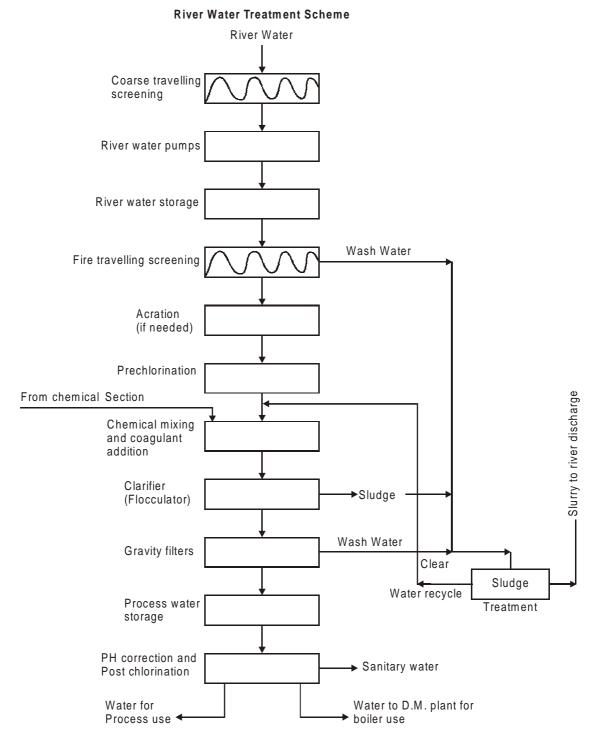


Fig. 1. Block diagram for river water treatment scheme.

In case where carbonate hardness is minor, addition of milk of lime is required to precipitate iron, $Fe(OH)_2$ and the hydroxide is oxidized during aeration:

$$\begin{aligned} & \text{FeSO}_4 + \text{Ca(OH)}_2 & \longrightarrow & \text{Fe(OH)}_2 + \text{CaSO}_4 \\ & 4\text{Fe(OH)}_2 + \text{O}_2 + 2\text{H}_2\text{O} & \longrightarrow & 4\text{Fe(OH)}_3 \end{aligned}$$

Manganese is converted into manganese dioxide by aeration:

$$2Mn(HCO_3)_2 + O_2 + 2H_2O \longrightarrow 2MnO_2 + 4H_2O + 4CO_2$$
$$2MnSO_4 + O_2 + 2H_2O \longrightarrow 2MnO_2 + 2H_2SO_4$$

If carbonate hardness is high, liberated $\rm H_2SO_4$ decomposes the carbonate as above. Otherwise alkalinity raising agents like milk of lime is to be used. The insoluble compounds of iron and Magnesium precipitated as above can be removed by gravity filters.

Quantity of air required for oxidation by aeration:

Example. For 0.2% Fe or $0.2 \times 10^4 = 2000$ ppm Fe, air required = 1×2000 lit/m³ or 2m/m³ of water aerated.

If quantity of water thus treated is 300 m³/hr, air flow required for aeration = 2×300 or 600 m³/hr.

Note: If water contains a little O_2 , addln. 28 lit of air/m^3 of water are to be added to form lime anti corrosive layer to maintain pH at above 6.5.

Removal of ferrous and manganaous ions by sodium hydrogen cation exchangers is possible if no dissolved air or oxygen is present.

E. Demineralisation by Ion Exchange Method

High quality water required for boilers and other process use, is further treated in ion exchangers in chemical plants and power generation plants for boiler use.

Process water from water treatment plant after chemical dosing, flocculation and sedimentation in a clarifier is further treated in demineralisation plant consisting of degassifier, pressure filter and for removal of dissolved oxygen and carbon dioxide and finally treated in cation, anion and mixed bed exchangers. Additional pressure filter is required in DM plant to arrest any suspended matter from process water treatment plant.

Filtration by pr. Sand filters is carried out in filters packed with gravel (non crystalline structure at bottom and sand layer at top). Water at 2–3 Kg/cm² pr. is fed at the top and during its downwords flow, fine suspended matter is arrested in sand bed and clear water is drawn from the bottom. Two filters are required—one remains in line and other one under back washing to remove the trapped suspended water. Depending on the capacity of DM plant, a battery of such filters is required.

F. Degasification of Water

(i) Thermal degasification of water removes dissolved gases (O₂ and CO₂) using live steam in degasification tower having contact plates. The water temperature is brought to near its boiling point. the solubility of O₂ and CO₂ is reduced due to heat as well as partial pressures are reduced to zero. Thermal degasification is either carried out under vacuum through a vacuum pump or a condenser cum ejector for exhausting liberated gases and excess steam are released from tower top. When condenser is used inlet feed water to degasifier is preheated in the condenser for heat recovery before it is fed to the tower from top through distributors. Pressure degasification is used mostly in power

plants using steam pressure controllers for uniform degasification temperature. In vacuum degasification, temperature controllers are used for this purpose.

(ii) Chemical degasification of water is usually carried out after demineralization of water by dosing N₂H₄, as hydrazine hydrate (purity 75% min.) to remove residual dissolved oxygen. The mineral content of water is not increased and excess hydrazine is decomposed due to heat in boilers. NH₃ gets mixed with steam and is condensed as condensate where as N₂ remains with steam and is removed as non-condensable gases from process condensers. Hydrazine concentration required for a typical DM plant is 2–5 ppm; the reactions are:

$$N_2H_4 + O_2 \longrightarrow 2H_2O + N_2$$

 $3N_2H_4 \longrightarrow 4NH_3 + N_2$

G. Ion Exchangers for DM water

Boilers, specially medium and high pressure boilers, require feed water of zero hardness and free from silica. Cation exchangers, filled with suitable resins to remove all +ve ions like Ca, Mg etc. and anion exchangers are filled with required resin for the removal of –ve ions groups including silica. Ion exchangers contain fine granules of organic substances, which are styrene based synthetic resins. Cation exchanger contains strong or weak acid groups and anion exchangers contain either strong or weak basic groups. Cation exchangers are regenerated after exhaust on suitable period of exchange of +ve ions in water by either dil. H_2SO_4 or HCl (5–10%) as per requirement. Similarly anion exchanger are regenerated after exhaust by weak caustic soda solution (3–5%). After exhaustion of cation and anion exchanger, backwash with water is carried out to remove suspended matter followed by regeneration with acid/alkali. First rinsing with water, removes excess regeneration chemicals and exchangers, thus regenerated, are put in line. All these operations are controlled by timer operated control valves. Normally 1 + 1 cation exchanger and 1 + 1 anion exchanger are required for 1 exchanger is in operation and 1 as stand by after regeneration.

Selection of Type Cation and Anion Exchangers Resin

Depending on the extent of hardness (temporary/permanent or carbonate hardness or non carbonate hardness or Ca/Mg hardness) present in treated process water or underground water, suitable type of ion exchange resins is to be selected. For medium and high pressure boiler, instantaneous removal of silica is required in mixed bed exchanger containing both cation and anion exchange resin. Cation exchanger (H exchange) removes alkalinity and hardness. The weak cation exchanger is charged with H ions. All the mineral content in water is reduced by the amount of carbonate hardness.

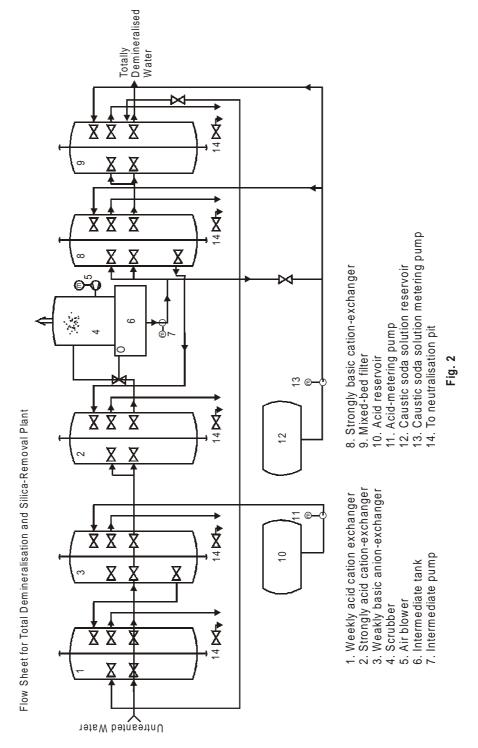
Decarbonation (H exchange)

Ca Ca
$$Mg.(HCO_3)_2 + A.H_2 \longrightarrow 2H_2O + 2CO_2 + A.Mg$$
 Na_2 Na_2

Regeneration:

$$\begin{array}{ccc} \text{Ca} & \text{Ca} \\ \text{A.Mg} + \text{HCl} & \longrightarrow & \text{AH}_2 + \text{MgCl}_2 \\ \text{Na}_2 & & \text{Na}_2 \end{array}$$

Obtainable value : < 0.5 mval/lit



Quality of acid required per m³ of decarbonated water is 14 gm 100% HCl/°dH carbonate hardness (German hardness unit).

Debasification (H exchange)

A strongly acid cation exchanger is used which is charged with H ions. All the cations contained in water are exchanged for H ions. The resulting water contains acids corresponding the anions.

Regeneration

$$\begin{array}{ccc} \text{Ca} & \text{Ca} \\ \text{AMg} + 2\text{HCl} & \longrightarrow & \text{A.H}_2 + \text{Mg.Cl}_2 \\ \text{Na}_2 & \text{Na}_2 \end{array}$$

Quantity of acid required per m^3 of debasified water is 32 gm 100% HCl/°dH cation hardness. A.H, stands for cation exchanger resin.

Anion Exchanger Resin (OH Exchange)

Strongly and weakly basic anion exchanger resins are used which are charged with OH ions. This type of resins removes acidity from water.

Deacidification

Strongly basic exchanger resin;

$$H_2CO_3 + A.(OH)_2 \longrightarrow 2H_2O + A.CO_3$$

 $H_2SiO_3 + A.(OH)_2 \longrightarrow 2H_2O + A.SiO_3$

Weakly basic exchanger resin:

$$2HC1 + A.(OH)_2 \longrightarrow 2H_2O + A.Cl_2$$

 $H_2SO_4 + A.(OH)_2 \longrightarrow 2H_2O + A.SO_4$

Regeneration with dilute NaOH solution.

$$A.CO_3 + 2NaOH \longrightarrow A.(OH)_2 + Na_2CO_3$$

 $A.SiO_3 + 2NaOH \longrightarrow A.(OH)_2 + Na_2SiO_3$
 $A.Cl_2 + 2NaOH \longrightarrow A.(OH)_2 + 2NaCl$
 $A.SO_4 + 2NaOH \longrightarrow A.(OH)_2 + Na_2SO_4$

N. B: A (OH)₂ stands for anion exchanger resin.

Quantity of dilute NaOH solution per m³ of deacidified water;

- (i) Strongly basic, 40–60 gm NaOH 100%/°dH anion hardness.
- (ii) Weakly basic, 18-22 gm NaOH 100%/°dH anion hardness.

(b) In case of total demineralization with removal of silica, the above scheme of resin usage is slightly modified for deleting basic anion exchange resin and entirely strongly basic anion exchange resin is used which ensures removal of SlO₂ and CO₂. Often due to initial CO₂ content of inlet water to DM plant, after degasser, is produced in cation exchanger from carbonate hardness; CO₂ the size of anion exchanger can be reduced and regenerating chemical requirement decreased by installing a CO₂ scrubber using air (counter current flow) to bring down CO₂ content to 10 ppm (10 mg/lit). Alternatively a mixed bed exchanger after anion exchanger contains both strongly acid cation exchange resin and strongly basic anion exchange resin. Mixed bed exchangers are however, always used in total demineralisation plant and a recycle condensate polishing unit (cation exchanger) is required. The conductivity of DM water, after mixed bed in a total demineralisation plant, should be below 0.5 μs/cm and the residual silica should be maximum 0.05 mg/lit (0.05 ppm). For super-critical boiler silica content should be about 0.01 ppm.

(c) Decarbonisaton

When only carbonate hardness is required to be removed, cation exchanger is filled with weakly acid exchanger resin. The hydrogen carbonate cations are exchanged for H ions. Hardness of salts imparting non-carbonate hardness and neutral salt remain in water. The mineral content of water is reduced by the amount of carbonate hardness.

(d) Neutral Exchanger Resin (Na Exchange)

Here all Ca and Mg ions are exchanged for Na ions and thus removed. The minerals content of the water remain unchanged.

Regeneration is by dilute sodium chloride soln.

$$\begin{array}{ccc} A.Ca + 2NaCl & \longrightarrow & A.Na_2 + CaCl_2 \\ Mg & Mg \end{array}$$

Possible hardness obtainable depending on composition of feed water is <1.8 mg CaCO₃/lit.

(e) Partial Demineralisation

Two strongly acid cation exchangers, connected in parallel – one in Na form and the other in H – exchange form, are used. The Na exchange resin removes all Ca and Mg ions for Na ions and NaHCO $_3$ from Na exchanger is decomposed by the acid in H exchanger. The mineral content of the water is reduced by the amount of carbonate hardness. Regeneration is by HCl & NaCl solutions respectively.

- (i) Series connection of exchanger. Weakly acid cation exchanger in the H form followed by strongly acid cation exchanger in Na form, the CO₂ liberated from carbonate hardness can be removed by degassing after Na exchanger. Water quality is same as that of partial flow method. Regeneration is by HCl and NaOH respectively.
- (ii) Mixed bed exchanger. A single cation exchanger containing both weakly acid and a strongly acid exchange resins can be used also. The quality of water is equal to that for parallel flow

method. Regeneration is 1st by dilute HCl and then by NaOH. This method is suitable for water when non-carbonate hardness comprises 20–40% of total hardness.

(f) Condensate Polishing

For recycle of steam condensate with tolerable limits of impurities, cation exchanger, containing strong hydrogen resin, is used. Here NH_4^+ ion in condensate upto a certain limit can be used. Regeneration is by dilute acid, H_2SO_4 or HCl.

(g) Zeolites

Initially Na_2 zeolite, a cation exchanger was developed for removal of hardness in water. Chemically zeolite is sodium salt of aluminium orthosilicate.

$$Na_2(Al_2Si_2O_8) + CaCl_2 \longrightarrow Ca(Al_2Si_2O_8) + 2NaCl_2$$

After exhaustion it is regenerated with 10% NaCl soln.

$$Ca(Al_2Si_2O_8) + 2NaCl \longrightarrow Na_2(Al_2Si_2O_8) + CaCl_2$$

6. DESALINOTION OF SEA WATER:

The process is based on reverse osmosis. In case of osmosis, water moves through a semipermeable membrane from a low conc. to high conc. of solute due to pressure difference caused by solute as per Henry's law. The osmotic pressure is the pressure required to stop the flow of solvent through the semipermeable membrane.

In case of reverse osmosis, the barrier membrane is usually called semipermeable which is selective so that solvent can only pass through the membrane while the solute can not pass through the membrane. This property of the semi-permeable membrane is used in osmotic pressure filtrations. In order to separate water from dissolved solids by reverse osmosis, the applied pressure of water, containing dissolved solids, must be greater than osmotic pressure.

The principle of separation of salt (NaCl) from sea-water by reverse osmosis can be calculated from the following equation;

1 $FW = A.(\Delta P - \Delta \pi)$

Where, $FW = \text{water flux through the cell, } gpd/ft^2$ (Us gallon per day/ft²)

A = water transport co-eff, gpd/ft atmosphere

 ΔP = pressure difference applied across membrane, atmosphere

 $\Delta\pi$ = osmotic pressure difference across semi-permeable membrane, atmosphere

The solute flow is given by equation:

2. F S = B. ΔC

Where, $FS = \text{salt flux, gpd/ft}^2$

B = salt transport co-efficient

$$\Delta C = C_1 - C_2$$

 C_1 , C_2 = conc. of solute at upstream & down stream of membrane respectively, lb/ft^2

Sea water purification plant usually contains, sea water pumping system, filters. Reverse osmosis battery of cells, desalted water tanks and finally vacuum distillers. Usually some salt is added to desalted water to impart test to water.

The most critical part of the purification plant is semi-permeable membrane. Usually synthetic poly amide (nylon fibers) is used for desalination of sea-water. For other reverse osmosis process natural cellulose acetate or nitrate is used where feed water to cells must be acidic to prevent hydrolysis of membrane.

Sea water desalination is suitable where fresh water source is scarce for potable water but the cost factor is quite high. In middle east, such plants in higher capacity range are quite common.

Water Treatment by Magnetic Filtration

Raw water can be treated for separations of suspended & dissolved solids by magnetic filtration method.

Separation method;

This resorts to magnetic seeding first and then flocculation process separates diamagnetic suspended solids and dissolved solids.

The paramagnetic suspended solids present in fluids, minerals and pharma items as well as oils have no magnetic seeding requirement. for separation.

Selection of magnetic filtration depends on various factors viz;

- (i) Size of feed materials in water.
- (ii) Relative magnetic response.
- (iii) Purity requirement of treated water, feed water temperature and point of feed.
- (iv) Permanganate strength.
- (v) Type of feed-liquid, wet and dry.
- (vi) Operating cost.

Process: Seeding of raw water with grounded Ferro magnetic particles, is done followed by verification. Finally the water is passed through a narrow constriction in a permanent magnet where remaining impurities are attracted and clear water is obtained.

The principal of magnetic filtration is also used for separation of Ferro magnetic particles/ pieces from ore trailing, coal & coal-washery where the above moving materials are caught using permanent magnet hung over the conveyor.

Ionic Load

To convert load of a water sample to their ionic equivalent, no. of ions must be divided by its equivalent wt. of ions. Exm.: to convert $Ca^{++} = 40$ ppm, dividing by equivalent wt., $\frac{\text{(Atomic wt.)}}{\text{valency}} = 20$, we get 2 meq of calcium.

Bacteriological contamination in raw water

Surface water often contains high micro-organisms due to contaminations with human excretion, untreated waste from municipalities, rain water pouring into rivers/lakes etc. Under ground water is usually free from bacteriological contamination but contains organic matter.

Quality of raw water

Avg. B. O. D

Acceptable source

0.75 - 1.5 mg/lit

(5 days, 30°C) Maxm. B. O. D.

1-3 mg/lit Avg. Colliform, MPN $0/100 \, ml$ Maxm, Colliform 0/100 ml6 - 8.5pН Chlorides < 150 mg/lit Fluorides < 1.5 mg/lit 0.01 mg/lit (max) Arsenic Pb $\leq 0.1 \text{ ppm}$ Chromium +6 $\leq 0.05 \text{ ppm}$ Copper \leq 3 ppm Iron & Mn ≤ 0.3 ppm 7n< 15 ppm N.B MPN stand for most probable number Typical analysis of safe bottled drinking water: as per IS-14543-98 as amended 2003 pH = 6.5-8.5Mercury as Hg = ppm 0.001, max Colour = 2, maxCopper as Cu = ppm 0.05, max Cl^- as Cl = ppm 200 maxManganese as Mn = ppm 0.1, max $SO_4^{=}$ as $SO_4^{}$ = ppm 200, max Zinc as Zn = ppm 5, max NO_3 as NO_3 = ppm 45, max Aluminium as A1 = ppm 0.03, max F as F = ppm 1.0, maxLead as Pb = ppm 0.01, max $HCO_3^- = ppm 200, max$ Cromium as Cr = ppm 0.05, max Nickel as Ni = ppm 0.02, max Alkalinity Minerals Selenium as Se = ppm 0.01, max Na^+ as Na = ppm 200, max Cadmium as Cd = ppm 0.01, max K^+ as K = ppm -Barium as Ba = ppm 1.0, max Ca^{++} as Ca = ppm 75, max Phenolic compounds = ppm 0.001, max Mg^{+} as Mg = ppm 30, max (as $C_6 H_5 OH$) $Fe^{+ + +}$ as Fe = ppm 0.1, max Arsenic as As = ppm 0.01, maxColliform = nil Mineral oils = 0.01 ppm TDS = ppm 500, maxAnionic s. active E. Coli, SRB etc. - absent agent as MBAS = ppm 0.2, max Turbidity = N TU 2, max PCB = Not detectable B. O. $D_5 = nil$ Polynuclear aromatic = No Odour = agreeable hydrocarbons = detectable Total pesticide residue = $0.5 \mu gm/1$ Free chlorine = ppm 0.2, max Single pesticide = $0.1 \mu gm/1$ Taste = agreeable, $NO_2 = 0.02$ ppm (max)

Arsenic Removal Process

There are several arsenic removal processes:

	Process	Range of removal
<i>(i)</i>	Lime softening	0.2 to 0.03 mg/lit as As
(ii)	Charcoal filtration	0.2 to 0.06 mg/lit as As
(iii)	Ferric sulphide filter hydroxide	0.8 to 0.05 mg/lit as As
(iv)	Co-agulation with ferric hydroxide	25 to 5 mg/lit as As
(<i>v</i>)	Precipitation with ferric hydroxide	removed upto 0.6 mg/lit as As
(vi)	Micro filtration semi-permeable membrane	< 0.8 mg/lit

Micro filtration removes pesticides to allowable limit as per EN standard, EN 29000. Arsenic from arsenic bearing rocks is leached in underground waterstrata which when pumped out by tube wells for drinking purpose cause the arsenic poisoning in humans and animals.

Chlorination of Water for Disinfection

- (i) By direct injection of Cl₂ from Cl₂ cylinder.
- (ii) By bleaching powder spreading in sand/gravel filter.
- (iii) By electrolytic chlorinator.

Residual Cl_2 in drinking water = 0.2 ppm

Effect of Cl₂: kills bacteria, removes bad odour, reduces BOD & decolourisation.

Water Treatment Basic

- 1. Turbidity Due to presence of various sediments viz dirt, mud, clay etc. turbidity of surface water increase in raw water. If turbidity exceeds 14000 mg/1 pre-settlement pond is necessary before the water treatment plant, which removes 70% turbidity. Turbidity measured by Jackson meter or APHA. After settling pond 2.5 5 JTU water preferred.
- 2. Non carbonate hardness Due to sulphates and nitrates, soda ash removes them.
- 3. Algae For prevention of greenish algae growth a 0.3% CUSO₄, $5\mathrm{H}_2\mathrm{O}$ soln is suitable which acts as a biocide.
- 4. 1 mg/lit alum will react with 0.45 mg/lit alkalinity expressed as CaCO₃ or 0.28 mg/lit lime as CaO or 0.35 mg/lit slaked lime, Ca(OH)₂ or 0.48 mg/lit Na₂CO₃.
- 5. The floc formation reaction is reversible and its formation is favorable at pH 6.8 7.9.
- 6. Presence of nitrates and nitrites may be due to decomposition of organic wastes.
- 7. Above 600 ppm chlorides, a salty taste is developed.
- 8. Fluorides > 1.5 mg/lit (as F) is undesirable as it can cause mottling of teeth at 3 ppm and above.
- 9. Sand gravity filter, filtration rate is 1 m³/m²/min for a bed size of 1.15 m² and bed depth 30–45 cm of gravel below 60–75 cm sand. Period in between backwash 24–72 hrs and water required = 6% of filtered water.
- Water is classified as hard if it is containing more than 120 mg of divalent ions (Ca & Mg) per lit (454 mg/lit) usually expressed as CaCO₃

11. Sodium cycle ion exchange increases the soluble solids content as 2 sodium $(2\times23=46)$ are substituted for one calcium (40) or one magnesium (24.3).

- 12. Hydrogen cycle exchanger replaces 1 calcium or 1 magnesium with 2 hydrogen and this reduces the total solids but also reduces the pH.
- 13. In odour scale potable water should be less than 3.



METAL CLEANING PROCESS

A. METAL DEGREASING

(a) Chemical cleaning is done by trichlorethylene or percholorethylene. Special Vat is required with heating coils at bottom & cooling coils at top to reduce loss of chemicals due to heating during degreasing operation. The soiled articles are dipped in the vat and heated for 10–20 minutes.

For heavily greased articles, often dipping in boiling solvent may be required. Degree of cleanliness test is done by observing wetability, as shown in breaks or spray pattern test.

(b) Alternate to chemical degreasing by the above organic solvent, hot alkaline soln. dipping. is also done. It is a mix of sodium hydroxide, silicates and phosphates. The soln. saponifies oils and organic materials. The pH range of such soln. for steel is mildly alkaline or it is neutral for aluminium & zinc alloys.

B. ACID PICKLING FOR REMOVING SCALES ON METALS

(i) Iron & steel — dilute HCl for minor scale

- hot dilute H₂SO₄ for thicker scales

(ii) S.S - dilute HNO_3

(iii) Al alloys – dilute HF

(iv) Cu and its alloys – hot dilute H_2SO_4

(v) Brass - mix of H_2SO_4 , HNO_3 and little NaCl or $Na_2Cr_2O_7$ & H_2SO_4 .

C. CLEANING STEEL TUBES/PIPES FOR COMPRESSORS/PUMPS LUBE OIL CIRCUIT AND REFRIGERATION PIPE LINES

- (i) For smaller dia tubes. Dilute HCl (5–6%) is generally used at temperature of 30–40°C with circulation. Circulation is to be maintained at least for 30 hours or more depending on rust condition. Dilute $\rm H_2SO_4$ (5–6%) could be used for thicker scale deposits. Heating is done by L.P steam. This is followed by water wash, 2–3% alkali wash and again water wash.
- (ii) **Dipping process.** For large dia steel pipes for refrigeration pipe lines, dipping in 5-6% HCl or H_2SO_4 could be used. The after treatment with water wash, alkali wash & water wash has to be followed.
 - (iii) For S.S pipes/tubes use 5-6% dilute HNO₂

METAL CLEANING PROCESS 129

D. ELECTROCLEANING OR CATHODIC CLEANING:

Here the non ferrous items, to be cleaned, form the cathode in water containing electroplating bath where H_2 gas scours the cathode as it evolves at cathode. Anode is made of carbon rod. The disadvantage is that the cathode, thus cleaned, leaves the cathode surface passive due to H_2 pick up. An additional dilute HCl dip is required for the cathodic articles after electrocleaning.

Anodic cleaning is desirable for soiled ferrous materials since volume of $\rm H_2$ at cathode is twice the volume of oxygen at anode. The articles to be cleaned form the anode in an electrolytic bath containing water.

The electrocleaning D.C voltage is to suitably determined.

E. CATHODE COATING

Here the protecting materials are situated below the protected in the e.m.f series of metals. Example- Tin plated iron. Tin, the protecting metal is placed below iron or steel in the e.m.f or galvanic series.

F. ANODE COATING

Here the protecting material lies above the protected. Example- Nickel plated copper; Nickel, being the protecting metal lies above copper in e.m.f series.

G. ELECTRO DEPOSITION

Resins are coated on parts forming anode while resins form the electrolyte - cathode is made of carbon rod.

H. ANODISING

Al articles form the anode and cathode is SS or carbon rod. Oxygen liberated at anode form an oxide coating & colour is imparted on the anodized surface from the colour put in bath. The D.C voltages of the electrolytic bath varies for different electro cleaning or coating processes viz.

Cathode cleaning

Anodic cleaning

Cathode coating

(Tin plating on iron)

Anode coating

(Nickel plated copper)

Resin electro deposition

Anodising



MANGANESE DIOXIDE

There are three types of manganese dioxides of industrial importance.

A. SPEC. OF ACTIVATED MANGANESE DIOXIDE

 $MnO_2 = 90\%$ wt primarily grade

$$H_2O = 2\%$$
 wt

Others = 8% wt mainly lower manganous oxides. Other critical impurities viz Cobalt, Nickel, Copper & Molybdenum and conc. are limited to 0.001%.

Particle Size

 $80\% < 44 \mu m$ for Leclanche cell

85% < 44 µm for Zinc. Chloride battery

Activated Manganous Ore Process (Semi-synthetic)

Manganese ore (Pyrolusite) containing 80% Mn is roasted at 600° C to get Manganic oxide, Mn_2O_3 which is then reacted with hot sulphuric acid to get activated MnO_2

 $MnSO_4$ is separated by leaching with water and activated MnO_2 is dried. Activated MnO_2 is lesser effective than chemical manganese dioxide (C M D).

B. CHEMICAL MnO₂

Sedemar process for CMD: process involves step by step purification of impurities in pyrolusite (MnO_2) ore:

Pyrolusite ore \rightarrow Crushing \rightarrow Rotary mill drying
Partial air
Grinding \rightarrow Reduction with \rightarrow Rotary cooler \rightarrow MnO
Heavy fuel oil H.T

 \rightarrow Leaching with \rightarrow Neutralisation \rightarrow thickening with sludge removal H_2SO_4 Na_2CO_3

$$\rightarrow$$
 Filtering drum \rightarrow Carbonation with \rightarrow Filtration in a drum filter filter NH $_3$ and CO $_2$ to remove

$$\rightarrow$$
 Drying \rightarrow Roasting in shelf \rightarrow Belt cooler \rightarrow MnO₂ roaster at 320°C Tech. grade (MnO 1.85)

$$\rightarrow$$
 Oxidation reaction \rightarrow washing \rightarrow Filtration \rightarrow Drying \rightarrow CMD with H_2SO_4 battery grade $(Y - MnO_2)$

Reactions

$$Reduction: MnO_2 + \frac{Heavy fuel oil burning}{With ltd. Air} [15 \ MnO_2 + C_{15}H_{24}S_2 + 7.5O_2 \rightarrow$$

$$15MnO + 15 CO_2 + 10H_2O \uparrow + 2H_2S$$

Leaching : MnO +
$$H_2SO_4 \rightarrow MnSO_4 + H_2O$$

Na₂CO₃

Neutralisation :
$$Fe_2O_3 + 3H_2O \rightarrow Fe(OH)_3\downarrow + 3H^+$$

Carbonation:
$$MnSO_4 + NH_3 + CO_2 \rightarrow MnCO_3 + (NH_4)_2SO_4$$
 - by product

$$Roasting: MnCO_3 \frac{Roasting}{320^{\circ}C} MnO_{1.85} + CO_2$$

 H_2SO_4

Oxidation:
$$Mn_{1.85} + 2NaClO_3 \rightarrow MnO_2 + Cl_2 + Na_2SO_4$$
(CMD)

C. ELECTROLYTIC MANGANESE DIOXIDE (EMD)

Specification:
$$MnO_2 = 91\%$$
 (wt) – Hexanal modification

$$MnSO_4 = 1-3\% - hexanal modification$$

$$Fe = 0.02\%$$

$$H_2O = 3-5\%$$

Others =
$$0.001\%$$

Balance = lower
$$MnO_2$$

Density =
$$4-4.3$$
 gm/cc

Surface area =
$$40-50 \text{ m}^2/\text{gm}$$

Particles size =
$$74 \mu m (<200 \text{ mesh})$$

Manufacturing Process

Rhodochromite ore concentrate is leached with H_2SO_4 . The acidic $MnSO_4$ is purified by oxidation with MnO_2 and neutralized with lime to pH of 4–6 when heavy metal ions (Fe, Pb, Ni and Co), present in ore, precipitate. H_2S is often used for complete precipitation of heavy metals as sulphide. After filtration and bringing conc. (filtrate) to 75–160 gm/lit $MnSO_4$ and H_2SO_4 , 50–100 gms/lit $MnSO_4$ soln. is then electrolysed (bath). The cell consists of open steel tank lined with hypalon, rubber or ceramic. (electrically non conducting). The anode is made of graphite, Ti or hard lead. The cathode material is manganese.

The paraffin layer over electrolyte is used to reduce evaporation.

Electrolysis parameters:

Cell voltage =
$$2.2-3.0 \text{ v}$$

Anode current density = $70-120 \text{ A/m}^2$
Bath temperature = $90-98^{\circ}\text{C}$
Yield = $70-90\%$

EMD is deposited on anode. Cell operation is stopped when solid E M D thickness of about 20-30 mm is obtained at anode in 15–20 days. During electrolysis, H_2SO_4 conc. is increased while $MnSO_4$ conc. is depleted. Hydrogen is liberated at cathode.

Cell Reaction

Anode:
$$Mn^{+2} + 2H_2O \longrightarrow MnO_2 + 4H^+ + 2e$$

Cathode: $2H + + 2e^- \longrightarrow H_2$
 $Mn^{+2} + 2H_2O \longrightarrow MnO_2 + 2H + H_2$

E M D after end of electrolysis is removed mechanically, crushed & thoroughly washed with hot D.M water, dried and finally grounded. The grinded product is again mixed with water and pH brought to 6.5-7 with alkali, dried to specified moisture and packed.

Modern trend is to use Ti anodes and use of passivation retardants (finally grounded MnO_2 , Mn_2O_3 & Mn_3O_4) in electrolyte bath and use of current density over 150 A/m².

Uses of Manganese Dioxides

- (i) Activated MnO₂ is used as a depolariser in dry cell battery.
- (ii) Chemical MnO₂ (CMD) is used in glass industry, drystuff and varnish. Catalysist, colouring of bricks and ceramics, welding rod manufacture, metrological products and also as a trace nutrients for plants.
- (iii) Electrolytic manganese dioxide (EMD) is mainly used in dry cells as a depolariser and ferites manufacture for electronics use.



WIND TURBINE FOR POWER GENERATION

In high wind areas like sea coastal places, wind power is generated in wind turbine generators (WTG) which are usually two or three bladed; modern trend being to use two bladed WTG. Site selection is through wind mapping of the proposed site for few years and other project related infrastructure availability, including power evacuation through transmission lines of state electricity board and power transmission grid.

Generally the wind turbine generator is located high at 30–50 meter above the ground level (to have access to more wind speed for AC power generator at the WTG, (3 phase AC generator). The AC power is converted to DC by a rectifier and stored in large Ni-Cd battery house and power from battery is converted to AC 3 phase in inverter and transmitted to 3 phase AC transmission line after voltage boost up to grid voltage. The battery storage is used for low demand period. Nickel –Cadnium battery has higher cycles of operation, charge to discharge, about 2000)

The blade pitch could also be automatically adjusted to suit generation. In direct AC power transmission, power is transmitted to step up transformer by passing rectifier battery-inverter system or transmission to grid. A wind power generator farm requires a large area (5–6 acres/MW) as WTG are to be placed at specified distances. The center line distance between two adjacent WTG should be 7 times the diameter of WTG blade circles and 2 blade circles center distances should be minimum 5 times the diameter of blade circles. The minimum wind speed required is 6 miles/hr (9.66 km/hr) and maximum wind velocity allowable is 39 miles/hr (62.79 km/hr) with alternator cut off speed kept at 40 miles/hr (64.4 km/hr) during storm. The WTG capacity usually varies from 25 KW to 100 KW and the minimum capacity of a wind power firm could be 250 watt and the annual power production could be 600 thousand kilo watt-hr. The efficiency of power generation in WTG set is only 35 to 60 percent. A constant speed WTG spills wind energy at higher wind velocity to allow generator not to exceed rated capacity upto certain limit during storm before cut-off device is activated for which blade pitch auto adjustment device is put in two blade turbine.

Kinetic energy of wind, $E = 1/2 \rho u^2$ where u = wind velocity in m/sec and $\rho =$ density of air. For two bladed generators, equation for wind power is given below:

$$P/AT = 1/2 u^3$$

Since only 8/27/1/2 or 16/27 or 0.593 part of maxm. power can be extracted, the effective equation for power:

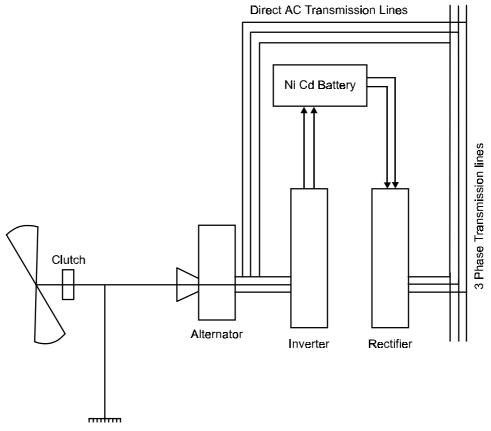


Fig. 1. 2 Bladed wind turbine power generator scheme (WTG).

PM/AT = 0.593. $\rho.u.^3$ or PM = 0.593. $\rho.u.^3\pi$ R^2

Where

PM = maximum power extracted

AT = cross section area of wind stream, sq mt. (blade sweep area)

0.593 = Betz co-eff maxm., fraction of power, which can be generated

 ρ = Air density (sea level), 1.221 kg/m³ (usually)

u = Initial steady state wind velocity, m/sec

And power co-eff

$$c\rho = \frac{P}{1/2.\rho.u^3.\pi R^2}$$

where

P = power delivered to the turbine, kg-m/sec or watt

 $\rho = 1.221 \text{ kg/m}^3 \text{ density of air}$

u = initial wind velocity m/sec

R = radius of blade area, m

Power co-eff, is the ratio between power delivered to the turbine to the power extracted between the cross sectional area; usually power co-eff is 0.35 to 0.60.

Note. Power density for a 4.50 m/sec wind velocity is 54 W/m^2 and the same for 13m/sec wind velocity is 150 W/m^2 . Power density is the power per unit cross section of wind stream.



CENTRIFUGAL PUMPS

A centrifugal pump transfers the input mech. energy through a rotating impeller into kinetic (velocity) & potential (Pressure) energy to the liquid. This addition of energy will cause it to do work, such as flow through a pipe or rise to a higher level.

While centrifugal force developed, depends both on the peripheral speed of the impeller and on the density of fluid pumped, the amount of energy imparted to the fluid per lb of fluid is independent of the fluid itself i.e its density or sp. gravity so long the liquid viscosity is not higher than that of water. Pump head is expressed in feet of fluid generated by a centrifugal pump at a given speed and capacity is usually expressed in m³/hr or cft/sec or GPM. In determining heads, it is required to convert pressure expressed in Psi or Kg/cm² into feet or meter of liquid.

CAPACITY

The volume of liquid pumped, is referred to as capacity and is generally measured in gallons per minute (gpm). Large capacities are frequently rated in cubic feet per second, or millions of gallons per day. When referring to the pumping of petroleum oils, the capacity is sometimes specified in barrels (42 US gal) per day.

HEAD

The height to which liquid can be raised by a centrifugal pump is called head and is measured in feet or meter of liquid. Water performance of centrifugal pumps is used as a standard of comparison because practically all-commercial testing of pumps is done with water.

System of heads: Head of a centrifugal pump is the energy content of the fluid expressed in ft lb/lb.

The total head of a system against which a pump must operate is made up of the following components.

- (1) Static head.
- (2) Pressure head.
- (3) Friction head.
- (4) Velocity head.
- (5) Entrance and exit head losses.

Static head. It is caused by the difference in elevation. Total static head is the difference in elevation between suction and discharge liquid levels. The static discharge head is the difference in elevation between the discharge liquid level and pump center line. The static suction head is the difference in elevation between suction liquid level and pump centerline. If the static suction head is –ve the suction level is below the pump center line and it is called static suction lift.

Pressure head. It is the head due to pressure exerted by the discharge and suction points.

Friction head. Friction head is the equivalent head expressed in vertical feet of liquid pumped that is necessary to overcome the friction losses caused by the flow of liquid through this piping etc. Friction head depends on the type of fluid, quality of fluid, size and type of pipes and fitting and interior conditions. Roughly it varies as the square of the capacity (flow).

Entrance and exit losses. When suction is from a reservoir, the point of connection of the suction line and reservoir there is a loss due to sudden contraction and is called entrance loss. A well designed bell mouth result in the lowest loss of pressure.

Likewise on the discharge side of the system when the discharge line terminates at some body of the liquid at the end of the piping this is called the exit losses. Generally the end of the piping is of the same size as of piping and the difference in velocity head is entirely lost. In some cases the end of discharge piping is a long taper so that velocity can be effectively reduced and the energy recovered.

Velocity head. It represents the kinetic energy of a liquid per unit mass of fluid at any point,

expressed in ft-lb per lb of liquid of
$$h_v = \frac{V^2}{2g}$$
 When $h_v = \text{vel.}$ head in feet (ft lb/lb)

$$V = vel.$$
 in feet/sec
 $g = 32.2$ ft/sec²

In high head pumps the K.E involved is relatively small but in low head pumps, it is relatively high. Thus in case of high head pumps, failure to consider it in determing head will not appreciably effect the result.

In determining the head existing at any point, it is necessary to add the velocity head to the pressure gauge reading as the pressure gauge can indicate only the pressure energy while the actual head is the sum of the kinetic (velocity) and potential (pressure energy) heads. Only in case where the suction & discharge line velocities are same (so also the velocity heads), the difference in suction gauge and discharge gauge readings will show the total head. for a +ve suction pump.

Vapour pressure. The vapour pressure of a liquid at any given temperature is that pressure at which it will flash into vapour if heat is added to the liquid or conversely that the pressure at which vapour at the given temperature will condense into liquid if heat is substracted.

Total head. The total dynamic head for a horizontal centrifugal pump is defined as follows.

$$H = H_d - H_s + \frac{{V_d}^2}{2g} - \frac{{V_s}^2}{2g} + P_d - P_s$$

where \mathbf{H}_d is the discharge head as measured at the discharge nozzle and referred to the pump shaft center line, feet. \mathbf{H}_s is the suction head expressed in feet as measured at the suction nozzle and referred to the pump center line. If the suction head is -ve the term \mathbf{H}_s the above equation is positive.

The other two terms in the above equation are the velocity and pressure head at the discharge and suction points respectively.

CENTRIFUGAL PUMPS 137

The total dynamic head is the energy imparted to the liquid by the impeller of the centrifugal pump. If the discharge and suction heads can not be determined separately it is done by Bernoulli's theorem. For complex systems involving both vacuum and pressure these are converted into absolute pressure expressed in feet of liquid.

For a vertical pump with the pumping element submerged, the total dynamic head is given by:

$$H = H_d + H_s + \frac{V_d^2}{2g}$$

where H_s is the distance from the suction liquid level to the center line of the discharge elbow and H_d is the discharge head in feet referred to the center of the discharge elbow. The last term in equation represents velocity head at the discharge.

The various discharge and suction heads are given in figures 1 and 2.

Characteristic Curves

Rising characteristic - head rises as capacity is decreased

Dropping characteristic – head at shut off is less than that at some capacities

Steep characteristic – large head increase as the capacity is decreased.

Flat characteristic – head varies slightly with capacity.

EFFICIENCY

The degree of hydraulic and mechanical perfection of a pump is judged by its efficiency. This is defined as a ratio of pump energy output to the energy input applied to the pump shaft. The latter is the same as the driver's output and is termed brake horsepower (bhp), as it is generally determined by a brake test.

Efficiency =
$$\frac{\text{Pump output}}{\text{bhp}} = \frac{\text{W.H.P}}{\text{bhp}}$$
$$= \frac{\text{QrH}}{550 \times \text{bhp}}$$

where Q is capacity in cubic feet per second, r is the specific weight of the liquid (for cold water = 62.4 lb per cu ft) and H is head in fect. Qr is the weight of liquid pumped per second. If the capacity is measured in gallons (US) per minute, equation becomes as below for water.

$$e = \frac{gpm \times 8.33 \times H}{60 \times 550 \times bhp}$$
, $WHP = \frac{gpm \times H}{3960 \times bhp}$

In above equation (gpm×H) /3960 it is the pump output expressed in horsepower and is referred to as water horsepower (W.H.P).

If a liquid other than cold water is used, the water horse power should be multiplied by the specific gravity of the liquid to obtain the pump output or liquid horsepower.

The pump efficiency as defined by above equation is the gross efficiency. This is used by engineers for the comparison of performance of centrifugal pumps. Besides this, there are a number of partial efficiencies used by designers and experts, which describe only one phase of pump

performance - hydraulic, mechanical, volumetric - and are of no interest to the users of pumps but are important to the study of pump performance.

AFFINITY LAWS

These are based on relations between capacity, head and break horsepower. Pump head varies directly as the square of the speed; the break horsepower varies directly as the cube of the speed and the capacity varies directly with the speed. The affinity laws are expressed by the following equations.

$$\frac{\mathbf{Q}_{1}}{\mathbf{Q}_{2}} = \frac{n_{1}}{n_{2}}; \frac{\mathbf{H}_{1}}{\mathbf{H}_{2}} = \frac{n_{1}^{2}}{n_{2}^{2}}; \frac{\mathbf{bhp}_{1}}{\mathbf{bhp}_{2}} = \frac{n_{1}^{3}}{n_{2}^{3}}$$

The affinity laws apply to each point in the characteristic curves. The letter n stands for speed and post script 1 and 2 stand for no.1 and no.2 pumps following the characteristic curves.

PUMP CONSTRUCTION

A centrifugal pump consists of a casing, impeller, casing wearing ring, gland packing, suction and discharge nozzles and bearing supports with roller/ ball bearing. The impeller may be backward vane type and the impeller may be open, semi closed or closed types. In backward vane impeller, head decreases as the through put increases; for forward vane impeller, head increases as the delivery increases. Open or semi open impeller is used for slurry handling; for multi stage centrifugal pumps, the stage arrangement is made in such a way that the differential pressure between any two adjoining stage chambers is kept to the minimum possible and several low pressure running joints are to be preferred to a few number of joints subject to relatively high pressure. Also for multi stage pump, minimum leakage at running joints is kept and to maintain this for a long period of time and also the sequence of stages should be such as to avoid excessive complication in the formation of inter stage passes.

NPSH

In the pumping of liquid, the pressure at any point in the suction line must not be reduced to the V.P of liquid. The available energy that can be utilised to get the liquid through the suction piping, suction water way of the pump into the impeller is thus the total suction head less the V.P of liquid. The available head as measured at the suction opening of the pump has been termed N.P.S.H.

Example (i) water at 62°F and O suction lift (sea level)

$$N.P.S.H. = 33.9 - 0.6 = 33.3$$

(ii) Do at 15 suction lift = N.P.S.H. =
$$33.9 - 0.6 - 15 = 18.3$$

Required N.P.S.H. It is a function of pump design and represents the min. required margin between suction head and the V.P at a given capacity. Required N.P.S.H, being a function of velocity at the suction passages and at the inlet to the impeller, increases as the square of the capacity. However, the available N.P.S.H. is reduced with increasing capacity due to friction loss in the suction piping. If suction pressure falls below vapour pressure of pumping fluid, there will be vapourisation of fluid and noisy operation of pump with drop in discharge pressure. This is called Cavitation Phenomenon. The priming of a centrifugal pump is done by filling up casing with water till air is driven out with discharge closed.

CENTRIFUGAL PUMPS 139

SPECIFIC SPEED

The basic definition of specific speed is that it is the speed (rpm) at which a theoretical and geometrically similar pump would run if proportional to deliver 1 G.P.M against 1 ft total head with its best efficiency at these service conditions. Specific speed is an index of pump type.

Formula
$$M_s = \frac{n\sqrt{Q}}{H^{3/4}}$$

where $M_s = \text{sp.}$ speed, n = r.p.m., Q = G.P.M at speed n and H = total head per stage.

Normal sp. speed range for single suction impeller is 500 - 1500 r.p.m. The lower the specific speed the higher is the head that can be developed for a total head and suction lift condition the specific speed should not be below a certain value for successful operation. Limitation chart for specific speed has been developed by Hydraulic Institute of U.S.A.

MECHANICAL SEALS

These are normally used for gland sealing in place of material like asbestos rope for stuffing boxes of centrifugal pumps. Mechanical seals reduce gland leakages of fluid to a very low amount and it is used also when corrosive, hazardous and costly fluids are handled. These are spring loaded, flexible shaft mounted design and continuously and automatically compensate for shaft run out, axial end play, vibration & wear. Usually fitted with carbon disks—one rotating and one stationery, which restricts the gland leakage to a minimum. However a small leakage is desired for lubrication when handling liquid process fluids.

LOSSES IN CENTRIFUGAL PUMP

Leakage loss: This reduces the volumetric efficiency due to leakage losses through the running clearance between the rotating impeller and the casing parts. Leakage loss increases with the increase of specific speed. In practice leakage loss is greater for smaller pumps because the clearance cannot be reduced below a certain minimum; also because the wearing rings of larger pump are wider and co-eff. of discharge is smaller.

Disk friction loss: The particles of liquid in the space between the disk (impeller) and stationery walls acquire a rotary motion. As a result of centrifugal forces, particles start moving outward in the immediate neighborhood of the disk and new particles approach the disk near the center. The power consumption increases as the clearance between the disk and the wall is increased.

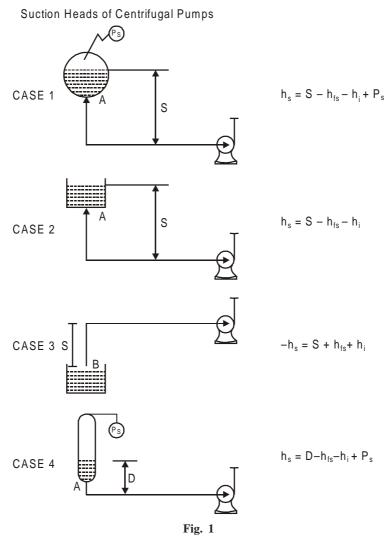
TECHNICAL LOSSES

Stuffing box and bearing losses. The friction loss in stuffing box is affected by size and depth of stuffing box, pump speed, pressure and method of packing and lubrication. Friction torque is very high with a tight gland but decreases rapidly as the gland is loosened and the leakage increases. Friction power losses increase approximately as the square of the speed. Pumps, with mechanical seal stuffing box, losses are minimum. Bearing losses using properly lubricated ball bearing or roller bearing, become minimum. Bearing lubrication and alignment is important to keep bearing losses at minimum.

HYDRAULIC BALANCING OF CENTRIFUGAL PUMP

For axial and radial balance in multistage centrifugal pump, some form of hydraulic balancing devices must be used in the form of a balancing disc or a combination of these two. The balancing disc of drum is nothing but a pressure reducing mechanism so used within the pump that the pressure differential across leakage joint is equivalent to the total pressure generated by the pump.

For double suction pump, the impeller is balanced by the discharge pressure as well as suction pressure acting each in opposite direction. Double suction centrifugal pump is usually of high capacity.

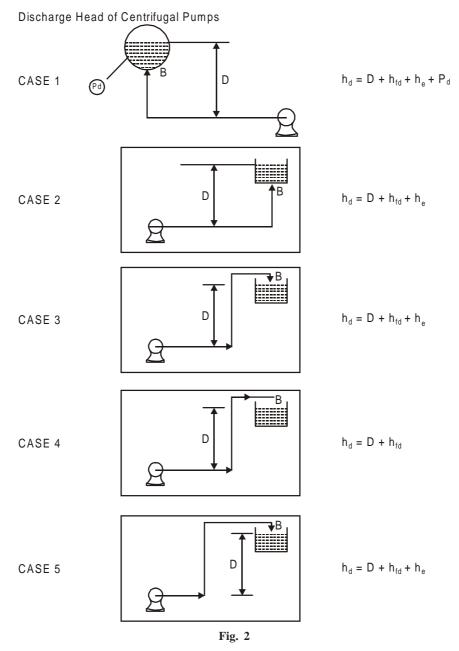


Where S = Suction head: h_{fs} = total friction loss in suction pipe, h_i = entrance loss at A D = Suction static head and P_s = Pressure of enclosed place. h_s = Suction head.

Remarks: (1) A gage in suction line to a pump measures the total suction head (above atmospheric)-velocity head at the point of attachment.

- (2) As a suction lift is -ve, vacuum gage will indicate the algebraic sum of total suction lift and (-) velocity head.
- (3) If P_s in partial vacuum, the P_s in ft of liquid is to be expressed as -ve.
- (4) Suction lift or head are measured below or above atmospheric.
- (5) Use a foot value for suction lift with casing plug for air venting.
- (6) The components in h_s will be in consistent units.

CENTRIFUGAL PUMPS 141



Where h_d = Discharge head (in abs. press, and also Pressure in ft. of fluid) D = Static discharge head; h_c = exit loss at B.H_{fd} = Total discharge pipe friction loss and P_d = Pressure gauge reading.

Remarks: (1) For horizontal pump datum for suction and dischrarge in pump centre line.

- (2) For vertical pump, datum is centre line of discharge line.
- (3) For comparatively short discharge lines, friction loss will be 10-20% of static head.
- (4) Discharge head will be given by pump discharge gauge.
- (5) The components in h_{ρ} will be in consistent units.

PUMP IMPELLER TYPES

- A. Forward curved vane—Head increases as the delivery rate increases
- B. Backward curved vane—Head decreases as the through put increases.

The pump direction of rotation being clockwise (pump end). Suction and discharge heads of centrifugal pumps are given in Fig. 1 and Fig. 2.



INDUSTRIAL AND TOWN GASES

1. PRODUCER GAS

Producer gas is essentially a mix of CO and N_2 together with H_2 , CO_2 , CH_4 & O_2 which are present in small percentages. The gas is generated by blowing a mixture of air or air enriched with oxygen and steam through an incandescent bed of coal or coke or anthracite.

There are mainly two types of producer gas generators viz (i) Revolving body generator with fixed grate (exam. Wellman gas producer) and (ii) Fixed body gas generator with rotating grate.

A. Wellman Gas Producer

The rotating body is made of heat resistant steel and lined with refractory bricks. The ash is discharged by the ash pan, rotating type, with water seal at the bottom and a stationery water cooled top cover. An automatic water cooled poker is operated from top to keep the bed in uniform condition of heat. Coal is fed from top by a mechanical feeder valve.

Pressurised air blast at 10" W.G by a turbo blower is introduced into the generator through a bottom head. Both generator & ash pan rotate slowly and ash is discharged automatically by ploughs inserted in ash pan which dump it on the ash boxes. Steam at 0.3–0.5 lb/lb of coal or coke or anthracite is added to the air flow to (i) control of Clinker formation by increasing the air blast saturation and (ii) to raise H₂ rich gas by the water gas reaction. Major reactions in generator are.

$$(i) C + O_2 = CO_2$$

$$(ii) H2O + C = CO + H2$$

(iii)
$$C + 2H_2O = CO_2 + 2H_2$$

$$(iv) C + CO2 = 2CO$$

The producer gas temperature at exit is $1250 - 1500^{\circ}$ C and pressure 1" W.G. The fuel bed is divided into four zones viz

- (a) **Ash Zone.** It is just above the grate and the ash zone serves to preheat the incoming air blast from bottom.
- (b) **Oxidation Zone.** Above the ash zone is the oxidation zone which is about 6" thick. Here reaction (i) takes place and the temperature is highest due to combustion reaction. Steam in air helps to keep a lower temperature to prevent clinker formation. Heat released by combustion reaction must be sufficient to carry out endothermic reaction and compensate for heat losses by radiation. The temperature of oxidation zone is 1100–1200°C.

- (c) **Above the oxidation zone is the top reduction zone.** Primary and secondary zones which is practically extend upto top of the fuel bed. The reduction reactions (ii), (iii) and (iv) take place in reduction zone and absorb potential sensible heat in the producer gas. The reactions (ii) and (iv) are very fast as the gases enters the reduction zone. As the gases pass, CO_2 and steam content decreases due to endothermic reactions & temperature of bed must be over $800 900^{\circ}C$ as at this temperature these reactions stop.
- (d) **Top heating zone.** Here lies the freshly added charge of feed coal/coke/anthracite which is dried & heated up by the incoming gases from reduction zone to start reaction as it descends to reduction zone. If coal is used, it is carbonised to coke liberating tar and volatile matter as well as SO₂. Depending on sulphur present in coal, SO₂ removal may be necessary to recover from producer gas in subsequent purification stage. The bed temperature raises constantly apart from sensible and radiation heat losses.

B. Coppee Gas Producer

It has fixed cylindrical body with rotating water sealed ash pan at the bottom which rotates at the rate of 1 rev. in 10 minutes by a rack a pinion arrangement. There is no refractory brick in jacket boiler. Air blast is introduced along with steam from bottom of the grate to increase air blast saturation so as to generate more H_2 . Steam is generated from jacket waste heat boiler in annular space provided in the body of the generator. The thermal efficiency of this generator is more.

- **1.2 Quality of gas generated depends on** (i) air blast pressure (ii) air blast temperature (iii) fuel size and type of fuel used and its quantity (iv) ash fusion temperature of fuel and steam/air ratio.
- 1.3 Producer gas output is around 120 MCF/ton of coal and its composition is as follows

$$CO = 24-28\%$$
 (vol)
 $N_2 = 52-55$
 $H_2 = 11$
 $CH_4 = 0.5$
 $CO_2 = 4-5$

The gross calorific value is 1068–1335 Kcal/m³ and density about 1.16 Kg/m³

1.4 Specification of Fuels for Producer Gas

Coal. It should be low in sulphur 1–1.2%, low in ash content but higher ash fusion temperature. High volatile and weakly coking coals are preferable. The tar fog adds as much as 15 B.T.U/cft to calorific value.

Coke and anthracite – Suitable for clean producer gas.

Typical composition of producer gas when using different feed fuels is given in page 145.

1.5 Operation Problems

Maintaining correct depths of feed through out the fuel bed for uniform gas distribution so as to prevent channeling and hot spots which lower the efficiency resulting in lower gas quality. In coppee gas generator no clinker formation occurs due to low shell temperature of jacket boiler. Due to poor quality of coal, ash discharge in Wellman producer may be problem due to clinker formation. Ash pan seal water is taken to a settling pond, clear water from pond is recycled along with make up water. Gas temperature control from producer generator is important as a function of operation requirement.

$\mathbf{F}_{\mathbf{r}}$	ıel	٦	- 11	SP	A

Composition	Coal	Coke	Anthracite
CO	24–29%	24–30%	25–27%
Н	11–15	11–14	14–18
CH ₄	0.5–2	0.5	1.2
Hydrocarbons	2–3	3–5	4–6
Nitrogen	52–57	52–55	50–53
Net Cal. Value,	1156–1352	1125–1201	1221–1299
Kcal/m ³ at 60°F			
at 30"Hg			
Sp. gravity (air = 1	0.9	0.9	0.9

- **N.B.** 1. Air for complete combustion of producer gas and air mix (cold) is about 0.9 1.2 cft/cft of mix
 - 2. The net calorific value of above mix is 578 640 Kcal/m³ and is less than coal gas air mixture having net calorific net value of 818 845 kcl/m³.

1.6 Industrial Use of Producer Gas

Application	Type of fuel used	Type of producer gas used
Heating coke ovens	Coke	Cold and clean gas
Regenerative furnace for	Coal	Hot raw gas
steels and glasses etc. manufacture		
Heating retorts	Coke	Hot raw gas
Dilution for town gas supply with air	Coke	Cold and clean gas

1.7 Efficiency of Producer Gas Generators

BS-945 standard is normally used to determine the efficiency of producer gas generators as given below.

Cold gas efficiency =
$$\frac{\text{Potential heat of gas}}{\text{Total heat of fuel}} \times 100$$

Hot gas efficiency = $\frac{\text{Total heat of gas}}{\text{Total heat of fuel}} \times 100$

Total heat in the gas in the sum of potential heat calculated from gross and net calorific values plus sensible heat in the gas. All values are expressed as B.T.U/ton of dry fuel.

1.8 Gas Exit Temperature from Generator

This gives the gasification conditions in the generator. For example low gas exit temperature may be due to one or more parameters as stated below.

- (i) Fuel bed too thick
- (ii) Wet fuel
- (iii) Low gasification rate

- (iv) Body surface temperature is too high (normal 50°C)
- On the other hand a high gas exit temperature indicates.
- (i) Fuel bed too thin or non-uniform fuel bed
- (ii) Channeling of hot gases in the bed with localized hot spots
- (iii) Producer gas is burning at the top
- (iv) Ash zone is non even
- (v) High gasification rate due to decrease in fuel cross sectional area because of the accumulation of clinker on sides and closing of air blast ports by clinker
 - (vi) Body surface temperature is too low (normal range is about 50°)

1.9 Cleaning of Producer Gas

When coke or anthracite is used, only water cooling in a packed tower is required followed by filtration in filter boxes packed with wood shaving and wood wool.

The filtering media may be mixed with iron oxide catalyst if H_2S is present in producer gas generator from coke or anthracite. The washing tower is packed with 1-2" coke or lumps and water is sprayed from top which cools the producer gas by a adiabatic cooling due to evaporation of scrubbing water. The water removes dust particles from gas entering at the bottom of washing tower and the water dust mix then flows into a settling pond where m.u water is added and recirculated.

2. SLAGGING ASH PRODUCER

The ash is converted to molten slag due to intense heat generated using air enriched with oxygen, in up run period. The fuel bed is deeper than conventional process and gasification rate is higher, 500 lb/sft. Temperature control is effected by adding limestone or BF slag along with coke charge. The operational problems are more due to molten slag, sticking on acid bricks refractory, causing choking.

3. WATER GAS OR BLUE WATER GAS

Water gas is primarily a mixture of CO and H_2 together other small quantities of gases viz CO_2 , N_2 and CH_4 . The gas is made by passing steam on a bed of red hot coke.

3.1 The water gas generator consists of a tall vertical cylindrical vessel made of steel. The vessel is lined with refractory bricks, except in jacket boiler portion, where insulating bricks do not insulate it. A rotating grate is provided at the bottom, which continuously removes ash into the ash box. Air and steam is passed alternatively from bottom to the red hot bed and blow gas and water gas are obtained respectively from top of generator. The reaction with steam is as follows.

$$C + H_2O \longrightarrow CO + H_2 \Delta H = 52110 BTU/mole$$
 ...(1)

$$C + 2H_2O \longrightarrow CO_2 + 2H_2 \Delta H = 35420 \text{ BTU/mole}$$
 ...(2)

The steam run is done, consequently, in both up and down directions through the red hot bed and water gas is collected alternatively from top and bottom of generator, followed by air up run, when the oxidation gases are vented to the atmosphere.

The reactions during air run are.

$$C + O_2 = CO_2 \qquad \dots (3)$$

$$CO_2 + C = 2CO$$
 ...(4)

The total cycle of operation lasts for 2.5–5 mins. The valves at the water gas off take lines at top and bottom of the generator, air valve, exhaust gases valve, steam valves for up and down run, and rotary coke feeders valves are operated automatically through hydraulic devices. Run with steam after air run with off gasses purged to vent, is also done in automatic sequence. LP waste heat boiler steam is used for steam run; bed temperature during air run is 1100–1200°C. The bed temperature comes down to 800–900°C during steam runs because of endothemic reactions (i) and (ii) The exit water gas after seal box can be scrubbed with water and gas stored in gas holder. The dust laden scrubbing water, after settling in a pond, is released with m.u water addition.

3.2 Composition of Water Gas

$$H_2$$
 ----- = 45.51% (vol)
 CO ----- = 45.40%
 CO_2 ----- = 3 - 6
 N_2 ----- = 3 - 7
 CH_4 ----- = 0.1 - 0.5

The water gas burns with a blue flame. The net calorific value is 2580–2758 Kcal/m³.

Sp. gravity
$$(air - 1) = 0.55$$

Theoretical bed temperature = 1900°C during air run

Actual bed temperature varies from 1100 - 1200°C during air run.

Factors for the quality generation of water gas are, quality of coke or anthracite, clinker removal efficiency, volatile matter & sulphur content of fuel and $\rm O_2$ enrichment of air can be avoided. The cycle timing is to be judiciously set.

The thermal efficiency of water gas generator is of the order of 60%.

3.3 Uses of Water Gas

It is used in furnace operations when rapid heating is required. It is also a source of $\rm H_2$ gas. The gas burns with a blue flame due to CO content.

4. CARBURETED WATER OR TOWN GAS

Here the water gas is enriched with hydrocarbon oil vapours (Diesel). The generator is similar to water gas generator and water gas generated and oil vapour from a separate carburator, is mixed with water gas followed by some cracking of some oil vapour in the super heater. Heat is supplied by burning some oil vapour in carburator as well as in super heater.

In the carburator, preheated diesel oil is vaporised @ 2 US gallons per 1000 cft of carbureted water gas which is generated by a water cooled burner at the top. Some cracking of oil also takes place in the carburator whose temperature varies from 600–1000°C. The remaining cracking of oil vapour takes place in super heater, filled with chequer work. The gas leaves the super heater at about 800°C. The heat required for cracking is generated by combustion of some oil in the super heater

and also by blow gas during the blow period so as to raise the temperature of carburator and super heater. Super heater top temperature is 650°C and bottom temperature is about 800–900°C. The outgoing gas is cleaned by water cooling in a scrubber and stored.

The composition of carbureted water gas is.

$$H_2 = 37\%$$
 (vol)
 $CH_4 = 14$
Ethane etc.
 $CO = 30.5$
 $C_nH_m = 7$
 $CO_2 = 5.6$
 $N_2 = 5.5$
Oxygen = 0.4

The gross calorific value is 4450 Kcal/m³ and net calorific value is 4075 Kcal/m³.

Sp. gravity (air = 1) is 0.63. The overall thermal efficiency is 80%.

Use of Carbureted water gas.

It is mainly used as a town gas for domestic consumption.

4.1 Semi Water Gas

It contains almost equal concentrations of H_2 and CO more than those in water gas or B.W.G to suit ammonia synthesis gas generation (H_2 and N_2 in the ratio of 3:1). The gas generator is with jacket boiler and rotating ash grate. The coke feed mechanism is done by automatic system and reversing mechanism, by hydraulic controller like those of water gas generator. This has up run period with auxiliary air to suit the production of necessary N_2 for ammonia synthesis after purification and CO conversion. The composition of the gas is as below.

$$H_2 = 34.2\%$$
 (vol.)
 $CO = 36.1$
 $CO_2 = 7.4$
 $N_2 = 21.5$
 $CH_4 = 0.8$
 $H_2S = 0.03$
 $Coke/cft\ SWG = 1.3 - 1.4\ kg$
 $Calorific\ value = 1700\ Kcal/m^3$

Coke used is about 4" size. Cold gas efficiency = 65%.

The cycle of operation of the generator proceeds in the following sequence as per hydraulic controller.

- (a) Blow run Primary air is blown up from bottom to bring up the temperature of bed to red-hot. The combustion gases are vented through stack.
- (b) Up run steam Preheated auxiliary air along with L.P steam is blown from bottom & semi-water gas is collected from top of the generator. Reactions;

$$C + H_2O \longrightarrow CO + H_2$$
 ...(i)

$$C + 2H_2O \longrightarrow CO_2 + 2H_2$$
 ...(ii)

$$CO_2 + C \longrightarrow 2CO$$
 ...(iii)

Reaction (i) is very rapid and stops when bed temperature is reduced to 800-900°C.

- (c) Down run steam Here L.P stem is blown downwards and semi-water gas is collected from bottom.
- (d) Final up run. Primary air is blown from bottom to remove remaining CO, $\rm H_2$ etc. and vented to atmosphere, as well as raising bed temperature uniformly. Ash from slow moving rotating grate is discharged into ash boxes from where it is periodically removed. The sequence time varies between 3–5 mins. The primary air, auxiliary air, steam change over and vent stack valves are opened and closed as per operation sequence by hydraulically controlled automatic controller, working at 850 950 psi through cam action, which controls power cylinder operation, attached to each value for the operation sequence.

The exit gas at 550 - 650°C from generator is passed through a water seal box and then washed in a Lymn washer tower with 0.7% Sodium Carbonate soln., which removes dust and cools the gas. The dust laden wash water is passed into a settling pond, which removes ash dust and top water is sent to a cooling tower after adding make up water and re-circulated. The hy. oil controller consists of power cylinder, double restriction value, throttle valve and interlock control valve.

For the production of ammonia synthesis gas, the water gas is passed through series of Iron oxide catalyst boxes, mixed with wood shavings when H₂S is absorbed and stored in gas holder.

The water gas for ammonia production is then treated in 2 stage shift reactors for CO removal in primary and secondary rectors so as to get ammonia synthesis gas with little CO, which is removed in ammonia plant. The CO conversion catalyst contains $Fe_2O_3 = 93.3\%$, $Cr_2O_3 = 3 - 8\%$, $K_2O = 2.07\%$ & $Al_2O_3 = 0.8\%$.

Semi water gas is exclusively used for the production of ammonia synthesis gas.

5.0 BLAST FURNACE GAS. (B.F)

About 60% of the heat in coke comes out in the exit gases from a Blast fumace during pig iron production. This gas is called blast furnace gas and has the composition as follows.

$$CO = 27\%$$
 (vol)
 $H_2 = 2$
 $CO_2 = 11$
 $N_2 = 60$

The net calorific value of the gas is 800–934 kcal/m³. Out of total heat available in B.F gas upto 80% heat is utillized in the steel plant and remaining 20% of the total heat is available as surplus, which is generally used in coke oven battery; heating boilers, reheating stoves etc.

5.1 Cleaning of the B.F. gas

The dust, associated with B.F gas, consists of mainly coke, iron oxide and lime. The conc. of heavy dust can be 1000 gms/100 cft and that of fine dust (< 5 μ) is 5 gms/100 cft. Less vigorous cleaning of gas is required for use in L.P boilers and reheating stoves.

There are two processes for dust cleaning.

Dry process: The gas from down comers of blast furnace is taken into a dust settling chamber where heavier dust particles settle down and conc. of dust is reduced to 10–100 grains/100 ft³.

The gas is then filtered in automatic bag filters and dust conc. is further reduced to 1 grain/ 100 cft.

Wet process: The gas from the blast furnace is scrubbed with low and high pressure sprays in a water scrubbers fitted with baffles and cross partitions followed by separation of entrained water droplets from saturated gas in an electrostatic precipitator. Water requirement for sprays is 24 US gallons/100 ft³. The scrubbed water slurry is thickened in a thickener and the clear water is recirculated after make up water addition.

6.0 COAL GAS

Coal gas is produced from H.T., LT and CVR carbonisation of coal for the production of coke. Coal gas by H.T coal carbonization process.

Crushed bituminious coal to 3 mm size is fed to silica brick lined particular oven of the coke oven battery by larrycar as per charging and discharge series of coke ovens. The top cover of the oven is replaced on the top of the oven and heating of coke oven is started through about 31 flues (depending on capacity) on each side by coke oven gas from both sides of the oven. At the end of 15–16 hrs of combustion, the temperature inside the oven reached to $1100-1200^{\circ}$ C which is the temperature for H.T carbonization of coal. The typical size of each oven, length between doors \pm 12900 mm. width 345–375 mm and height = 3100 mm for a 30 oven standard battery. The width of oven gives the carbonisation time approximaely @ 1 hr per 25 mm.

Coke oven gas comes out of the ovens at $600-800^{\circ}$ C and is cooled to $80-90^{\circ}$ C by spray of self produced ammonia liquor in the hydraulic main when major portion of tar is condensed and gas and liquor are separated in the separating box. From the separating box tar is sent to storage and ammonia liquor neutralised with sulphuric acid to produce ammonium sulphate by crystallisation and is separated by centrifuging.

Coke oven gas then enters the primary cooler when remaining tar and some naphthalene separate out. The gas is then pressurised in a centrifugal blower which, after cooling and tar separation in a tar catcher; the coke oven gas is then scrubbed in ammonia scrubbers, packed with R/R.

After separation of ammonia, the gas is sent to benzol tower where it is washed with regenerated wash oil, which is sent for recovery of coal carbonisation products. The gas after benzol recovery is sent for coke oven heating or synthesis gas making or any other heating requirement.

After carbonisation, red hot coke is pushed out of oven by combined stamping by ram pusher machine including door lifting mechanism. The red hot coke is pushed to a quenching car and taken to a quenching tower where it is cooled by spraying water and coke discharged to wharf.

6.1 Coal Specification

F. Carbon = 51% (vol) by diff. V.m = 27Moisture = 4 Ash = 17Sulphur = 0.7 Calorific value of coal is about 6300 Kcal/kg

Coal per ton of coke = 1.5-4 MT/MT coke

Coke oven gas composition.

 $H_2 = 55.7\%$ (vol) CO = 5.4 $CH_4 = 24.0$ $C_{n}H_{m} = 1.6$ $CO_2 = 2.2$ $N_2 = 5.3$

 $O_2 = 0.4$

 $H_2S = 2.3 \text{ gm/NM}^3$

Coal gas output = $265 \text{ NM}^3/\text{MT}$ coal

The net calorific value = 4029 Kcal/m^3

The density of coal gas (air = 1) = 0.49

Analysis of coke.

Moisture = 4.5%

Ash = 23 - 24

V.m = 1.5 - 2

Sulphur = 0.5

F.C = 73 - 74 (by diff.)

Ash fusion temperature = 1350 - 1410°C

Calorific value of coke = 5890 Kcal/kg

Crude Benzol output = 12.0 lit/MT of coal

Coal tar output = 3.5% of coal carbonized.

Uses of Coke

Gas coke from less coking coal or blends is used for gas generation viz water gas, town gas etc. Met. coke is used in metallurgy. Met. coke is less combustible than gas coke.

7. NATURAL GAS

Natural gas is obtained is association with crude oil from oil wells (it is also available from gas wells). After separation of crude oil in a series of separators, natural gas is transported through pipe lines after compression to desired level in NG fired gas engines coupled to NG compressors. Usually oil companies use a battery of such NG compressors.

The quality of NG depends on the type and location of source. Usually it contains mainly methane (CH₄), associated higher HC viz ethane (C_2H_6) (alkanes), Propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}) and hexane (C_6H_{14}) , together with Nitrogen, CO_2 and sulphur compounds (ppm level).

Raw natural gas is usually stripped of alkanes upto butane & propane for production of Liquified Petroleum Gas (LPG) for mainly domestic use by low temperature gas fractionation process while pentane is separated from N.G by absorption in a solvent. Analysis of treated N.G is as follows.

$$CH_4 = 85-91\%$$
 $C_2H_6 = 6.3$
 $C_3H_8 = 1.15$
 $CO_2 \& N_2 = 1.55$
 $Sulphur = 20 ppm$

The net calorific value of N.G. is 9001 Kcal/NM³. Natural gas is used either as a fuel or as a source of hydrogen; when propane and butane are not separated from NG it is called associated gas.

- (i) Natural gas thus stipped of LPG constituents & Pentane content, can be liquefied to facilitate transportation by ocean going refrigerated bulk carriers as liquefied natural gas which is then stored in shore based refrigerated liquid NG storage facilities in destination country where it can be regasified to natural gas for use mainly as a fuel or other uses. Alkanes upto butane (C_4H_{10}) is gaseous, pentane (from C_5H_{12} to $C_{16}H_{34}$) are liquids upto $20^{\circ}C$ and the rest are solids.
 - (ii) Liquification of natural gas for LNG.

Because of high critical pressure (47.3 kp/cm²) of methane, liquification of natural gas by usual compression and cooling method is difficult and uneconomic.

The critical temperature of methane is -82.5° C and B.P and heat of evaporation are -164° C (at 760 Torr) and 121.9 Kcal/Kg respectively.

There are few processes for LNG manufacture described elsewhere in this book.

(iii) Typical analysis of associated NG without LPG extraction (Upper Assam)

$${\rm CH_4}=77.9\% \ \ ({\rm vol})$$
 ${\rm C_2H_6}=9.38$ ${\rm C_3H_8}=6.01$ ${\rm C_4H_{10}}=2.75$ ${\rm C_5H_{12}}=0.69$ ${\rm N_2}=0.42$ ${\rm CO_2}=2.85$ Specific gravity = 0.739 Mol. Weight = 21.43 NCV Kcal/nm³ = 10484.

PHYSICAL DATA/GRAPHS

Calculation of Calorific Values or Solid Fuel for bituminous coals containing 5-45% volatile matter

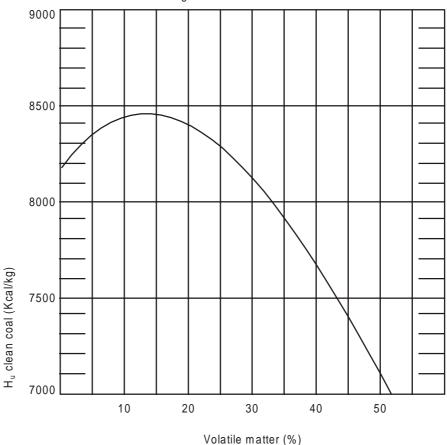


Fig. l. Graph for calculation of calorific values of solid fuels.

$$H_{ij}$$
 clean = 8150 + 38.83 (A + W) - 1.1806 (A + W)²

A ash content, %

W water content, %

$$\frac{100 - (A + W)}{100} \times \text{volatile matter of clean coal} = \text{volatile matter of raw coal.}$$

Conversion of gross into net calorific value H_0 into H_a (raw coal) for solid and liquid fuels.

$$H_{u raw} = H_{O raw} - 5.85 (0.09 H + W) kcal/kg. (H = hydrogen content. %)$$

When the moisture content alters from w₁ to w₂ the net calorific value (raw coal) becomes

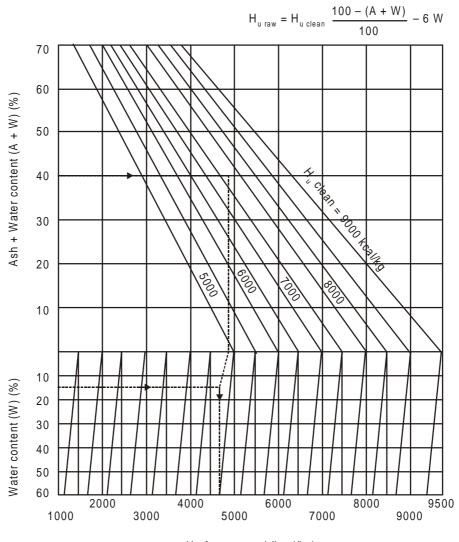
$$Hu_2 = (Hu_1 \, + \, 6 \, \, w_1) \, \, \frac{100 \, - A_2 - W_2}{100 - A_1 - W_1} \, - \, 6W_2 \, \, ; \, \, A_2 = \, \, A_1 \frac{100 - W_2}{100 - W_1}$$

For coke, $H_{u clean} = 7,950 \text{ kcal/kg}$

For wood and wood shavings, H_{ij} raw = 4.950–51.9 W

Source: Borsig pocket book 3rd edn. 1970.

Net calorific values Hu (kcal/kg) of Clean and Raw Coal



Hu for raw coal (kcal/kg)

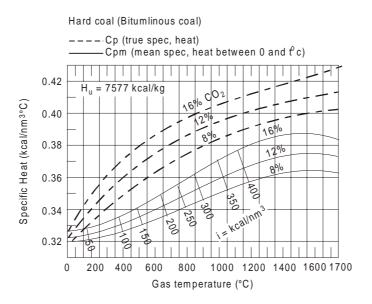
Fig. 2. Graph for net calorific values of clean and raw coal.

Example: For bituminous coal with H_u clean = 7750 kal/kg, A=25% and

W=15% (so that A + W = 40%) we obtain $\boldsymbol{H}_{u\;raw}=4,\!560$ kcal/kg

Note: $H_u = net \ calorific \ value \ (H_o = gross \ calorific \ value).$

Source: Borsig pocket book 3rd edn. 1970.



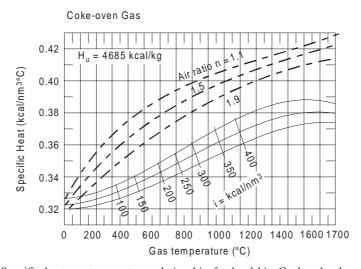
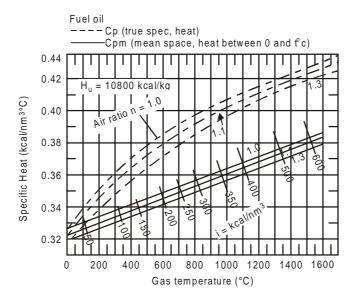


Fig. 3. Specific heat-gas temperature relationship for hard bit. Coal and coke oven gas. **Source :** Justi, E, Specific Heat, Enthalpy, Entropy and Dissociation of Industrial gases, © Springer Verlag 1938.



Natural Gas

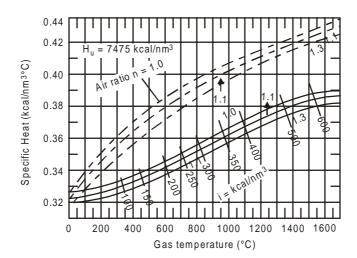


Fig. 4. Specific heat-gas temperature relationship for fuel oil and natural gas.

Source: justi, E, Specific Heat, Enthalpy, Entropy and Dissociation of industrial gases © Springer-Verlag.

Specific air and flue gas volumes for hard (Bituminous) and soft (Brown) Coal

The graph is valid with a mean ash content A of 6% and mean CO_2 Max 18.9%. If A 76% the value taken from the diagram must be reduced by a correction factor K as follows: spec. air volume V_{LO} by $K = \frac{A-6}{169}$ and spec flue gas volume V_{G} by $K = \frac{A-6}{169}$ [3 + (n-1)]. When A < 6% the same value are used for calculation The curves are not valid for coke, wood peat.

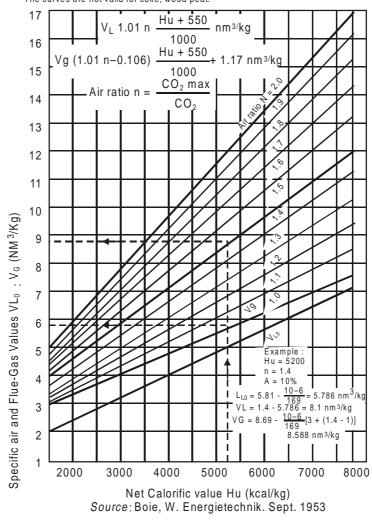
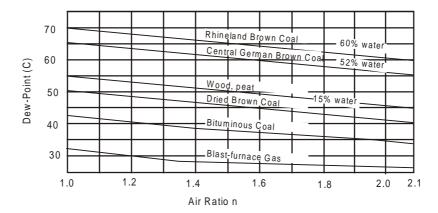


Fig. 5 Specific air and flue gas volumes for hard bit and soft (brown) coal.

Dew-point temperature of flue-gases

The graph below shows the flue-gas dew-point temperatures of various fuels, only steam (water vapour) condensation being taken into account. The values are based on an 80 % relative humidity of the furnace air at 20° C



Where sulphur is present in the fuel, the dew-point is considerably affected by the combustion of the sulphur contained in the flue- gases. The diagram which show the dew-point temperature for different sulphur-content values in the fuel-oil.

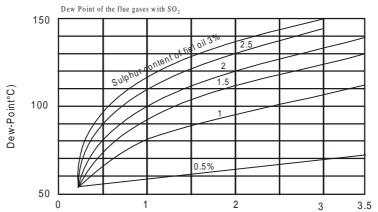


Fig. 6. Dew point temperature of flue gas for various solid fuels/ B F gas and sulphur bearing flue gases from fuel oils.

Source for water dew-point: Gum z, fuel and firing technology, Springer Verlang 1962 © source for acid dew-point: Glaubitz, VGB-Heft 68.1960.



LNG PRODUCTION

- 1. Because of high critical pressure of methane, liquified natural gas LNG cannot be produced by compression and cooling economically. The critical pressure and temperature of methane are 47.3 Kp/cm² and -82.5°C respectively and B.P and heat of evaporation being -164°C (at 760 Torr) and 121.9 kcal/Kg. LNG is produced by cryogenic process.
- 2. Pretreatment of natural gas mainly methane, mixed with other paraffins, is necessary to remove sulphur compounds and other components that would either freeze out, thus restricting the flow of natural gas, or will lead to pollution upon combustion after reevaporation of L N G.

3. N G liquefaction processes.

The commonly used processes are (a) Baseload liquefaction process and (b) Cascade Process of cooling using three refrigeration loops of propane (B.P = -44.5°C at 760 Torr), ethylene (B.P = -103.9°C at 760 Torr) and methane (B.P = -164°C at 760 Torr).

- 3.1 In base load liquefaction process, heat is to be removed from N G to cool it to -160° C by rejecting heat to atmosphere or water. This is an efficient process suitable for large scale L N G production.
- **3.2** In cascade liquefaction process using 3 refrigerant loops of propane, ethylene and methane, each refrigerant supplies refrigeration at discrete temp level. This process has nine stage refrigeration.

Physical data for propane, ethylene and methane are as follows.

		Critical temp °C	Critical press Kp/cm ²	B. P °C	Heat of evaporation Kcal/kg
Propane	:	96.8	43.5	-44.5	101.8
Ethylene	:	9.5	51.7	-103.9	125
Methane		-82.5	47.3	-164	121.9

4. CASCADE PROCESS

Cascade process of refrigeration uses separate loops and suitable refrigerant for each loop. The refrigerant in L.P circuit is condensed by evaporating next higher temperature (B.P) circuit refrigerant in the cascade evaporating cooler or in other words, the refrigerating effect of higher temperature (BP) circuit is used to remove heat of condensation from lower temperature (B.P) circuit. In short, only the cascade evaporating cooler with lowest evaporating temperature generates the reqd. refrigerating effect.

In natural gas liquefaction, three temperature (B.P) levels form nine cascades using three refrigerant cycles of propane, ethylene and methane, each of three stages. The methane refrigeration loop is open due to the fact that it is combined with N.G feed and after final let down in flash vessels liqued methane forms part of LNG production. The flowsheet is given in Fig 1.

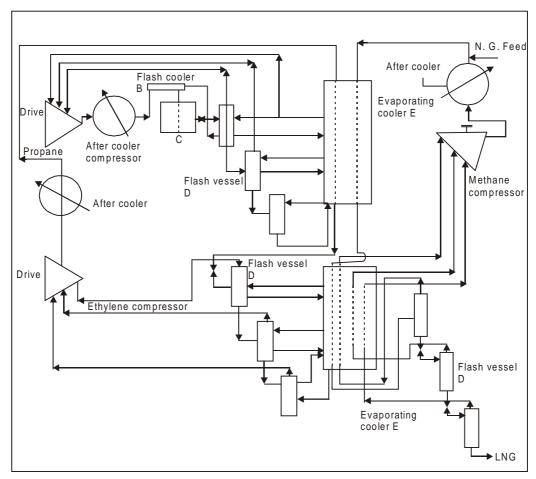


Fig. 1 Cascade Process for LNG Production.

Each of these three temperature levels (B.P) corresponds to preset pressure let down in flash vessels (D) for evaporating the refrigerant in heat exchange with N.G feed and separate propane refrigerant stream in propane evaporating cooler (E) and then to ethylene evaporating cooler (E). In this process heat is removed from NG at successively lower temperature and heat is rejected to cooling water or air via warmest refrigerants, generally propane and after compressions and after flash cooling (B), liq propane refrigerant is stored in tank (c) and compressed ethylene gas, after water cooling, is sent to propane evaporator for cooling, followed by cooling and condensation in ethylene evaporator cooler (E).

After ethylene evaporator, N.G is condensed and after flashing in flash vessels (D) temperature of liquid N.G falls, liquified and separated and stored in refrigerator vessels. The evaporated N.G from flash vessels is recycled via ethylene evaporator cooler and is fed to methane compressor suction, compressed and after cooling, N.G meets the make up N.G. stream and the process goes on.

LNG PRODUCTION 161

Liq. N.G is transported by refrigerator tanker or trucks. For transportation by ships, N.G is unloaded in on-shore refrigerated LNG storage tanks; from where it is evaporated by steam heating and NG is distributed to end users through pipe lines.

Processing N.G before LNG Production

Natural gas is freed from CO₂, moisture and if sulphur is present and it is to be sweetened.

	Sp. enthalpy of evaporation	Volumetric refrigerating		
	at std B.P. kj/kg	effect at -15° C to $+30^{\circ}$ C kg/m ³		
Propane	439	2238		
Ethylene	48	1995		

5. STORAGE OF LNG

Double integrity tank with suspended inner tank of concrete lined inside with S.S is used. Lining material is 9% Nickel and 5000 series Al metal.

6. LNG DATA

- (i) 0.035 m^3 at 111 °K is derived from 18 m³ of LNG. Storage temperature of LNG is 170°K at 2.24 Mpa (325 PSIA).
- (ii) Heat of vapourisation of LNG is 232 $\rm Mj/m^3$ of LNG at 0.1 Mpa. Heat required for regasification of LNG is 0.3 $\rm KJ/m^3$ of gaseous NG.



PRODUCTS MANUFACTURED FROM BENZENE, ETHYL BENZENE, ETHYLENE, ETHYLENE OXIDE, ETHANOL AND OTHERS

A. PRODUCTS MANUFACTURED USING BENZENE AS RAW MATERIAL

FKO	DUCIS MANUFACTO	KLD	USING BENZENE AS NAW WATEN
1.	Styrene	\rightarrow	Polystyrene A B S resin S B R / Latex Polyester resins SAN resin
2.	Cyclohexane ↓ Cyclohexanol Caprolactum	\rightarrow	Adipic acid \rightarrow Hexamethylenediamine \downarrow Caprolactum \rightarrow Nylon
3.	Cumene	\rightarrow	Phenol → Bisphenol A Acetone → Methyl metha-crylate Cellulose acetate (adsorbent) Methyl isobulyl ketone Methyl Phenyl ketone Aldol chemicals (Hexamethylene glycol)
4.	Nitrobenzene	\rightarrow	Aniline → Aniline isocynate ↓ Polyester resin
5.	Malic anhydride	\rightarrow	Polyester resins
6.	Chlorobenzene ↓ Phenol	\rightarrow	$DDT \rightarrow Insecticides$
7.	Anthraquinone	\rightarrow	Dyes

- 8. Dichlorobenzene → hexachlorobenzene (BHC)
- 9. Dodecyl benzene (for detergent use)
- Benzene Sulphonic acid 10.
- 11. Glyoxal
- 12. Benzaldehyde
- 13. Propyl benzene → Isopropyl benzene
- Lindane (Y isomer of BHC) 14.

B. ALCOHOL, C2H5OH (ETHANOL) GRADES

Purity % Vol.

(i) Industrial alcohol 96.5 (ii) Denatured* alcohol 88

(with methanol)

(iii) Fine alcohol (Pharma use) = 96–96.5 (iv) Potable alcohol = 43 (v) Absolute alcohol or rectified spirit 99.7-99.8

=

(vi) Gasol (Gasoline with alcohol) 98% gasoline with 2% alcohol*

*Gasol also used in some south American countries with Methanol in the proportion of 2.5-5% methanol and rest gasoline.

"Proof" of Alcohol

U.K : Proof 87.7 equals 50% concentration at 10°C.

U.S.A.: Concentration is $\frac{1}{2}$ of proof at 15°C.

N.B. Indian whisky is 75° proof (42.8% conc.)

C. PRODUCTS MANUFACTURED USING ETHANOL AS RAW MATERIAL

- 1. Vinegar
- 2. Acetaldehyde/Acetic acid
- 3. Ethyl acetate
- 4. Ethyl chloride/bromide
- 5. Other Ethyl esters
- 6. Ethyl amines (for rubber processing)
- 7. Sodium ethoxide
- 8. Acetic anhydride
- 9. Dyes and intermediates
- 10. Diethyl ether
- 11. Glycol diethylethers and others
- 12. Xanthenes
- 13. Drugs and medicinal chemicals
- 14. Organo-silicon products
- 15. Synthetic resins

D. ETHYLENE OXIDE IS USED FOR THE PRODUCTION OF :

- (i) Methyl hexanol \rightarrow Defoaming/wetting agents and plasticiser
- (ii) Penta erythritol \rightarrow Alkyd resins, explosives, Moulding powder
- (iii) Trimethyl propane → Alkyd coalings, lube oil additive, Textile finishes & Urethane foam
- (iv) Acetic acid \rightarrow Acetic anhydride, \rightarrow Aspirin, Vinyl acetate, Cellulose acetate.
 - → Acetyl Chloride → Organic synthesis and dye. Chloroacetic acid → Sod. carboxy methyl cellulose, ethyl acetate, Thioglycolic acid herbicides.
 - → Cellulose acetate
 - \rightarrow Acetate salts \rightarrow Flavours, perfumes and solvents.
 - \rightarrow Vinyl acetate \rightarrow PVC acetate and Poly Vinyl acetate.
- (v) Per Acetic acid \rightarrow Bactericide, Bleaching agent, Fungicide, Organic Synthesis, Polymerisation and Catalysts.
- 3. Ethylene dibromide → Dyes, Fumigant, medicines, Tetra ethyl lead (scavengers)
- 4. Diethyl Ketone \rightarrow Solvents.
- 5. Polyethylene → Electrical Cables, Pipes, fittings, containers, etc, monofilament film and sheet moulding powder and granules.
- 6. Mono, di-and Tri Ethanol amines.
- 7. Vinyl toluene \rightarrow Surface coatings.
- 8. Ethyl alcohol \rightarrow Acetaldehyde, ethyl ether, chloroform, Dimethyl amine, ethyl acetate, Ethyl bromide Ethylene dibromide, glycol ethers.
- 9. Ethyl Chloride \rightarrow Anaesthetics, Ethyl cellulose, TEL.

E. ETHYLENE DICHLORIDE

- → Ethylene diamine, adhesive, Corrosion inhibitors, rubber latex stabilisers and Textile lubricant.
- → Agri-fumigant, vinyl chloride
- \rightarrow Fibres, plastics.
- \rightarrow Tichloro ethane \rightarrow Vinyl iodine chloride \rightarrow fibres, filaments and plastics.
- → Ethylene amine → Tri ethylene di-amine, Urathane foam, Catalyst. Flocculant, pesticides, and surface active agent.
- → Poly ethylene amines, → Adhesive corrosion inhibitors, paper processing and deemulsifiers
- 10. D E A \rightarrow Formalin.

F. PRODUCTS FROM ETHYLENE PRODUCED FROM NAPHTHA

- 1. Ethyl benzene
- 2. Ethylene Oxide

- 3. Ethylene dibromide
- 4. Diethyl toluene (Solvent)
- 5. Poly ethylene (Plastics)
- 6. Ethyl alcohol
- 7. Ethyl chloride
- 8. Ethylene dichloride
- 9. Ethylene amine

G. PRODUCTS FROM ETHYL BENZENE

1. Acetophenone \rightarrow Perfumes

Pharmaceuticals

Solvent

2. Benzoic acid \rightarrow Benzyl benzoate

Phenol

Sodium benzoate

Plasticizers Perfumes

Flavouring chemicals

Pharmaceuticals

3. Styrene \rightarrow Polystyrene (Plastics)

S B R rubber

Chlorostyrene → Flame retardant resins

Alkyd Polyester resins

SAN (Plastics)

Styrenated oils

4. Diethyl benzene \rightarrow Drying oils

Elastomers

Resins

5. Ethyl anthraquinone \rightarrow H₂O₂ \rightarrow Peroxide chemicals as bleaching agent

6. Ethylene Oxide \rightarrow Nonionic detergent

Polyester (Dacron)

Ethyl Glycol (antifreezing agent)

As solvent for quick drying varnishes and enamels

7. Ethylene dibromide \rightarrow Dyes

Fumigant

Pharmaceuticals

Tetraethyl lead (TEL) scavenger

8. Ethyl alcohol \rightarrow Hard drinks

Acetaldehyde

Ethyl ether

Chloroform

Diethyl amine

Ethyl acetate

Ethyl bromide

Ethyl chloride → Ethyl cellulose

Ethylene dibromide.

Glycol ether

9. Ethylene dichloride → Ethylene diamine

Vinyl chloride \rightarrow PVC

Fumigant

Tetrachloromethane → Chloride, vinyldine

10. Ethyleneimine Triethylene diamine

Urethane foam Flocculant Plasticizers

Surface active agent Polyethylene amines

11. Acetaldehyde → Acetic acid → Acetic anhydride

Acetyl chloride (Dye) Chloroacetic acid Cellulose acetate Vinyl acatate

PVA

Acetate esters

(Flavour, Perfume and solvents)

12. Chloroacetic acid → Herbicides

Sod. carboxy cellulose

Ethyl acetate

Thio glycolic acid

13. Ethylene diamine \rightarrow Adhesive

Corrosion inhibitors

Stabilising agent for rubber latex,

Textile lubricant

14. Polyethylene amines \rightarrow Demulsifying agents, adhesive

corrosion inhibitor and paper work



SYNTHETIC IRON OXIDE PIGMENT

Five type of pigments from synthetic iron oxide can be made with varying tints of red, yellow, orange, violet and red.

A. Manufacture of Iron Oxide Pigments by Roasting Process

Synthetic iron oxide is prepared by (i) roasting iron pyrites for 4 hrs. at 600°C, (ii) roasting ferrous sulphate for 9 hrs. at 700°C and (iii) Ammon. ferrous sulphate at 700°C and then further roasting for 3 hrs at 100°C and calcining α Fe₂O₃ (red haematite ore).

Various colours of synthetic iron oxide can be made by roasting hydrated Ferrous Sulphate salt mixed with other salts for use as pigments. It is also made by calcining $\alpha \operatorname{Fe_2O_3}$.

- (a) Zinc and Al. sulphate gives orange-red colour.
- (b) Calcining $FeSO_4$ at lowest possible temperature gives dull red colour. Two stage calcination gives brighter colour and by product Na_2SO_4 can be made by absorbing SO_2 gases in soda solution.
- (c) Calcining FeSO₄ with Mn salts at higher temperature gives blood red colour to darker colours.

Reactions:

$$\begin{split} \operatorname{FeS}_2 + 2\operatorname{H}_2\operatorname{O} + 7\operatorname{O}_2 & \xrightarrow{\operatorname{Heat}} \operatorname{FeSO}_4 + \operatorname{H}_2\operatorname{SO}_4 \\ & 2\operatorname{FeSO}_4 & \xrightarrow{\operatorname{Calcining}} \operatorname{Fe}_2\operatorname{O}_3 + \operatorname{SO}_2 + \operatorname{SO}_3 \\ & \operatorname{FeSO}_4\operatorname{H}_2\operatorname{O} & \xrightarrow{\operatorname{FeSO}_4} \operatorname{H}_2\operatorname{O} + \operatorname{6H}_2\operatorname{O} \\ & \operatorname{6FeSO}_4\operatorname{H}_2\operatorname{O} & \xrightarrow{\operatorname{Heat}} \operatorname{650^\circ\operatorname{C}} \to \operatorname{2Fe}_2\operatorname{O}_3 + \operatorname{Fe}_2(\operatorname{SO}_4)_3 + \operatorname{6H}_2\operatorname{O} + \operatorname{3SO}_2 \\ & \operatorname{Fe}_2(\operatorname{SO}_4)_3 & \xrightarrow{} \operatorname{Fe}_2\operatorname{O}_3 + \operatorname{3SO}_3. \end{split}$$

Ferrous sulphate is usually made from pickling of iron scraps with sulphuric acid and crystalising salt:

$$Fe + H_2SO_4 = Fe_2O_4 + H_2$$
.

Heating of Ferrous Sulphate in presence of air:

$$6FeSO_4H_2O + 3/2 O_2 - 3Fe_2O_3 + 6SO_3 + 6H_2O.$$

B. Manufacture of synthetic iron oxide pigments having soft pure colours is done by precipitation and hydrolysis process

Precipitation process gives soft pigments with bright hue. The process consists of removing excess pickling $\mathrm{H_2SO_4}$ in mother liquor, left after acid pickling of iron scrap. The liquor is neutralised with scrap iron. The solution of iron salt (FeSO₄) is then mixed with NaOH in an open seed reaction vessel with oxidation by air at a temperature of 20–25°C. Alkali is used in such a way that the solution remains acidic pH. The reaction time is 10–100 hrs. depending on temperature, kept (10–90°C), and desired crystal size of FeSO₄7H₂O is achieved. The precipitate is yellow pigment (α -FeOOH-Ferrous Oxy Hydroxide) which along with the mother liquor is taken either to a pigment reactor or a tank, with scrap basket for further neutralisation of acid.

If precipitation is carried out at 90°C in pigment reactor, with air oxidation at pH > 7, black iron oxide pigment is obtained with a magnetic structure and reaction is stopped at Feo/ $F_2O_3 = 1:1$.

The exit pigment slurry is filtered in a centrifuge, dried in a furnace and ground in a mill grinder and further dried in a barrel dryer. Total processing time can be 2–7 days. If yellow nuclei is produced in pigment reactor, highly consistent yellow iron oxide pigment with pure colour can be obtained.

By slightly altered route and parameters, red iron oxide pigment can be made. If the pickling solution contains other metallic ions in large quantities, this has to be removed to get bright colour pigments. This process, known as Peniron process, is widely used for yellow iron oxide.

- C. (i) Calcination of α FeOOH with small quantities of magnesite compounds gives homogeneous brown (FeMn)₂O₃ pigment.
- (ii) Brown pigment-Controlled oxidation of Fe_3O_4 at 500°C produces a single phase γ Fe_2O_3 with a neutral brown hue.
- (iii) High quality iron oxide pigment, also called copperas reds, is made by thermal decomposition of $FeSO_47H_2O$ in a multistage (3 stage) rotary dryer used for calcining which produces α Fe_2O_3 . The α Fe_2O_3 is transferred from a tank filled with agitator and transported to a cyclone to remove soluble waste and red iron oxide is sent to dryer followed by grinding in pendular mills pin mills and jet mills depending on hardness accrued.
- (iv) Orange iron oxide with (γ -FeOOH) is obtained if dil solution of Ferrous salt is precipitated with NaOH or other alkalies until almost neutral. The suspension is then heated for a short period, rapidly cooled and oxidised. The suspension is filtered, dried and ground in rotary mills.
- (ν) Very red iron oxide pigment, with pure red colour, may be obtained by first preparing α Fe $_2$ O $_3$ nuclei and continously adding of iron (II) salt with atmospheric oxygen addition at 80°C. Hydrolysis and neutralisation are carried out by adding NaOH and keeping pH constant. The rest of the process-filtration, drying and grinding are same as in other processes. Some neutral salts are also produced as by products in the precipitation and hydrolysis process.

D. Properties of Iron Oxide Pigments

The final products is same for all the processes, Fe^{+3} - α Fe_2O_3 but properties are dependent on method of preparation. Thermal dehydration of yellow geothite gives lowest density product (4.5 gm/cc).

The pigment value results from physical properties, determined by physical state (particle size, crystal structure, particle shape, agglomeration etc. The chemical properties involve composition, purity and solubility. The most important physical-optical aspect of pigments is its ability to colour

environment in which they are dispersed and make it opaque. The opacity of a pigment lies in its ability to prevent transmission of light which is applied. The yellow pigment size is 0.1–0.8 μm and refractive index of 2.9–3.22.

The maximum dispersion of visible light occurs when pigment particle size range is 0.16-0.28 μm . Red pigment has highest density of 5.2 gm/cc and size = 0.3-4 μm .

E. Test Lab Instruments

- (i) Sieve testing facility.
- (ii) Refractive index determination instrument.
- (iii) Atomic absorption spectro photo meter for crystal structure.
- (iv) X-ray florescence analyser.
- (v) Chemical analysis for composition and moisture determination.

Uses: In construction materials viz ceramics, cement, roofing granules, coating materials, plastics colouring, paper and magnetic recording.

Table 1
International specification of iron oxide pigments

	ISO	ASTM	DIN
Black Pigment	1248	D 769	ISO1248
Brown Pigment	1248	D 3722	ISO1248
FeO Content	_	D 3872	_
Red Oxide Pigment	1248	D 3721	55913T1
Yellow Pigment	1248	D 768	ISO1248



DYES, INTERMEDIATES AND DYEING

Dyes are complex organic compounds mostly soluble in water while some dyes are soluble in dilute mineral acids. They are various types of dyes used for dyeing of textiles and yarns (natural or synthetic), textile printing, colouring of plastics and other materials. Dyes are classified as under:

- 1. **Basic Dyes**—These are cationic dye mainly amino and substituted amino compounds, soluble in acids only.
- 2. **Acid direct dyes**—Anionic dye used for dyeing protein based fibres-wool, silk, synthetic nylon and some types of polyacrylic fibres, applied from acid dye bath. These dyes are water soluble. Example—Chlorantine (ciba).
- 3. **Azo dyes**—Insoluble dye produced in-situ on fabric by coupling diazotised materials containing one or more azo groups—N: M—as chromosphore usually with hydroxyl/amino group/oxyquinone nitrosogr./Zanthene gr. or auxaphoromones gr. Example—Diamond black F. Many azo dyes were banned both in India and abroad due to health hazards.
- 4. **Reactive dyes**—These dyes, under suitable conditions, recat to form a covalent bond between the dye and cellulose fibres (cotton) and rayon. Example—chromazol.
- 5. **Disperse dye**–Forms finely divided solid solution with synthetic material fabrics/yarns viz. synthetic cellulose acetate, plastics and polyester. These dyes are substantially water insoluble.
- 6. **Vat dyes**—Water if soluble dye which are derivatives of anthraquinone or indigoid groups. These usually contain two keto groups which are manually applied to fibres from alkaline dye both containing a reducing agent (sod. hdydro-sulphite). This process is called "Vatting" or "solublising". Example—Victoria blue.
- 7. **In-grain dyes**—These are produced in situ on fibres when cotton impregnated with aniline and oxidised with an oxidising agent.
- 8. **Vegetable dye**-Naturally occurring colouring matter, containing organic dye. Example-Henna.
 - 9. **Solublised vat dyes**—There are indigo dyes in acetic acid or ammonium sulphate solvent.
- 10. **Mordant dyes**—These dyes are those which receive a mordant (hydroxides or salts) to form complexes called "Lakes" resulting in satisfactory dyeing on fibres (substrate). Example—anthracene dye (alizarine).

11. **Food colours**—These are nontoxic coal tar dyes suitable for adding in food products. These have stringent standards for food colours. Products for exports to USA require FDA rules compliance. Eu standards to be followed for exports to Europe.

Dye Intermediates

These are made from coal tar primary compounds viz Benzene, tolune, naphthalene, cresol, anthracine, xylenes etc. Coal tar itself contains 200 aromotic compounds. The primary compounds of coal tar are converted to dye intermediates by series of reactions like nitration, sulphonation, alkali fusion, reduction, chlorination, oxidation and condensation so as to form hydroxyl, amino and other groups, introduced into the original hydrocarbon materials to form intermediates. Dyes are made from these intermediates.

Dyes are usually named by the dye compounds or patented name, given by reputed manufacturers. Germany is pioneer in making dyes.

Dyeing Process

Water requirement—A high quality of soft water, having low hardness, is required in dyeing process. The amount of water required varies for different materials to be dyed. For example 1 kg of cotton yarn will require about 5 gallons of water in dye vat. In case of wool the ratio is 1:14. For dyeing process, involving circulation of dyeing solution, water requirement is less, about 1:10. Post dyeing process required water for acid/alkali removal from substrate as well as final washing with water.

The percentage of dyeing materials required is based on wt. of materials to be dyed (substrate) For example, in case of Acid dyeing on wool, usual % of dyeing materials required are:

- (a) $H_2SO_4-4\%$
- (b) Glauber salt-20%
- (c) Acid dye-X%

For colour fastness, often post washing with required chemical solution is required.

Dyeing Equipment

Various equipment are required depending on process of dyeing of textiles materials. The process can be manual, semi continuous or continuous.

Colour Index of Dyes

Basic information in given in colour index international (9 vols) and all dyes are given a C.I. no. and also a general name. A difference of 5 in between two dyes. Colour wheel is given in Fig. 1 in Chapter 32.

Banned Dyes

Germany has banned 20 azo dyes. India had banned some 65 acid, direct and disperse dyes and 45 benzidine dyes.



FLOURESCENT OR OPTICAL WHITENING AGENT (FWA)

These are complex organic compounds soluble in water and is used to impart excellent whiteness yellowish tint of textiles is produced by absorption of short wave length ultraviolet light (violet to blue). Optical brighteners absorbs maximum UV light-in the wave length of 350–575 nm range and emit the absorbed energy in the blue fluorescent range, having maximum wave length of 415–495 nm in the visible range. The material looks like dazzling white.

Most of the FWAs are derivatives of stilbene (common) or 4,4 diamino stilbene trizoles, oxazoles, imidazoles which are five members nitrocycles gr. often 6 members FWAs viz coumarines are used. FWAs are different for particular textile viz cotton, polyester, paper pulp etc. For cotton and paper bleaching, suitable FWAs are bistrianzinyl and bisstyrylbiphenyl di-sodium salt. For polyester use. 4 methyl-N-methyl napthalamide can be considered. FWAs are arranged in a series starting from FWA-1 to FWA-220 and are characterised by groups as R, R₁, R₂ R₃,

Example:	FWA	R, Group
	16	OCH ₃
	21	- N(CH ₂ CH ₂ OH) ₂
	26	$-N(CH_2CH_2OH)_2$
	22	- N \ O

Fluorescence effect of organic FWAs is the fraction of light energy that is absorbed and emitted; in fluorescence, concentration of whitening agent, to be used, varies from 0.002–0.2%.

Types of FWAs for use in bleaching of different materials

Material	FWA	FWA no.
1. Cotton	Bistrianzinyl	70
2. Polyester	4 methoxyn	74
	Methyl naphthalamide	75 and 52–55
3. Wool, Cellulose acetate-	coumarins	67
rayon and polyamides		68 and 69
4. PVC and Synthetic fibres		14, 47, 70

5. Paper pulp	21, 24, 26
6. Moderate washing temperature (tex.)	20, 22
7. PAN Fibres	50, 51, 52, 72, 73

Often some stabilising materials are required during bleaching. The toxicology of FWA used must be considered and LD-50 must be high ($\rm LD_{50}$ above 5000 mg/kg). Also environmental water pollution must be considered and suitable water pollution treatment method must be utilised.

Uses of FWAs

Detergent 50%, cotton, synthetic textiles (15%), plastics and paper pulp (30%), and for soaps and biological staining.



A

FLAME RETARDANTS, HALONS, FIRE ALARMS/HYDRANTS AND RUBBER AND EXPANDED PLASTICS

(I) FLAME RETARDANTS

- 1. Flame retardants are active chemicals (inorganic and organic) applied to fabrics, plastics and other materials for retarding flame generation when such coated fabrics or other base materials get ignited due to some reason. The list of such chemicals are given below:
 - (i) Zinc borate, (ii) Al hydroxide (iii) Molybdenum carbonate (iv) Bromine compounds (v) Chlorinated alkanes (vi) Halogenated phosphate esters (vii) Aluminium oxide trihydrate (viii) Magnesium hydroxide (ix) Cyclo aliphatic compounds (x) Ferrocene and (xi) Antimony trioxide.
- 2. A flame retardant either inhibits or even supresses the combustion process and depending on the nature of base material, a flame retardant can act physically or chemically in solid, liquid or gaseous phases. Flame retardants interfere with combustion during a particular stage of process viz during heating, decomposition, ignition or spread of flame.
- **3.** Physical action of flame retardants by way of:
 - (a) cooling-endothermic process triggered by a retardant e.g., Aluminium oxide trihydrate,
 - (b) protective layer formation-gas/solid protective layer e.g., halogenated phosphatic esters
 - (c) dilution-inert substance (fillers) and additives which arrest gases from decomposition and dilute the fuel e.g., Aluminium hydroxide.
- **4.** Action of some flame retardants is base material specific viz Ferrocine in polyurethane; Aluminium oxide trihydrate and Magnesium hydroxide do not generate smoke.
- 5. Application-After cleaning of fabric, a small portion of retardant chemical solution is sprayed over the fabric and allowed to dry slowly. Test is to be carried out after cooling to ascertain the extent of flame retardation viz determination of oxygen index before and after application of retardant. In case of plastic with flame retardant, it is mixed with plastic during moulding

stage and burning characteristics of treated plastic is determined and so also for the virgin plastic. Halogenated flame retardants are also used in plastics.

Typical composition of a treated plastic is polycarbonate, 93% decarbomo diphenyl ether 5% and antimony trioxide, 1.9%.

6. Uses-electronic, electricals, toys, tents, carpets and drapers and children sleep ware etc.

(II) HALONS

Halogenated Fire Extinguishing Chemicals

Halon is a trademark for tetra fluoro ethylene polymer. Halons are new fire extinguishing chemicals designated as 4 digit nos. The chemical compounds contain halogen atoms in addition to carbon atoms:

- (i) 1st digit indicates no. of carbon atoms
- (ii) 2nd digit indicates no. of flourine atoms
- (iii) 3rd digit indicates no. of chlorine atoms
- (iv) 4th digit indicates no. of bromine atoms.

Types of Halons:

Remarks

(a) Halon 1001 (CH₃Br)

(b) Halon 1211 (CBr C1 F₂)

Active agent 6%

(c) Halon 1301 (CF₃Br)

Active agent 5%

(*d*) Halon 2402 ($C_2F_4Br_2$)

Characteristics

Halons are efficient flame extinguishing chemicals which causes flame to sink and stay at the base of the flame. It removes the active chemical species involved in chain reactions for flame propagation. Halons are over two and a half times more active than CO_2 and suitable for liquid combustible materials fires. Halons are generally not used in solid combustible fires.

It is self extinguishing and inert to all chemicals and resistant to high and low temperature.

Toxicity: Except Halon 1301, rest are non toxic. Halon 1301 has TLV-TWA = 1000 ppm and $MAC = 6100 \text{ mg/m}^3$. Halon concentration above 10% is dangerous to human being.

Application: It is applied by portable fire extinguisher. Fixed installation should be unoccupied. Concentration upto 4% is tolerable for one minute only.

(III) FIRE DETECTION ALARMS

There are three methods of fire detection, (1) Ionisation detection chamber by α particles and (2) photo electric detection chamber by difference in photo voltaic cell e.m.f. and (3) fusible alloy water sprayers.

1. Ionisation Smoke Detection Chamber

The process uses the principle of generating α particles from Radium or any other artificial Radium isotope or ultra violet rays; α particles in the air $(O_2$ and $N_2)$ molecules, thereby knocking

out an electron from air molecules. The molecules, so hit, become ions and move to -vely charged electrons.

If air particles, containing smoke and dust, enter the chamber, the ionisation chamber conditions is changed. The solid smoke particles will absorb α particles with the result that fewer no. of particles are now available for ionisation of air and the current passing through the circuit will be reduced, thereby triggering a connected alarm circuit. A cold cathode tube (CCT) is usually used for the smoke alarm detection. The system is used in offices, shops etc.

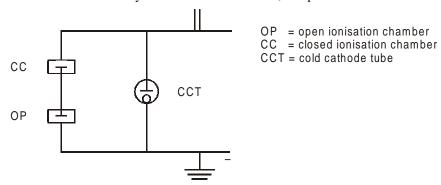


Fig. 1. Ionisation smoke detection circuit.

2. Photo Electric Cell for Smoke Detection

The system uses a photo electric cell chamber with air inlet and outlet provision in between light source and photo cell. Air, containing smoke and dust, while crossing the light to photo cell, changes the photo voltaic cell e.m.f. This triggers an alarm circuit due to reduced intensity of light from light source as a result of smoke and dust in air. The system is used in offices, shops etc. and is less costlier than isotope based detector.

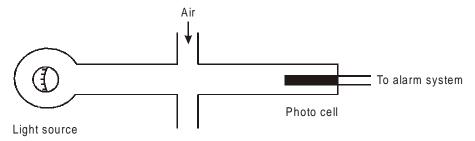


Fig. 2. Photo electric smoke detection system.

3. Fusible Alloy Water Sprayers

The system is suitable for storages containing combustible materials. The system is a part of a fire hydrant system and a fire water pipe line grid is placed over head in combustible storage. The fusible plug sprayers are put in the firewater grid mouths having threaded connections for easy replacement.

The fusible alloy melts due to heat, whenever there is a fire in the combustible material storage below, resulting in water at fire hydrant pressure is sprayed on the fire thus putting out the fire. With the fall in firehydrant pressure due to operation of water spraying system, an alarm circuit is also triggered. New fusible alloy sprayer nozzles are to be put once such sprayers are activated by fire.

(IV) RUBBERS AND EXPANDED PLASTICS

A. Natural Rubber

Available from 2 species, the Hevea brasili-ensis tree and Parthenium argentatun called guayute bush. Natural rubber crystillises at below 20°C.

Latex: pH = 6.5 - 7 $Density = 0.98 \ gm/cc$ $Total \ solids = 30-40\%$ $Rubber \ phase = 96\% \ (wt. \ rubber)$ Hydrocarbon = 1% Protein = 3%

The field latex is processed by adding 0.4% ammonia and then centrifuged. After centrifugation, the cream rubber concentrate is raised to 1.6% ammonia (wt.).

B. Rubber blends are used in 75% for all elastomars. Heterogeneous blends of natural rubber, SRB or (cis-butadiene rubber-styrene) are used mainly in tyre treads as it reduces abrasion. Homogeneous blends of rubber are rarely used; such homogeneous blends are formed if difference in solubility parameters is smaller than 0.7.

C. Expanded or foamed plastics

These are blends of plastics with air. They are classified according to cell structure, viscosity and nature of parent plastics. Their uses are mainly for thermal insulation (ps foam) and flexible foams for damping and cushioning for packaging. Poly ethylene, Poly urethane, Polystyrene and Plasticised PVC are semi rigid to flexible foams. PS copolymer with acrylonitrile or maleie anhydride foam has increased resistances to heat and solvent. Surface treatment of such foams with fire retardants (e.g. hexabromocyclodecane or pentabromo phenyl allyl ether) makes the foam flame proof (class B₁-low combustible as per DIN 4102).

Modulus of elasticity of expanded plastics decreases approximetely proportional to their polymer content. Tensile strength of Foamed plastics follows the law of simple mixing. The cell structure could be open, closed or mixed. Open celled foams are always air filled, regardless of blowing or expanding gases. Trapped gases in closed cell structure can be exchanged by surrounding air by diffusion only through polymerisation. All plastics can be foamed either by air or N_2 or chemical blowing agents (Azo dicarbo amide, Hexamethylene tetramine).

D. Above glass transition temperature T_g 20°C or more elastomers exhibit rubber like behavior. The sheer moduli at this temperature range vary between approximetely 0.1 and 100 N/mm² and exhibit a high visible deformability.

(V) FIRE HYDRANT SYSTEM

1. Every manufacturing and storage facility, large and medium, is to be provided with fire fighting facilities as per statutory requirement. The designing of such a system by the approved company is required as per requirement of the factory act as well as TAC requirements. This is essential for installation's safety against hazards of fire. Fire insurer of the factory needs to know whether the factory has a fire licence which is possible if the Fire installation is provided by a TAC approved co. TAC stand for Tariff Advisory Committee.

- 2. A composite fire protection system of a factory usually consists of:
- **2.1** Underground fire hydrant system with loop design and isolation valve.
- 2.2 Overground fire hydrant system for different floors.
- 2.3 Hydrants water supply at 8 kg/cm²g press with strategic underground loop isolation valves.
- **2.4** Fire pumphouse with booster pump (constant running) = (1+1) electric driven and electric driven fire pumps (1+1) plus a standby diesel operated pump with heavy duty battery with charger, are usually provided. Water is from fire water reservoir.
- **2.5** Accessories for hydrant like standpost (4") with hose coupling. Fire hoses with hydrant coupling, 3" nozzle, Pr. gauges tapping pt. at end points of hydrants. The fire water pump starts whenever pressure falls to below 7.5 kg/cm²g.
- **2.6** Foam maker is connected to Fire hydrant system for Foam-water spraying inside Fuel oil storages as well as water sprinking on tank body.
- **2.7** A Fire station with a Fire water cum foam tender, Fire hooter alarm system, Remote fire alarm switches at strategic plant stations to alart Fire station, Fire axes, portable fire extinguishers etc. are essential requirements for fire station.
- 2.8 Portable Fire extinguishers, compressed CO₂, Soda-acid (CO₂), Carbon tetra chloride, dry powder, and foam fire extinguishers are to be provided for any fire including electrical fires at strategic locations of plant areas as per TAC requirement. Their nos. and capacity will also conform to TAC requirement. Trolley mounted compressed CO₂ fire extinguishers can also be used. Foam and Halon fire extinguishers are also put into use. Sand buckets and empty buckets for water are also to be provided in plant areas.
- **2.9** Source of reserved water for fire hydrants—This can be a surface water reservour close to Fire station or an overhead fire water tank coupled with factory drinking water supply from own W.T. Plant or outside water service provider. Often an overhead fire water tank is provided.
- **2.10** In addition, (i) the empty bags storage of the end product, if in bulk, is also provided with fusible alloy fire water spraying system with own alarm system and (ii) fire detection alarm systems in offices/godowns. Packed goods storages are also provided with fire detection alarm.
- 3. Classes of fire has been given in Vol. II B, T-34.



FLOAT GLASS, CARBON BLACK, ELECTROPHORESIS, DRY ICE AND TECHNOLOGICAL DEVELOPMENT IN IRON AND STEEL INDUSTRY AND ELECTROLYTIC CHLORINATOR

(I) FLOAT GLASS

1. Float glass is transparent, both sides are flat and parallel and polished so that a clear and undistorted vision and reflection is obtained. It was discovered in 80's and process of manufacture perfected. The glass is made by floating on a heavier molten metal viz molten tin (having greater density than glass).

2. Pilkington Float Glass Process of Manufacture

The charge raw materials for glass is melted in a glass furnace and conditioned by adding sodium sillicate, arsenic/antimony trioxide. The melt glass is flown in a molten tin bath where a top glass layer, typically 9m wide 45m long of desired thickness floats over molten tin. The temperature of molten tin bath falls in the working range of temperature of glass. Because of extreme good surface of molten tin, molten glass, as it flows over tin, smoothen sits surface and no further polishing, smothening of glass surface is necessary. The glass body is rigid enough to travel without damage, by the time it leaves the bath. Tin is used as a medium of floatation because of its surface tension of 0.55 N/m and density 5–9 gm/cm³ compared with surface tention and 2.2–2.5 gm/cm³ density of glass. The m.p. of tin is only 505°K.

The float glass is of mirror quality and production capacity is more due to higher velocity which is 5-10 times more than other float glass manufacturing process like Libbey-Owner's process. Pilkington process requires 4 persons/shift for 100 MT/day plant. The glass melting bath capacity usually is 2 MT of melt per sq. mt per day. Heat input of 10,000 Kj/Kg of glass and temperature 1948°K and cycle of heating 16–17 hrs. (initial slow heating).

3. Uses of Float Glass

Mirrors, show cases, display windows, Glass doors etc.

(II) CARBON BLACK

A. Surface Area

Grade Surface area (m²/gm)
Coarse thermal black 10
Fine Pigment grade 1000
Tyre grade reinforcing 80–150
Carbon Black

Carbon black having surface area of 150 m²/gm is of 1.0 nm pore dia. Furnace black CB has 10–25 nm pore dia. and varies from 1–90 nm pore dia. depending on process used.

B. Density

1.8-2.1 gm/cc. (Graphitation increases it) to 2.185.

C. Carbon black Feed Stock (Petroleum) specification (CBFC)

Flash point = 70°C min Boiling range = 200°C plus BMC Index = 105–125

(US Bureau of mines corelation index)

Pour point = 50° C (approximetely)

Viscosity =

Temp. of solidfication =

Alkaline Content =

Mid B.P =

Sulphur content = 2-4.5%

 $\frac{C}{H}$ ratio = 62–332

The CBFC usually consists of:

Monocyclic aromatics = 10–15% Bicyclic aromatics = 50–60% Tricyclic aromatics = 25–35% Tetra cyclic aromatics = 5–10%

Note: In India CBFC contains 4–4.5% sulphur which reduces the BMCF yield (BMCI = 82–83).

D. Composition of Carbon Black

Carbon = 80–95% wt. Hydrogen = 0.3–1.3% Oxygen = 0.5–1.5% Nitrogen = 0.1–0.7% Sulphur = 0.1–0.7%

- E. Some grades of carbon black: N 220, N 330 and N 660.
- F. ASTM grades of carbon black are SAF, ISAF, HAF, FF. and FEF.

G. Other Types of Carbon Black Raw Materials

	Raw material
=	NG
=	Coal tar
=	CBFC
=	CBFC
=	CBFC
=	C_2H_2
	=

There are two processes of manufacture of Carbon Black by incomplete combustion (Partial oxidation) and thermal Pyrolysis. Surface area of different carbon blacks varies depending on raw materials and process.

(III) SEPARATION OF MATERIALS BY ELECTROPHORESIS

This is an advanced technique for separation of ores, plastics and resins, vermicullite-mica rock, making iron ore superior concentrates and causing removal of silica from iron and chromate ores.

Electrophoresis is caused by applying electric field either from a high voltage DC source or from charged particles's own field. The charging of particles could manifest in three forms viz. ion bombardment, conductive induction or contact charging.

For grannular ores/materials, these materials fall on a grounded roller and charged by corona discharge placed above the roller surface. Both conductors and non-conductors in ores/materials thus become charged but only the conductor looses the charge on falling to grounded roller of the crusher in different heaps. Uniform electric field is produced by corona discharge. In the di-electrophores application, catalyst fines from Petroleum products and fibres from food stuff (in air media) are separated.

(IV) DRY ICE

Manufacture

 ${
m CO}_2$ gas from sources viz. brewery etc. is drawn through a blower and is subjected to water wash to remove aldehydes, higher alcohols (amyl alcohol), glycerol, ${
m H}_2{
m S}$ etc. After washing, ${
m CO}_2$ gas is passed through a cooler and then through active carbon separator for removal of moisture and hydrocarbons if any. Two active carbon separators are used-one remains in line while the other one is regenerated by live steaming of bed and water cooling tubes followed by air purging from previous use. The water cooler is embedded in active carbon separator for removing heat of separation by cooling water. Since pore diameter of active carbon is 0.3 nm and is less than the molecular diameter of gases to be removed and the active carbon molecular sieve allows only ${
m CO}_2$ gas, to pass through as its molecular diameter is 0.28 nm only.

After first stage molecular separator, CO_2 gas is further treated with Potassium Permaganete wash to remove organic matters which give bad smell. CO_2 gas is then dried in a silica gel drier with hot air regeneration when moisture in CO_2 gas is reduced to low dew point level, usually -50° C. After drying, CO_2 gas is further passed through 2nd stage active carbon separator to remove last traces of moisture and impurities. In silica gel drying, regeneration temperature is $120-150^{\circ}$ C and

heat consumption per kg of water removed is 8000 Kj. In molecular sieve when moisture is removed, usually 12000 Kj/kg of heat is consummed (for 2 layer ms).

Extremely pure CO_2 gas, thus produced from m.s. separator column, is then compressed to 70–76 kg/cm²g, CO_2 cooled in after cooler and chilled by refrigeration in chiller—when liquid CO_2 is produced. Liquid CO_2 is then expanded to atmospheric pressure through nozzles in the chiller when snow like dry CO_2 is formed by its own refrigeration effect. 1/3 rd of CO_2 is transformed into dry ice and remaining cooled CO_2 gas is recyled to CO_2 compressor suction. The solid dry ice is compressed in a hydraulic press and moulds of 12–100 kg blocks are usually made. By expanding liq. CO_2 to ambient press, the temperature of CO_2 falls below the tripple point of CO_2 which is – 56.5°C at 75.1 PSIA (518 Kpa). The heat of formation of dry ice is 573 Kj/kg.

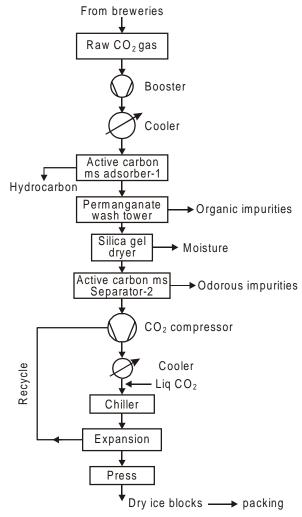


Fig. 1. Block diagram for dry ice maufacture.

Uses of Dry Ice

It is mainly used in food industry for the transportation of deep frozen products and laboratory chilling or other uses.

(V) TECHNOLOGICAL DEVELOPMENT IN IRON AND STEEL INDUSTRY

1. Blast furnace

Japanese have developed artificial intelligence in determining internal reactions, resulting in temperature variation in a zone and overcoming this by correcting feed additions for uniform temperature.

2. PCI (Pulverised Coal Injection) System

By injecting pulverized coal in B.F. coke requirement is reduced. By PCI technology, injecting 1 kg of coal, coke requirement comes down by 0.1 kg and corresponding coal requirement for coke production reduce by 1.5 kg. Optimum PCI ratio is 100–105 kg of coal/ton of pig iron; lowgrade coal and iron ore can be used.

3. DIOS Process

Direct iron ore smelting process (trial run NKK in 1993-94).

Here B.F. is in two section with production section at the top of smelting reduction section. No coke and only low grade coal and lower grade of iron ore, can be used.

Feed is given to bottom section from where it traverses to upper section where it is prereduced with CO gases from bottom under fluidised condition. The prereduced iron ore falls to the bottom section through central pipe when molten metal is produced and tapped.

4. Steel Making

- (i) Open Hearth process is gradually being phased out in Japan. It is only 15% in operation and EAF with continuous casting and annealing is used thus saving in cost time and 10% reduction in manpower has been achieved.
- (ii) Scrap charge melting is carried in furnace and refining with alloying materials in laddle. By this power consumption in furnace heating is reduced by 1/5th and production is increased by 1/3rd. D.C. Arc furnace instead of A.C. induction furnace also saves power.

5. BOF (Basic Oxygen Furnace)

Here, CaO, lime powder is injected in tyre along with oxygen. The power consumption, in steel making, varies from 4.6 Gcal to and 8 Gcal/ton.

The main objective of the above development is saving in energy, process optimization for more productivity, computerised control operation and saving in manpower so as to reduce cost and time of operation.

(VI) ELECTROLYTIC CHLORINATOR

Chlorination by liquid chlorine injestion in circulating cooling water and drinking water are old methods for disinfection. Modern method of chlorination is by electrolytic chlorinator which is fed by sodium hypochlorite solution at preset chlorine dose to water for different end uses which require disinfection. Chlorine kills bacteria and HClO reacts with enzyme.

The sodium hypochlorite solution is prepared in an electrolytic cell by the following reaction using purified brine solution :

$$2Cl^{-} \longrightarrow Cl_2 + 2e$$
 (anode)

$$Cl_2 + H_2O \longrightarrow HClO + H^+ + Cl^-$$
 (cathode)
 $HClO \longrightarrow ClO^- + H^+$
hypochlorite
 $Cl_2 + H_2O \longrightarrow HOCl + HCl$

ClO⁻ then combines with Na+ ion to give sodium hypochlorite. The cell can be mono polar, bipolar or once through/recirculating.

The process consists of storing purified brine in a saturation tank from where saturated brine flows to brine circulation tank. The brine is then pumped to electrolyser cells assembly with a rectifier. The outlet sodium hypochlorite is divided into two parts—one part goes to hypochlorite storage tank and the other goes to brine circulation tank. NaClO from storage tank is then taken to feed points.

Beneficial Effects of Chlorine Apart from Disinfection

Odour control, reduces BOD, control sludge bulking and slime formation etc.

Uses of Electrolytic Chlorinator

Drinking water, swimming pool and cooling water disinfection, Hospital sterilisation, food and beverages, brewery and bottling plants. NaOH plant, sea water pumping stations etc.



CERAMIC COLOURING MATERIALS

- 1. Industrial ceramic pigments are prepared by solid state reaction with minerals, suitable for particular reactions. Whiteness or opacity is introduced into transparent ceramic materials, such as glazes, by the addition of substances called opacifiers that will disperse in those materials of glazes as discrete particles. There discrete particles scatter and reflect some incident light. The dispersed substances in glazes must have refractive index that differs appreciably from clear ceramic materials i.e., glazes. The refractive index ND²⁰, of ceramic materials (glazes) is 1.5–1.6 and refractive index of opacifiers must be greater than that of glazes. In case of glazes viz. tin oxide (III) (ND²⁰ = 2.04), Zirconia (ND²⁰ = 2.4, Zircon (ND²⁰ = 1.85), titania (ND²⁰ = 2.5) and for anatase and titania-rutile ND²⁰ = 2.7.
- 2. The glazes and other ceramic coatings in ceramic materials after application of glazes with opacifiers pigments are then fired in electric furnaces or hot blue gases at a temperature less than 1000°C. Usually % of opacifiers differs according to type of opacifiers. For example, finely ground Zircon (as opacifiers) is used at a concentration of 8–10% Zircon. The glazed porcelain will be colourless if no pigment is used.

When pastel colour is required in porcelain, opacifier, along with a compatible ceramic pigment, is added to the coating. The pigment chosen, should belong to the same opacifier group. For example, Zircon opacifier should be used with Zircon or Zirconia pigments. For black colour, Zinc or Cobalt free ceramic pigment is to be used.

3. COLOUR COMBINATION OF GLAZES

3.1 Yellow Pigment

Three combinations are available for firing temperature, more than 1000°C viz. Zirconia-Vanadium yellow with Zirconium silicate (opacifier) and Tin oxide with vanadium yellow.

3.2 Pink or Purple Pigment

Chrome-alumina, Pink spinnel is free, from CaO and low concentration lead oxide or basic oxide. Most stable pigment is Iron-Zircon combination.

3.3 Gray Pigment

Diluted black Pigment with white opacifier. Other combination is Tin based opacifier with Tinantimony carsilerite.

3.4 Green Pigment

Chromium is basic pigment but it has various limitations. Usually Zircon-Vanadium blue and Zircon-presscodynrium yellow are used. For bright green colour two parts of yellow pigment and one part of blue pigment with Zircon (opacifier) are used.

Copper containing pigments with opacifier is not used for making food containing ceramic articles and non food items are made at lower firing temperature.

3.5 Blue Pigments

Cobalt-Al. oxide (CoAl₂O₄) or cobalt with SiO₂ are used with Zircon based opacifiers.

3.6 Brown Pigments

Zinc, nonchromite brown spinnel or tin oxide (spinnel), iron chromite brown spinnel or chromoiron manganese brown spinnel.

3.7 Red Pigment

Cadmium Sulphoselenide or mixture of cadmium sulphide and cad. selenide, in the ratio of 4:1 (orange), 1.7:1 (red) and 1.3:1 (deep red).

- **4.** Segar cone no. and temperatures for firing of glazes is given in vol. IIA.
- **5.** There are 19 spinnel class pigments, Zircon group has 3 pigments, Baddeyte and borate groups, each has one pigment, Phosphate group has 2 Pigments and Rutile/Cassiterite group have 12 pigments.

6. APPLICATION OF COLOURS ON CERAMIC MATERIALS

There are five ways (i) As an engrave on a raw body (ii) as a body stain (iii) as an under glaze colour to a bisque body (iv) as a coloured glaze (Pigment, dispersed in glaze) and (v) as an over glaze already formed and fired glaze as an overcoat.



GLASS FIBRES FOR INSULATION AND OTHER USES

1. The mineral fibres or glass fibres consists of finely divided fibrous glass, highly dispersed with specific area varying from 0.1–0.2 m²/gm. The fibre is oriented in longitudinal direction only and the fibre is isotropic in 3rd dimension. Its open-ended Pore system offers little resistance to flow which forms the basis of its good accoustic and thermal insulation properties. Its Low Thermal conductivity, is based on fibre diameter and bulk density. The material is unsuitable for load bearing structure construction. The material is also called glass wool or mineral wool due to its similarity with wool. Glass wool is generally used for hot insulation.

Table 1
Thermal conductivity of mineral fibres

		Thermal conductivity wm ⁻¹ °K ⁻¹
Туре	Temp°C	Unit
Glass Wool	100	0.07
Glass Wool	200	0.078
Rock Wool	100	0.053
Rock Wool	200	0.090
Spl. rock Wool	100	0.041
Spl. rock Wool	200	0.060

2. MATERIALS USED IN PRODUCTION

(i) Glass Wool

Quartz sand, limestone, dolomite, phanolite, kernite feldspar, nephelime-senite, menite, baryte and ulexite. Other chemicals used are sodium carbonate, sodium sulphate, barium carbonate along with recycle glass and resin bonding material.

(ii) Rock Wool

Single material with limestone as additive to increase maleability. Minerals of suitable composition, such as basalt, rhydite etc. are used.

(iii) Slag Wool

Blast furnace slag with limestone is used.

3. BROAD COMPOSITION OF MINERAL FIBRES

Vitreous fibre having dia, 3–6 μ m = 90–99.8% and length 3–10 cm.

Phenol formaldehyde resin modified with = 10% (max) UF or melamine formaldehyde

Aliphatic mineral material = 1% (max)

Emulsifiers (noniomic Polyethylene, xylene) = 0.2% (max)

Polymethyl siloxanol = 0.5%

4. Chemical composition of mineral wool various with the process used. There are three processes of manufacture viz. (A) Owen's rock wool process (B) Rotary Process and (C) Centrifugal blowing process. Mineral wool is inert to organic solvents even at higher temperature water and aqueous solution attack glass surface and reduce resin bond. Chemically the fibres are composed of silicate glass. Slag wool and rock wool are soluble in acids and are easily attacked by acid flue gases.

Table 2
Chemical analysis of mineral fibres

A. Glass wool		B. Rock wool	C. Slag wool
Process used	Rotary	Owen's Process	Centrifugal blowing
Limiting temperature	570°C	700°C	735°C
SiO ₂	57.3% (wt.)	52.7% (wt.)	46.8% (wt.)
Fe ₂ O ₃	0.35	1.8	1.0
Al_2O_3	3.6	8.0	10.2
FeO	0.1	1.4	0.3
TiO ₂	_	0.6	_
ZrO_2	4.0	_	_
MgO	4.0	4.0	2.3
CaO	8.6	20.9	37.7
BaO	1.7	_	_
Na ₂ O	11.2	10.3	0.9
K_2O	1.7	0.6	0.6
B_2O_3	5.0	_	_
F	2.3	_	_
MnO	_	_	0.3

5. PROCESS OF MANUFACTURE OF GLASS FIBRES

(i) Melting tank, consisting of reqd. amounts of raw materials, is a cross fired recuperative-regenerative furnace or 4 steped flame furnaces or electric melting furnaces. Gas or oil is used in the furnaces whose capacity can be 3.5 t/m³. For rock wool, cupola furnace can be used with fuel, either coke, oil or gas.

- (ii) Owen's Process uses steam or compressed air for blowing.
- (iii) Rotary Process is a two step process suitable for soft and long filaments.
- (iv) Centrifugal type blowing is used for slag wool manufacture.

6. GLASS WOOL AND ROCK WOOL

Glass wool and rock wool (mineral wool) are highly dispersed systems of finely divided fibre glass with specific surface area of 0.1–0.2 m²/gm; glass wool filament dia. is 5.5 μ ; density, 15 kg/m³ and Thermal conductivity (glass wool) at 200°C = 0.078 Wm⁻¹.°K⁻¹. These are suitable for hot thermal insulation.

The mineral wool is having higher filament dia. and density of 6.5 μ and density = 30 kg/m³ respectively and its thermal conductivity at 200°C is 0.090. A special variety of rock wool has filament dia. of 5.0 μ ; density = 100 kg/m³ and thermal conductivity (rock wool), at 200°C is 0.060 Wm⁻¹.°k⁻¹.



PLASTICS

- 1. These are synthetic long chain high mol wt. hydrocarbons and other groups formed by polymerisation reactions viz. addition polymerisation and condensation polymerisation in presence of some additives which improve the product quality. The hydrocarbon material, which is polymerised, is called monomer. Addition polymerisation or free radical addition polymerisation yields a polymer product of high mol. wt. The condensation polymerisation or ionic polymerisation is a combination of monomers with elimination of simple molecules viz. H₂O or methanol or others. Linear polymer are having short chain molecules and no branch chains and as such, molecular wt. of these polymer is lesser. Molecular wt. of plastics varies from 10000 to 100000 or more. Plastics polymers, prior to curing (heating process), is called resins. Monomers of two different types when polymerise gives condensation polymers viz Styrene acrylonitrile (SAN) Acrylic Butadiene Styrene (ABS).
- 2. There are two types of plastics: Thermoplastics and Thermosetting plastics

 Thermoplastics can be melted repeatedly without loss of mechanical or physical properties and reformed.

Thermoplastics

Polyvinyl Chloride (PVC)

Polyvinyl Acetate (PVA)

Polyethylene or polythene, PE (Low density and high density)

Polypropylene (PP)

Polystyrene (PS)

Polyvinyl Alcohol (PVA)

Polymethyl methacrylate (PMMA)

Cellulose Acetate (CA) polymer

Cellulose Nitrate (Celluloid) polymer

Polyacrylo nitrile (PAN)

Polycarbonate (PC)

Polybutadiene (PB)

Styrene acrilonitrile (SAN) and PTFE

PLASTICS 191

Thermosetting Plastics

These plastics are formed from certain virgin plastics by heating and cooling process which cannot be remelted and reformed as it sets to a permanent form on cooling. On reheating it is likely to decompose or deform.

Examples:

Melamine formaldehyde resin

Polyethylene terepthalate (PET)

Phenol and Urea formaldehyde (PF/UF)

Polyurethane (PUR)

Polymer silicones

Polyall (alkyd resin polymer)

XLPE (Polyethylene cross linked)

Acrylic resin

ABC

Nylon-6, Nylon-66

Polyester resin (Poly condensation of dicarboxylic acid with dihydroxy alcohols)

Furan

Acetal (Polymer of formaldehyde)

Epoxy resin

In addition to the above, there are other plastics, suitable for medical, scientific and industrial uses.

3. PROPERTIES OF PLASTICS

The properties are characterised by the following main physical and mechanical properties as stated below:

Density and specific gravity. Plastics are generally solids with a few exceptions e.g., polysilicones which are liquids.

Melting point, Vical softening point (°C) and Glass transition temperature, (°C), GTT gives ability of a solid plastic material to crystallise and when relevant, indicates crystaline m.p. The ability of a plastic to crystallise is determined by regulating its molecular structure. Usually GTT/T_g of many polymers, except co-polymers is 2/3rd of crystalline m.p. In case of amorphous polymer, glass transition will indicate whether or not the polymer is glass or rubber at a given temperature after processing. Other properties are Tensile strength, Flexural strength, Modulus of elasticity, Impact strength, Solvent Chemical, Electrical property (Die-electric constant), Water absorption rate and melt flow index. Plastics detoriate in heat and sunlight specially when there is no U.V. protection additives.

Virgin plastics are available in solid form (Pellets/granules); few plastics are in fluid form and powder form.

4. ADDITIVES

For processing of plastics these are used to improve the quality, mechanical and electrical property. Along with additives, some percentage of used plastics are added to the processing materials to improve melt properties. The additives are classified in several groups as under:

- (i) Fillers (Solids and reinforcement fillers e.g., talc in P.P., usual fillers and reinforcements are: Talc, Cellulose, Silica, Kaolin, $Al(OH)_3$, Natural and precipitated carbonate, Carbon fibres, mica powder, glass fibres and spheres etc.
- (ii) Antioxidants—These are used to prevent degradation of plastics by chain breaking to prevent oxidation and synthesis between antioxidants. Chemicals used are Tiophenols, alkylidene-bisphenols (300–600 mol. wt.) and alkyl phenols.
- (*iii*) Light (UV) stabilisers (UV radiation 360–380 nm wave length-to stop UV absorption from sun light. Chemical used are Benzophenons, Nickel compounds, Cyanocinnamates, Salicylates, Benzoates etc.)
- (iv) PVC stabilisers—to prevent, detoriation by thermal stress. Chemicals used are Methylene mercaptide, Butylene carboxylate, Barium-Cadmium or Ca-Zn stabilisers.
- (v) Plasticisers—These are high boiling organic compounds usually liquid which gives better processing properties and imparts flexibility and stretch-ability of plastics/resin or elastomers.
 - (vi) Electron beam crosslinking of PVC gives higher m.p. PVC.

Thermal conductivity of plastics is low, usually 0.0004 cal-cm/ $^{\circ}$ C.cm².sec and linear thermal expansion co-eff. of plastics varies from $30 - 70 \times 10^{-6}$ m/m $^{\circ}$ C.

For PVC processing more plasticisers are required until brittle point is exceeded and properties change from rigid to soft. Type of plasticisers also depends on type of moulding-Injection, extrusion or blow moulding. Common plasticisers are Phthalates (Phthalic anhydride and isophthalic acid). Trimettileates, polyester, glutonic acid, acrylic acid, oleates, stearates, benzoates, terephthalic acid and hexanol etc.

- (vi) Lubricants-added to improve viscosity of melt. Examples—Fatty alcohols, dicarboxylic acid esters, fatty acid esters of glycerol, fatty acid and fatty acid amines.
 - (vii) Cellulose derivities—used in coatings and adhesives.
- (viii) Dye/pigment for colouring-generally azo/anthraquinone based dyes are used as pigments and metallic oxides and inorganic hydroxides are used in plastics including amorphous carbon. Size of pigments used varies from .01 to 1 μm.
- (ix) Antistatic agent in plastic materials—High electrical charge develops into plastic materials due to high volume and surface resistance and requires antistatic agent viz. cationic compounds, quaternary alkyl carbonates and anionic compounds viz. alkyl sulphonate is to be added into the charge. Surface resistance of a plastic should not be more than 10^6 ohm. To provide earthing to atmosphere from processing room, so as to prevent static electricity flash.

5. PLASTIC PROCESSING

The virgin plastic moulding material usually in pellet form is mixed with required additives in proper quantities in a Banbury mixer. The mixer is then throughly mixed and plastic processing is done at above the crystalline melting point or in case of amorphous (powder) polymers above its glass transition temperature. The charge is melted electrically and then led into the kneaders or rollers maintained at 150–210°C and the melt is taken to moulds for the desired product.

In case of sheets/film products, film/sheeting machines are used. For cast films, cellulose acetate is used.

Various types of plastics are used in packaging industry. The list of different plastics forms, types and polymers used are given below:

PLASTICS 193

Forms Types Polymers

Films Blown films Polyolefins, PVC, PET

nylon and EVA

Cast films PP, PS, PET and nylon

Coextruded films Polyolefins, nylon

Oriented films PP

BOPP PS, PP, PET

Strings for sacks LLDPE, HDPE, PP

Lamination Extrusion lamination

on paper/Al foil Polyolefins

Dry bond lamination PET, BOPP, MET

Injection blow moulding Containers, bottles PS, PVC, Polyolefins

(stretched) PET, SAN, PP

Multilayer bottles Polefins, EVOH Containers PS, PP, HDPE

Transparent Containers HDPE, MMA

Closures PS, LDPE, HDPE, PP, ABS

Foamed Sheets and casting PS, Polyurethane

NB. EVOH is ethylene vinyl alcohol. Compression moulding is no longer used now. Food products packages are generally irradiated at 1.5 mega rads.

6. OUT LINES OF SOME PLASTIC MANUFACTURE ROUTES

- (i) Ethylene \rightarrow Ethylene Benzene \rightarrow Styrene \rightarrow Polystyrene
- (ii) Ethylene \rightarrow dichloroethylene \rightarrow Vinyl Chloride \rightarrow PVC
- (iii) Ethylene \rightarrow LLDP/HDP

Injection moulded

- (iv) Propylene \rightarrow Cumane \rightarrow Phenol \rightarrow nylon
- (v) Propylene \rightarrow Isopropyl alcohol \rightarrow Acetone \rightarrow Acrylics
- (vi) Propylene \rightarrow Polypropylene
- (vii) Acetone \rightarrow Acetic anhydride \rightarrow cellulose acetate

7. FOAMED PLASTICS OR EXPANDED PLASTICS

Foamed polystyrene, polyurethane and polyethylene are common plastics used in insulation, packaging/lining of shoes soles etc. Process of manufactures involves in heating the polymer in presence of additives and blowing agent, followed by cooling of the reactor effluent and finally pouring the effluent into the mould. Blowing agent is different for different polymers.

8. PLASTICS FABRICATION MACHINERIES

- (i) Injection moulding machine
- (ii) Injection blow moulding machine
- (iii) Extrusion machine
- (iv) Film making machine

- (v) Cast sheeting machine
- (vi) Lamination machine
- (vii) Sacks making machine on flat/circular looms.

9. PLASTICS FOR PACKAGING

The following plastics resins or polymers are used in packing industries:

PVC, PET, BOPP (Biaxially oriented polypropylene), PP, PE (Low and high density), PS, SAN, LAN, PAN, EVA (Ethylene Vinyl acetate), EVOH (Ethylene Vinyl Alcohol), EMA and Foamed plastics etc

10. PROCESSES FOR PE MANUFACTURE

- (i) H.P. process
- (ii) Zieglar process
- (iii) Philips process
- (iv) Standard oil process



FLOCCULATION

Flocculants are chemical additives for flocculation, used in the separation of suspended particles in slurry or fluid by agglomeration and thereby help settling. Flocculants are used generally for beneficiation of ores, purification of water etc.

A. INORGANIC FLOCCULANTS

Alum (Ferric alum, Pot. alum etc.) Poly Al. chloride, Sod. Aluminate, Ferric chloride, Ferrous sulphate, Ferric sulphate and Sodium silicate.

About 10% solutions are used for inorganic flocculants.

B. ORGANIC FLOCCULANTS

Basically these flocculants are cationic, anionic or amphoteric polymer compounds (mainly polyacrylamides) of high molecular wt. For neutral suspension of fluid/slurry, anionic or nonionic organic flocculants are excellent when the slurry contains inorganic solids. The cationic flocculants are the best for neutral suspensions, containing more organic solids. Most of the organic flocculants are available in company trade names, some of which are given below:

Trade name		Manufacturer
1. Superfloc, Accurac	_	Amer cyanamid (USA)
2. Calgon, Hydraid	_	Calgon (USA)
3. Separen, Purifloc	_	Dow chemicals (USA)
4. Herobloc, Reten	_	Hercules (USA)
5. Nelco	_	Nelco chemicals (USA)
6. Polyfloc, Betz	_	Betz Laboratory (USA)
7. Sedipar, Polymin	_	BASF (FRG)
8. Magnafloc, Percol, Zetag	_	Allied chemicals (UK)
9. Praestol	_	Chemische Fabrik Stockhausen (FRG)
10. Kurifloc	_	Kurita Kogya (Japan)
11. Di aclear	_	Mitsubishi chemicals (Japan)
12. Sanpoly	_	Sankyo chemicals (Japan)
13. Sanfloc	_	Sanyo chemicals (Japan)
	195	

14. Rohafloc — Rohm (FRG)

15. Floerger — Soe Nationale de Flocculant (France)

Tests Required for Flocculants

Sedimentation test, Filter Plate test, Buchner funnel test, press. filter test, Determination of filtration rate etc.

INDUSTRYWISE USE OF FLOCCULANTS

0011	TIMIDE OUL OF TEOCOGEANTO	
	Industry	Uses and type of flocculant used
1.	Ores beneficiation	Floatation process, thickening and filtration of concentrates etc. Flocculant used is copolymer of acrylamide and sod. acrylate.
2.	Potash mining	Classification of Potash solns, dewatering of tailings. Flocculant is same as in 1.
3.	Barytes and Flourites mining	Separation of floatation tailings. Flocculant, same as in 1.
4.	Phosphate mining etc.	Water recovery in mines, filtration, Gypsum filtration, Phosphoric acid clarification etc., Flocculant used in poly acrylamide and which is used as in 1.
5.	Salt works	Classification of raw brines and sludge dewatering. Flocculant used is poly sod. acrylate and as used in 1.
6.	Kaolin mining	Thickening of Kaolin slurries. Flocculant used is same as in 1.
7.	Coal mining/washery	Clarification of wash water, floatation tailings and filtration of concentrated tailings and filtration/dewatering of tailings. Flocculants used as in 1, Polyacrylamide and Polyethylamine.
8.	Bauxite beneficiation	Thickening of redmud from Bayer process. Flocculant used is poly Sod. Acrylate.
9.	Paper industry	Dewatering of slurries and retention of Kaolin on paper machinery, clarification and dewatering of pulp recovery effluents. Flocculants used are polyethylamine, Poly acrylene polymer, copolymer of acrylamide and cationic substituted methacrylates. (neutralised and quaternised)
10.	TiO ₂ Manufacture	Clarification of black liquor and filtration of TiO ₂ . Flocculants used as polyacrylamide, last flocculant in Sr. 8 and cationic carbonyl polymers.

FLOCCULATION 197

11. Uranium manufacture Filtration of alkaline or acidic solns. Flocculant used are polyacrylamide and polyethylene

oxide

12. Sugar processing Clarification of sugar juice and dewatering of sludge. Flocculant used is same as in 1.

13. Steel works, foundries

Clarification of BF gas scrubbing water, clarification of effluents from sintering and pickling plants, clarification of electrolytic

Flocculants used is same as in 1.

14. Bio-technology field Dewatering of biological slurries. Flocculants

used are same as in 8.

15. Water treatment plants

Thickening of activated

Thickening of activated sewage sludge, effluent purification, floatation of activated sewage sludge, phosphate precipitation and mechanical dewatering of sewage sludge. Flocculants used is inorganic flocculant, copolymer of acrylamide and sod. acrylate,

effluents and purification of electrolytic solns.

polyacrylamide.

16. Potable water works

Flocculation of surface water, clarification of wash water of filters and filter conditioning.

Flocculants used are inorganic flocculants, copolymer of acrylamide and sodium acrylate, polyalkalyne polymer and polyethylamine.



PHOSPHORIC ACID

Phosphoric acid is a key material for the manufacture of other phosphatic and N.P.K fertilizers or N.P. fertilizers. These are mono ammonium phosphate MAP (N = 11%, $P_2O_5 = 52\%$ wt), Diammonium Phosphate (N = 18%, $P_2O_5 = 46\%$), triple superphosphate ($P_2O_5 = 46\%$) etc. With addition of Muriate of potash, KCl, N.P.K. grades are manufactured. About 85% phosphatic fertiliser are made form wet process phosphoric acid.

Commercial wet process phosphoric acid is classified according to the hydrate form in which Calcium Sulphate crystallizes:

Hemihydrate – CaSO₄.1/2H₂O

Dihydrate – CaSO₄.2H₂O

The process is called wet because conc. sulphuric acid is used to digest the rock phosphate ores. By 1980, hemihydrate and improved dihydrate processes were developed and 30–50% P_2O_5 wet process phosphoric acid plant, upto 1300 Mt/day, came up.

The other dry process or electric furnace process of Phosphoric acid manufacture is an efficient process originally came up in 1935. But its use has declined except for the purpose of manufacture of elemental phosphorous or the acid as an intermediate for making phosphorous element.

Rock Phosphate Ores

These are of various types e.g., fluorapatite, $Ca_{10}F_2(PO_4)_6$, Chlorapatite $3Ca_3(PO_4)_2CaCl_2$ and Phosphorite. Rock phosphate is characterized by BPL (Bone Phosphate of lime) value.

Chemical reaction

When a pure rock phosphate ore, say fluropatite, is reacted with sulphuric acid, the following reaction takes place. There are various other reactions, as rock phosphate ores generally contain various other impurities. For simplicity they are not shown below:

$$Ca_{10}F_2(PO_4)_6 + 10H_2SO_4 + 10nH_2O \rightarrow 10CaSO_4nH_2O + nH_3PO_4 + HF$$

where n = 0, 1/2 or 2, depending on hydrate form in which Calcium Sulphate crystallizes. The reaction is the net result of two stages reaction. In the 1st stage, phosphoric acid reacts with monoclacium phosphate and in the 2nd stage monocalcium phosphate reacts with sulphuric acid to form phosphoric acid. The two reactions take place in a single reaction.

The impurities in rock phosphate as well as in sulphuric acid, precipitate in many side reactions. Most rock phosphates have a higher $CaO : P_2O_5$ ratio than fluorapatite. The additional CaO consumes

PHOSPHORIC ACID 199

more sulphuric acid and forms more calcium sulphate. The HF formed reacts with silica and other more complex compounds. A variable amount of fluorine is volatilized as SiF_4 , HF or both. The amount volatilized and the form it does so depend on phosphate rock composition and process conditions. Numerous side reaction compounds, some complex are formed in the reaction shown above.

The heat of reaction, when n = 2 (dihydrate process), is calculated to be 230 or 257 kilo cal/gm mole of apatite. If the reactants enter the reactor at 25°C and products leave at 82°C, some heat of reaction is carried out with the reactants, the net heat to be dissipitated is 403 kilo cal/gm mole if 100% sulphuric used. In case of other acid concentration excess heat dissipitated is:

Sulphuric acid	Heat dissipitation
98%	385 kilo cal/gm mole
93	329 kilo cal/gm mole
75	180 kilo cal/gm mole

Table 1
Analysis of Florida Rock Phosphate

Constituent	% by wt. Range	Median
P ₂ O ₅	29–38	32
CaO	46–54	51
SiO ₂	0.2-8.7	3
$Al_2O_3 + Fe_2O_3$	0.4–3.4	1.4
MgO	0.1–0.8	0.2
Na ₂ O	0.1–0.8	0.5
CO ₂	0.2–7.5	4.5
F	2.2–4.0	3.7
CI	upto 2.9	1.0
CaO: P ₂ O ₅ ratio (wt.)	1.35–1.7	1.5
Organic carbon	0.005-1.7	0.3

Recommended quality of R.P. should be as per median analysis.

- 1. Bulk density (Florida R.P.) = 136.157 Kg/m^3
- 2. Source of R.P. are: USA (Florida and Tennessee Valley), Israel, Jordan, Algiers, and Morocco. Indian Udaipur R.P. quality is poor as it contains about 10% silica.

Dihydrate Process

This process is widely used because it is relatively simple and adaptable to wide range of grades and types of rock phosphate ores and gives 26-32% P_2O_5 conc. of phosphoric acid with reaction at 70-85°C. The separation stage after reactor, is only one (filtration stage to remove gypsum or by centrifuging).

Assuming 94% overall P_2O_5 recovery, the number of tons of rock phosphate required per ton of P_2O_5 required as Phosphoric acid is as follows:

Table 2

Туре	Grade of rock % P ₂ O ₅	Rock required in Tons/ton of P ₂ O ₅ in acid
Low	29	3.67
Medium	33	3.22
High	38	2.80

Selection of Rock Phosphate Ores

Generally Phosphoric acid plants are designed on the basis of some standard rock phosphate. However, it is better to consider the use of rock phosphate from other countries, having slightly different specification and to design plant facilities accordingly should it be found necessary to use rock phosphate from other countries to avail of opportunities of competitive rates or to avoid disruption to supply due to hostility or non-availability. The extra investment will be more than to compensate for savings due to freedom of choice.

The extra facilities required in such cases are:

- 1. Additional grinding facility for harder rock
- 2. Extra filtration capacity
- 3. Slurry handling systems that can cope up with acid insoluble impurities in rock
- 4. More corrosion resistant materials for rocks that have corrosive impurities.

Complete chemical and mineralogical analysis of rock phosphate and trial run for selecting rock phosphate or changing the source, are required.

Factors to be considered selecting rock phosphate:

- (i) R.P. to contain min. 32% phosphate as P₂O₅ for 16% W.S. P₂O₅
- (ii) BPL values of 68-72% and H₂SO₄ usually 98% at calculated amount
- (iii) Presence of impurities viz. iron pyrites, Al silicates and various fluorides within limits
- (iv) Non Fluorides, iron, organic matter, Al silicates gives poor quality product
- (v) Acid consumption is more if more Al and iron are present.

Sulphuric Acid Requirement

It can be determined from R.P. analysis. The followings are the typical parameters:

	High	Medium	Low
CaO: P ₂ O ₅ ratio in rock	1.70	1.50	1.35
H ₂ SO ₄ reqd., ton/ton of P ₂ O ₅	3.15	2.78	2.50

Receiving and Storage

- 1. Rapid unloading and delivery system of R.P.
- 2. Less loss of R.P.
- 3. Easy storage with ability to separate shipment of supply storage
- 4. Efficient retrieval from storage

PHOSPHORIC ACID 201

- 5. Storage covering against rain, dust and wind
- 6. Provision for expansion
- 7. Storage capacity should be one and half times the shipment capacity of tankers.

Rock Grinding

Dry grinding is used in older plants and some new plants, suitable for multi compartment digesters. Prayon require 60%-200 mesh (Taylor) or 0.074 mm opening. Other new plants require 25%-200 mesh, 60%-100 mesh, all minus 35 mesh. Ring roller mills often used with air classification. The power requirement depends on rock size, hardness and fineness is about 12–20 Kw per ton of R.P. including air classification in bag type filters with a automatic shaking. Softer rock requires 2/3–1/2 of the above value. But dust pollution is frequent due to leakage from pneumatic conveying.

Wet grinding is generally found in plants located near R.P. mine. It is done in ball mills. A slurry containing 62 to 70% solids is produced and fed to the digestors via a surge tanks. Power consumption is lesser, 11–12 Kw/ton and there is no dust problem. For open circuit wet grinding the power requirement is 18 KWH/ton. The major disadvantages are, faster erosion of balls and liners of mills, decrease in amount of recycling water that can be used elsewhere in the plant and close control of water/solid ratio in grinding.

Calcinating of Rock Phosphate

It is a part of ore beneficiation process, often found necessary to eliminate high organic matter content or decreased carbonate content or both. For organic matter removal, fluidized kiln at 830°C is sufficient. The organic matter in R.P. also form part of fuel cost. Calcined R.P. also enhances production of R.P. by 30–40% and saves antifoaming reagent in digester.

Reaction in Digestors

There are several types of reactions vessels designed by manufacturers. The most important factor is production of gypsum crystal of such shape and size which will allow rapid filtration of slurry from digestor.

The losses of P_2O_5 due to lower recovery of P_2O_5 are:

- 1. Unreacted rock
- 2. P₂O₅ crystalises with gypsum through isomorphic substitution of HPO₄ for SO₄
- 3. Phosphoric acid lost in the gypsum due to incomplete washing
- 4. Others are spillage, leakages, washing of filter cloth, piping, equipment, scale removal and losses as sludge.

Digester or Reactor

A multicomponent reaction vessel is used having agitators. Sulphuric acid is poured with recycled of weak phosphoric acid and discharged into 1st, 2nd or 3rd compartment (no. of compartment depends on plant capacity) as reaction system is designed not to mix R.P. and sulphuric acid directly to ensure slow growth of gypsum crystal to a relatively longer size for ease of filtration. Retention time of reactors varies from 15 hrs. to 3 minutes and usually it is 1.5 hrs. to 12 hrs. or more. Also, a high concentration of free H₂SO₄ will result in the coating of R.P. with CaSO₄ reaction product, thus blocking further reaction. A serious block in reaction systems can take hours or even days to rectify.

The rock slurry from wet grinding is discharged into 1st, 2nd or 3rd compartment or divided among them. The reaction temperature varies from 85–100°C. A portion of rock slurry is withdrawn for temperature control and fed to a vacuum flash cooler. Part of cool slurry is fed to attack system and part to digestor. The slurry moves from last compartment to first compartment. The digestor tanks permit completion of reaction and lowering of any super saturation under mild agitation. A small adjustment can be made by adding small R.P. or sulphuric acid as required.

Premixing recycle weak phosphoric acid with conc. H_2SO_4 , evolves much heat and vapours of H.F., SiF_4 which is also carried out, separately in some in plant in flash vacuum cooler to separate H.F. and SiF_4 which can be used to produce hydroflourosilicic acid.

In Swenson Gulf isothermal process, a Swenson crystalliser is used as single reactor suitable for granules of R.P. (0.42–1.1 mm or smaller) where such R.P. can be used with lower operating and m/ce cost and control of atmospheric pollution.

A thin spray of conc. H_2SO_4 acid is sprayed on top of slurry while R.P., mixed with weak P_2O_5 , is fed from bottom; an agitator agitates reactor fluid so that isothermal condition is maintained. The reactor slurry is filtered; waste and weak acid is recycled. Reactor cooling is by flash cooling. Such plants can be built up upto 650 MT per day.

In Rhone poulene process, temperature of reactor is controlled by flow of air on surface of reactor by evaporative cooling of droplets of slurry picked up by a sprayer system. Sulphuric acid is also added as a spray at top of reactor. R.P is introduced through center at top zone of maximum agitation. The process is suitable for 100-80 MT per day P_2O_5 . There are other processes using single or multiple reactors.

Process Key Parameters

Control of $\rm H_2SO_4$ content in liquid phase is very important for close control of reactions, an optimal values of 1.5% is typical and is difficult to control when reaction time is sort. Most of the processes used 8 hours reaction time with Kellog-Lopker dihydrate process (used in England) which requires a short residence time of 1.5 hrs. with two reactors but uses a automatic $\rm SO_4$ control instrument for close control of sulphate.

Crystal form (s)	No. of separation stages	Conc. of product acid $\% P_2O_5$	Temp. of reactor	Recrystallisation temp.
Hemihydrate	1	40–50	85–100	-
Hemihydrate- dihydrate	1	26–30	90–100	50–60
Hemihydrate- dihydrate	2	40–50	90–100	50–65
Dihydrate- hemihydrate	2	35–38	65–70	90–100

Table 3

Hemihydrate Process

In hemihydrate process of phosphoric acid manufacture, a high conc. of acid is obtained, until that acid may not be further concentrated. Such consideration will depend on whether waste heat steam from on site sulphuric acid plant can be used elsewhere in the plant. When concentration is not necessary, both capital and operating cost become less. Product phosphoric acid is also somewhat sludge free and less aluminium in acid. However, better material of construction is required in reactor, pump, filtration, centrifuging as reaction temp. is high which enhances corrosion.

PHOSPHORIC ACID 203

Hemihydrate-Dihydrate Process

This process, as developed by Nissan Japan and named Nissan H Process, uses only one filtration process and gives pure by-product gypsum which can be used in other products of manufacture without any further treatment. The P_2O_5 recovery from R.P. is 2-3% or more as losses of P_2O_5 in gypsum is very less. However the plant cost is higher due to elaborate process stream. Hemihydrate-Dihydrate Process with two stage filtration of centrifuging is also provided by Fisons HDH Process and Nissan C Process. However, extra capital cost, due to additional filtration stage, is offset by additional recovery of P_2O_5 .

Filtration of Digestor Effluent

The effluent from digestor or reactor is filtered to remove gypsum and any insoluble materials from rock phosphate or formed in the reaction from phosphoric acid completely and efficiently by continuous filtration, usually rotary tilting pan type filters, travelling pan filters, horizontal table filters and even belt filters are used. The cycle of filtration in these filters proceeds as follows:

- (a) Deposition of phosphoric acid-gypsum slurry on filter cloth
- (b) Collection of phosphoric acid from filter by application of vacuum
- (c) Two-Three counter current washers to completely remove the phosphoric acid from gypsum and from filter cloth
- (d) Discharge of washed gypsum
- (e) Washing of filter cloth to prevent scale formation.

In the washing stage, successively weaker solution of phosphoric acid is collected. The last wash is with fresh water or sump water. Very weak phosphoric acid, collected from last section, is returned to the preceding section. The filtrate from the first section is often returned to the reactors. In addition, some portion of product acid is also recycled to reactor to control percentage solids at 40–50% level. The design filtration rate is 6.5 t/m²/day. The filtration rate varies due to various factors; type of R.P. and impurities including presence of insoluble matters like clay, use of crystals shape modifiers in reactors, control of reaction conditions viz. temp., conc. and viscosity of acid and extent of recovery. Filtration rate also varies due to design of filter, % vacuum, type of cloth and other criteria.

Concentration and Clarification of Phosphoric Acid

Dihydrate Process Phosphoric Acid has a concentration of 26-32% P_2O_5 . This acid can be used in manufacture of some phosphatic fertilisers but for most other purposes, it is economically preferable to concentrate it by evaporation. The concentration of P_2O_5 for phosphatic fertilisers and other uses as below.

Table 4

Product	Phosphoric acid conc. % P ₂ O ₅	
MAP (depending on process)	40–54	
DAP	40	
Shipment grade	54–60	
Superphosphoric acid for shipment for fertiliser production	69–72	
TSP-Den Process	50–54	
TSP-Slurry Process	38–40	

Precipitates formed in phosphoric acid during or after conc. are usually collected at bottom of container. The precipitates formed before conc. are mainly calcium sulphates and fluorosilicates. Accordingly to acid conc. a no. of precipitates can be formed during and after conc. These precipitates are called sludges and cause problems in handling and use of the acid.

Phosphoric acid concentrators may by termed as indirectly heated concentrators or directly heated ones (uses are declining due to difficulties of recovery of phosphoric acid mist and fluorine compounds from exhaust gases). Super phosphoric acid is made by concentration of 54% P_2O_5 acid in directly fired concentrator. Prayon, Nordac and others have developed acid concentrators from 30% to 54% P_2O_5 . Fuel requirement for this range of conc. is 140,000 Kcal/t P_2O_5 and power 70 Kwh/t P_2O_5 . Any liquid or gaseous fuel can be used. For conc. from 54% to 70% P_2O_5 , fuel required is 600,000-800,000 Kcal/t P_2O_5 .

Indirect heated concentrators are heated by steam or some heating media viz. dowtherm heated by flue gases from a furnace in an exchanger. Common type of evaporators or concentrators with forced circulation or evaporator-crystalliser, where precipitates grow into coarse crystals and removed by centrifugation or settling. For conc. from 30% to 54% P_2O_5 . It can be carried out in 1, 2 or 3 stages. Steam required for conc. is 1.90 t/t P_2O_5 , power 11–16 Kwh/t P_2O_5 and cooling water 6 m³/t P_2O_5 for condensers. Fluorine removed during conc. is about 70–80% of original conc. in acid, most of it is volatilized or condensed in condenser and recovered.

For conc. from 54% to 70% P_2O_5 , H.P. steam (27 ata 230°C), required is 1 ton per t P_2O_5 , power, 24 KWh/t. Fuel for downtherm heating is 640,000 Kcal/t P_2O_5 . In concentrating Phosphoric acid to super phosphoric acid 69%–72% P_2O_5 , most of fluorine is volatilized so that F content is reduced to 0.2–0.3%. Reactive silica is added during conc. to enhance fluorine evaporation and F can be brought to 0.1%. Such acid is suitable to produce dicalcium phosphate or ammonium phosphate, used for animal feed also.

Advantage of Super Phosphoric Acid:

- 1. Saving in freight cost
- 2. Sludge elimination
- 3. Acid is less corrosive
- 4. Suitable for production of clear liquid fertiliser (ammonium polyphosphate solution).
- 5. The acid can be used to produce compound fertilisers by melting route.

The main disadvantages are higher energy requirement, high viscosity (acid required heating upto 60°C prior to pumping) and corrosion in concentrator.

Table 5Chemical composition or Super Phosphoric Acid

	Phosphoric	acid,	as	P_2O_5	=	69–72%
١	Fluoride as	F			=	0.2-0.3

When reactive silica is added during concentration of Phosphoric acid, F content can be brought down to 0.1%.

Uses: For dicalcium phosphate production, ammonium phosphate.

Use of Sludge in Phosphoric Acid

Precipitated sludge in phosphoric acid contains about 38 (Max) distinct Phosphate compounds depending on impurities present in rock and sulphuric acid. The precipitates appear before, during

PHOSPHORIC ACID 205

and after conc. Precipitation is a continuous process in storage of phosphoric acid. The usual method of separation of precipitates is by centrifuging/filtration. Sludge formed after conc., contains a high proportion of complex Al and Fe phosphate compounds *e.g.*, (Al, Fe)₃KH₁₄PO₄)₁₈4H₂O. The separated sludge is mostly citrate soluble and is often used in T.S.P. Production where TSP is sold on the basis of citrate solubility and not water solubility basis. The sludge can be mixed in the production of nongranular MAP which is used as an intermediate for the production of compound NPK fertiliser.

Material of Construction

Reaction tanks/ reactors and its agitators are subjected to most severe corrosive action. The tanks are often made up of lined steel tanks or concrete with carbon brick lining inside. Suitable concrete mixture with additives are used in case there is carbon brick lining damage. The flash coolers and circulating pumps as well as filters are subjected to severe corrosion. Abrason is most prominent in vessels starting from reaction to filtration steps. The quantitative value of corrosion is the result of chemical and physical factors. The presence of impurities in phosphoric acid enhances corrosion.

1. Physical Factors

Peripherical speed of process fluids;

The speed, usually considered in a phosphoric acid plant is given below

Filter cell = 30 m/min

Pipes = 60 m/min

Agitators = 250 - m/min

Pump impeller = 1000–1500 m/min

2. Temperature

Although temperature level is lower, corrosion gets enhanced with rising temperature.

3. Chemical Factors

- (i) Conc. sulphuric acid in presence of metal cations, Ca⁺⁺, Al⁺⁺, Fe⁺⁺, etc.
- (ii) Excess H_2SO_4 this causes more corrosion if excess is more than 1.5–2% or H_2SO_4 conc. is beyond 20 gm per lit. in reaction mixture. Pitting, due to chlorides, is enhanced at this conc.
- (iii) Presence of Fluorine in R.P. The conc. varies from 10–14% or P_2O_5 in R.P. The HF acid in formed between reaction of R.P. and H_2SO_4 .
 - (iv) HF has a great affinity for silica:

$$6HF + SiO_2 = H_2SiF_6 + 2H_2O$$

However, HF is more aggressive acid in corrosion process than H₂SiF₆ (Fluosilicic acid).

(v) Presence of Chloride in R.P. beyond .01 – .05 limits enhances pitting in metals.

Table 6 Analysis of single super Phosphate

Single super phosphates contain mono, di and tri calcium super phosphates along with iron and Al sulphates, calcium fluoride and gypsum. Typical analysis of single super phosphate is as below:

 P_2O_5 (W.S) = 18% (6% as free acid corresponding to 8.3% H_3PO_4)

$$Water = 5.39 \text{ (Water of constitution)}$$

$$P_2O_5 \text{ (Citrate soluble)} = 0.40$$

$$P_2O_5 \text{ (insoluble)} = 0.46$$

$$CaO = 26.6$$

$$F = 1.1$$

$$SO_3 = 31.3$$

$$Fe_2O_3 = 0.48$$

$$SiO_2 = 1.75$$

$$MgO = 0.14$$

$$Al_2O_3 = 0.25$$

Capital Cost

The capital cost (1990) of a 600 MT/day phosphoric acid plant is of the order of US dollar 26.9 million + 50% cost for off sites facilities. The break up cost is as follows:

R.P. storage = 4.4%, Phosphate rock grinding = 17.6%, reactions and filtration = 44.9%, acid conc. = 14.7%, gypsum scrubber and ponds = 15.3% and acid storage = 3.3%. This is as per European conditions.

TSP contains 46% P₂O₅ and is also called concentrated super phosphate.

New technology for phosphoric acid manufacture:

Israel Mining Industry has developed a process using HCl for manufacture of phosphoric acid instead of $\rm H_2SO_4$.



ELECTROPLATING PROCESS

In plating process, metallic ions in the electrolytic bath are reduced and deposited on cathode as a metallic coating when current of required density and voltage (D.C.) is passed to bath. The anode can be the pure metal, being deposited in soln. or it can be insoluble anode, usually carbon rod, when metallic salt of the metal is reqd. to be added to the electrolyte to maintain concentration of metal ions.

The electrochemical process is controlled by (1) Faraday's laws of electrolysis (2) Standard single electrode potential and (3) Ohm's law. Faraday's laws gives the quantity of materials deposited, being directly proportional to the amount of current flow and its duration. It is inversely proportional to the oxidation state of metal in the electrolyte. Ohm's law gives the flow of current being directly proportional to the applied D.C. voltage and inversely proportional to the resistance of the system. The internal resistance of the electrolyte bath depends on various factors.

Standard single electrode potential of the metal to be deposited, gives min D.C. voltage for plating. The actual voltage reqd. is determined as per various competing reactions in the bath. Single electrode potentials are given in table 18 (vol. IIA). A normal $\rm H_2$ electrode is used to determine potentials of other metals.

As per Faradays Law
$$W = CtZ$$

where W = wt. of ions deposited, C = Quantity of electricity passed, coulombs (current in amps \times time in secs) t = time in secs, Z = Electro chemical equivalent of metal ion or wt. of ion deposited by 1 Amp current in 1 sec.

96500 coulombs of electricity (1 Faraday) is reqd. to deposit/liberate 1 gm. equivalent wt. of any element.

As per Ohm's Law
$$-c = \frac{V}{R}$$

where c = current flow (amps) V = potential difference, (Volts) R = resistance, (Ohms)

Standard single electrode potential of a metal in soln. of its salt containing one gm-ion of the metal per litre and a normal hydrogen electrode. The e.m.f. of a electroplating bath is the difference of single electrode potentials of electrodes in the bath.

1. TYPES OF ELECTROPLATING

There are five types of plating processes of coating on base metals:

- 1. Rack Plating
- 2. Barrel Plating
- 3. Spot plating or brush plating
- 4. Pulse plating
- 5. Non electrolytic deposition

1. Rack Plating

Parts to be plated, are fastened to fixtures (cathode) in the plating bath where it is immersed either manually or some auto processes. The fixtures carry the plating current to the parts.

2. Barrel Plating

The parts (pins, clips, lip stick cans, buttons etc.) which are small pieces are put in a plastic hexagonal perforated container which is rotated either manually or automatically through the electrolytic bath. The parts slowly tumble while the barrel is rotated and all are exposed to the plating action. Current is supplied through various types of controls into the mass of parts where it is transferred piece to piece by contact during rotation.

3. Spot Plating or Brush Plating

Here plating is not done by total immersion only. Using anodes, surrounded by absorbent material that do not require immersion of parts and portable equipment for spot plating is done. The anode is a saturated soln, which is rubbed over the surface area to be plated. Very high localised current density is used because of movement and abrasive action on absorbent material. This is a patented process till 1995. This is suitable for electrodeposition of worn out machine parts.

4. Pulse Plating

This is immersion plating with the difference that current is passed in short intervals of higher intensity followed by stoppage of current. Each cycle is indicated as ratio of on time/off time duty cycle in % and the frequency of time length of each cycle. Not all metals can be used here for deposition as some metals can not tolerate variation in current flow more than 5–10%. The process was under research till 1996.

5. Non Electrolytic Deposit

There are three types of deposit, namely immersion or displacement deposit, noncatalytic chemically reduced deposit and catalytic chemically reduced deposits.

2.0 ELECTROPLATING BATH AIDS

Various chemicals are used for pH control, good plating quality, brightness, hardness of deposits etc.

(a) Rack Gold Plating on Copper or Copper Alloys

Gold plating solution:

Gold chloride = 2 gms/lit (0.27 oz/gallon US)

Pot. cyanide = 0.025 gms/lit

Pot. pyrophospate = 80 gms/lit

Bath temperature = 65–87°C

ELECTROPLATING PROCESS 209

D.C. voltage = 6V

Current density = Amp/cm^2

Anode = S.S.

Anode-cathode ratio of area = 3.1

N.B. Technical grades of chemicals should be used for better results.

(b) Tin Plating on Iron

Tin plating solution:

 $SnCl_2H_2O = 15 \text{ gms/lit } (2 \text{ oz/gallon US})$

NaOH = 19 gms/lit

NaCN = 7.5 gms/lit

Hot boiling soln. is used

D.C. voltage = 6V

Current density = Amp/cm^2

anode-cathode ratio of area = 2.1

(c) Cadmium Plating

CdO = 30 gm/lit.

sod. cyanide = 40 gm/lit or

Cd cyanide = 40 gm/lit

Anode-cathode ratio of area = 2.1

D.C. voltage = 4-6 V

Current density = Amp/cm^2

Efficiency = 95%

Temp. = 20-35°C

Total NaCN/Cd = 3.75 : 1

D.C voltage = -

(d) Chromium Plating

$$CrO_3 + H_2SO_4 + catalyst soln. = 250-350 gms/lit$$

 $CrO_3/SO_4 = 75 : 1 \text{ or } 125 : 1$

Temp. = 32-43°C (decorative articles)

37-65°C (hard deposit)

C.d. = $10-20 \text{ Amp/dm}^2 \text{ (decoratives)}$

= 15-35 Amp/dm² (hard deposit)

(e) Copper Plating

CuCN = 22.5 gms/lit

Sod. cyanide = 34 gms/lit

Sod. chromate = 15 gms/lit

NaOH = as reqd. to adjust pH

Analysis: Cu = 16 gm/lit

Free CN = 7.58 gms/lit

Temp. = $32-43^{\circ}$ C

C.d. = $1-1.5 \text{ Amp/dm}^2$

Voltage = 6 V

Anode Cathode area ratio = 1.1

Efficiency = 30%

(f) Bright Gold Deposit

 $KAu (CN)_2 H_2 O = 4-16 \text{ gm/lit.}$

KCN = 15-90 gm/lit.

Pot. carbonate = 0-30 gm/lit.

Pot. Phosphate = 0-45 gm/lit.

KOH = 10-30 gm/lit.

Brightner = 0.1-10 gm/lit.

Temp. = 15-25°C

C.d. = $0.1-0.5 \text{ Amp/dm}^2$

Agitation = Reqd. (moderate)

Anode = Platinum/SS or gold

DC voltage = 6-12 V

Anode-cathode area ratio = 3.1

(g) Pure Aluminium Metal

Pure Aluminium is made by electrolysis (which forms the cathode where Aluminium is deposited. The anode is the crude metal rod. The electrolyte is AlCl₃. Voltage maintained is 4V D.C.

(h) Aluminium Production

Aluminium production by electrolysis of pure bauxite in a cell house containing a large no. of cells called "pot" which are connected in parallel at 4V.D.C. Bauxite is mixed with cryolite (Sod. Al flouride) in reqd. proportion and 8% Calcium flouride is used to reduce melting temp. to 1000–950°C. Crude Aluminium is deposited on cathode which forms bottom of the pot and oxygen is liberated on carbon anode rods, suspended in the bath. Oxygen then reacts with carbon of anode

to form CO_2/CO . For maximum current efficiency, wt. ratio of $\frac{NaF}{AlF_3}$ is maintained at optimal level and AlF_3 is added at regular interval to compensate the volatility loss. Bath is maintained 12–15°C over the melting point. The polarities of cells (anode and cathode) are changed at intervals to over come polarisation.

3. OTHER CONSIDERATION IN ELECTROPLATING

(i) Strike soln.—The sol. is so designed as to deposit thin layer at relatively high c.d.

- (ii) High over voltage—maintained to overcome high hydrogen deposition potential at cathode.
- (iii) Covering power-higher c.d. to deposit metals in recess/bodies.
- (iv) Throwing power-ability of soln. to deposit higher coating thickness of metal into low current density area.
- (v) Depositing potential of metal-It should be lower than that of hydrogen.
- (vi) Alloy plating—Two or more metals of alloy should be present in electrolyte and their deposition potential is sufficiently close.
- (vii) Stabiliser-It is an additive to electrolyte to prevent oxidation of iron or Fe⁺².
- (viii) Brightener-Additive to ensure brightness of coating by modifying grain structure.
- (ix) Cathode coating–When the protecting metal is situated below the protected metal in the e.m.f. series. Example–Tin plated iron. Whenever tin losses integrity, bared iron comes in contact with moisture and a galvanic couple arises where tin serves as cathode (+ve electrode) and iron as –ve electrode (anode). The electron flow from bare iron surface to tin where they discharge H ions while iron decays sending more and more iron into soln.
- (x) Anode coating—It is reverse of cathode coating.

3.1 Signs of Cathode and Anode

Signs of cathode and anode terminals are exactly opposite to those in galvanic cells where anode is -ve electrode and cathode is +ve electrode while in electroplating or electrolysis, on the contrary, cathode is -ve electrode where ions give out charge and anode is +ve electrode where metals go into soln. as +ve charged ions.



COOLING TOWERS

1. Cooling towers and spray ponds are devices for the cooling of water by transfer of heat, from hot recirculated cooling water from factory plant facilities. The c.w. gains sensible heat from various heat exchangers; by exposing the surface of hot water to incoming / surrounding air which cools the water by partly evaporating the hot water so as to remove the latent heat of water and also a part of sensible heat of hot water is removed. This is due to difference in temperature between hot water and incoming/ surrounding air to the cooling tower system or spray pond. The total heat thus removed to the air from the hot recirculated water in the cooling tower, or spray pond is the sum of latent heat of evaporation and sensible heat. The air temperature must be lower than the hot water temperature. The cooling of water in cooling tower or spray pond takes place upto and below the wet bulb temp. of air in warmest summer months.

Cooling Tower Types

- (i) Induced draft mechanical tower.
- (ii) Forced draft mechanical tower.
- (iii) Parabolic chimney type cooling tower.
- (iv) Spray ponds for smaller cooling duty.

Out of two types of mechanical draft cooling towers only Induced draft tower with fan at the top of tower is widely used because there is no chance of short circuit of moist hot humid air, as found in forced draft tower, with fan at the bottom of tower. I.D. cooling towers can be grouped in a row of several towers depending on cooling duty and water rate, per unit cross section, is 2-3 times more than that of natural draft towers. In I.D. cooling tower maximum approach to W.B. temperature is economically possible. Running cost of mechanical draft C.T. is higher due to power cost of fans. Hot water is put into the sump at the top of tower and it flows into C.T. through nozzles at the top deck. Splash bar fills inside the tower gives the increased area of contact of water with the air.

Wind velocity below 4 km/hr is suitable for I.D. tower; cooling approach, upto 5 °F. of W. B. temperature of air is possible during summer months for design purpose. I.D. cooling towers have double entry of air through lowers at two sides and air and water flows counter currently.

In mechanical draft cooling towers, hot water from plant facilities is directly taken to the top and flows through two flapper valves into top deck having plastic nozzles for flow of hot water into the basin. Cooling water level in top deck is kept at 3"-5" height.

COOLING TOWERS 213

Natural Draft Cooling Tower

These are hyperbolic tall, usually concrete, towers with hot water spraying arrangement at the top through which water falls through the empty tower without any splash bars. Air enters at the bottom of the tower and flows upward by the draft produced due to difference of temperature between top water zone and bottom zone of cold water. Operation and maintenance cost is low but drift loss from top is more and cooling approach is lower. Wind velocity, higher than 4 Km/hr is suitable but precipitation loss is more. First cost is higher.

In natural draft cooling tower hot water pump, at the bottom of the C.T., boosts the pressure for sending hot water to the top sprayers due to higher head required to lift the hot water. This increases the operation cost. Cold water pump usually recirculates the cold water to the plant. Thermometers are used for measuring Hot and Cold water temperature and pitot tube is used for measurement of cold water flow. Hot and cold water header pressure measurement are usually provided.

2. SPRAY POND

Here hot water is sprayed through a series of spray nozzles in cold water pond and temperature of water comes down due to sensible heat transfer and evaporation which removes the latent heat. The heat duty is less and operational cost is the least. Cold water is recirculated to the plant facilities from spray pond.

In general for all types of cooling water systems emergency cooling water circulation pumps with stand by emergency power, are usually required to run the pumps/critical equipment on power failure. A pit pump provision for draining of cold water basin is usually kept as well as cold water outlet strainers for cold water outlet to cold water pump, are provided.

3. DESIGN CRITERIA

Cooling approach: It is the difference between cold water and wet bulb temperature of water. A minimum of 5°F cooling approach during summer months is possible.

Dew point temperature: Temperature at which air-water mixture is saturated with water vapour.

Cooling range: It is the difference between hot water temperature and cold water temperature.

Wet bulb depression: It is the difference between dry bulb and wet bulb temperature.

The following parameters are required for designing a cooling system.

- (i) Quantity of water to be cooled, m³/hr.
- (ii) Wet and dry bulb design temps. selection.
- (iii) Air velocity through the towers. m/sec.
- (iv) Maximum and minimum dry bulb temperature.
- (v) Hot water and cold water temps required.
- (vi) Height of tower, m and tower fill volume, m³.
- (vii) psychrometric chart of air at atmospheric pressure.

4. PERFORMANCE COEFFICIENT OF A COOLING TOWER

This is based upon the heat dissipated per square metre of cross-sectional area of cooling tower per degree C/ degree F cooling approach to the wet bulb temperature.

Performance co-eff =
$$\frac{W}{S_a} \frac{\left(t_{wl} - t_{w2}\right)}{\left(t_{w2} - t_{w.b}\right)}$$
 kcal/hr m² °C
Where
$$W = \text{Cir. rate, m³/hr.}$$

$$S_a = \text{Packing area. m²}$$

$$t_{w1} = \text{Hot water temp. °C.}$$

$$t_{w2} = \text{Cold water temp. °C.}$$

$$t_{wb} = \text{Wet bulb temp. °C.}$$

5. PSYCHROMETRIC CHART AT ATMOSPHERIC PRESSURE

The relation between dew point, saturation point of air and specific humidity of air is given by Psychrometric chart. It shows saturation curves for air at different % saturation upto 100% saturation (dew point curve) at different dry bulb temperatures in horizontal axis vs partial pressure of water vapour in air as well as specific humidity in vertical axis. See psychrometric chart in chapter 44

Dew Point and Humidity

- (i) Dew point temperature can also be found out from steam table by knowing partial pressure. Dew point remains constant so long air remains unsaturated. Dew point rises if some additional moisture is added to the air as partial pressure of water vapour rises.
- (ii) Wet bulb temperature is the dynamic equilibrium temperature attained by water surface exposed to air when the sensible heat transfer from air to the water surface is equal to the latent heat of evaporation of water carried away to the air from the water surface.
- (iii) Percentage relative humidity It is the ratio between partial pressure of water vapour at any temperature to the difference between total pressure less partial pressure of water vapour at the same temperature.
 - (iv) Dry bulb temperature It is the ambient air temperature.
- (ν) Percentage humidity of air It is a ratio between kg of moisture carried in 1 kg of dry air at the desired temperature to the amount of water vapour carried by 1 kg of dry air at saturation.

6. SIZING OF COOLING TOWER

As per graphical method given in Perry'.

7. COOLING TOWER FAN

These are motor driven axial 4/8 bladed cast aluminium fans with reduction gear box located at the top of cooling tower (I.D. tower). Air swept volume through the tower is one of the key factors in proper performance of cooling tower. A medium height chinmey around perimeter of fans sweep is installed for providing required draft of air.

In F.D. cooling tower fan is located at the base of cooling tower.

8. COOLING TOWER MATERIAL OF CONSTRUCTION

Normally Ascu treated wood (Pine, fur etc.) is used for construction of C.T. structure, splash bars, desks, fan chimney, stairs etc. S.R.P. grid support is used for splash bars. Two end covers are made of asbestos sheet and also the louvers at opposite sides. Concrete cooling tower body is also made.

COOLING TOWERS 215

Cooling tower basin is made of R.C.C. work. Water level is kept at about 6–11 inches above the wooden support base in C.T. basin. Basin cold water outlet is provided with double S.S. screen. Make up water is added to the basin through float actuated control valve as per C.T. basin level.

9. WET BULB TEMPERATURE CALCULATION

Formula $t' = t - \frac{k_w}{h_{fg}} \times h^1_{fg} \left(\mathbf{W'} - \mathbf{W} \right)$

Where $t' = \text{Wet bulb temperature } ^{\circ}\text{C}$.

t = Dry, bulb temperature °C.

 $K_w = \text{Diffusion co-eff. of water vapour through film of air water vapour mix, kg/sec. m}^2$.

 $h_{f_0}^1$ = Enthalpy of vapourisation at wet bulb temp. kcal/kg.

 $h_{\rm fg}=$ Enthalpy of vapourisation at dry bulb temp. Kcal/kg.

W' = Spec. humidity at wet bulb temp, kg moistre/kg dry air

W = Spec. humidity at dry bulb temp, kg moistre/kg dry air

10. COOLING TOWER BLOWDOWN

The blowdown rate from a cooling tower depends on allowable concentration build up of a constituent in make-up water. Usually a conc. cycle of 2–3 is maintained in circulating water. Formula for concentration ratio.

Concentration ratio = $\frac{\text{Concentration of a constituent in cir. C.W.}}{\text{Concentration of the constituent in m.u. water.}}$

This indicates concentration of one constituent in m.u. water and can go upto twice or thrice in circulating water. The blowdown rate from cooling tower basin is to be kept accordingly. The C.T. blowdown valve pit is kept at the back of the cooling tower. The C.T. blowdown water is never to be discharged into the factory storm water drain. This is taken separately through pipeline to C.W. treatment plant as C.W. is always treated usually with chromate-phosphate dosing in the range of 10 ppm chromate and 20 ppm phosphate for corrosion control of C.W. pipelines and connected equipment.

11. M.U. COOLING WATER

A continuous flow of make up water is needed to compensate for evaporation loss, drift loss and blowdown loss of circulating water.

M.U.water flow = evaporation loss + drift loss + blowdown water. Usually evaporation loss is calculated @ 1% of circulating cooling water flow per 12° F cooling range (difference between Hot return cooling water temperature and cold cooling water temperature both in same temperature scale). Drift loss is taken as 0.1–0.2% of circulating water flow. Blowdown rate is as per concentration cycle adopted.

12. PRESSURE DROP IN CIRCULATING COOLING WATER CIRCUIT

The sum of the pressure drops in various cooling water loops (incoming and outgoing) in the plant should be zero. This is as per Hagan-Poiseuille' equaiton. The cooling water pump pressure

should be sufficient to send the cooling water to the remotest plant facility and allow the return cooling water to rise to the top of cooling tower. C.W. pipeline sizing is to be done considering proper velocity of water.

13. TREATMENT OF COOLING WATER

Treatment of cooling water is required to keep the rate of corrosion of carbon steel of C.W. pipelines and connected equipment to min. level. Usual method is to put required quantities of sodium dichromate and sodium hexametaphosphate so as to keep a concentration of chromate-phosphate in the ratio of 10:20 ppm.

For control of pH of circulating cooling water, usually alkalies are put into cooling water so as to make the pH at 6.9–7.3. The pH of cooling water will, however, depend on the make up water pH and presence of sulphate reducing bacteria in a circulating cooling water. Now a days instead of phosphate-chromate treatment which requires reducing Hexabalent chromium to trivalent chromium in the blowdown cooling water, the quaternary ammonium compounds are used to control corrosion, pH, and sulphate reducing, nitrifying and other bacteria, algae and fungi growth. Use of the quaternary ammonium compounds in required doses depends on test runs with the dosing chemicals. The chemicals are, however, costly. Manufacturers claim that no treatment of C.T. blowdown is required. Microbiological analysis of c.w. is to be carried out.

14. RATING OF COOLING TOWER DUTY

It is usually expressed as quantity of cooling water circulation rate in m³/hr at design hot and cold water temps based on basic data, supplied by customer or as amount of heat to be removed in KW or MW units (kcal/hr). One KW of heat removal is equal to 856.8 kcal/hr.



PAINTS AND PAINTING

1. COLOUR SIGNIFICANCE

(i) Attention galling: Various colours of paints cause attention in the following decreasing order.

Red - orange

Red - blue

Yellow

Pink

and luminous yellow- green.

- (ii) Adding coolness or warmth: Red-orange (hottest), reds and yellows. Blues and the violets convey coolness.
- (iii) Creating moods: For stimulation and excitement, warm colour especially red-orange, red and orange. Blue-violet, violet and blue colours are subdued colours and tranquillizing colours are yellow-green, green and blue-green.
 - (iv) Suggesting size: For spaciousness, use. whites and lime blues.
 - (v) For feeling of closeness and confinement use dark colours.
- (vi) Camouflaging: To hide overhead structures, extend wall colour to whole area. To hide pipes projections etc., paint them with the same colour as their surrounding.
- (vii) Saving on light: Use highly reflective colours (ceilings-white), Light reflection factors are given in table.

2. PAINTS

Paints are homogeneous mixtures of paint vehicles and pigments. Paints are used mainly for protective treatment of base materials, metals or wood mainly for decorative purpose.

2.1 Typical Components of Paints or Lacquers

2.1.1 Paint vehicles:

- (a) Non Volatile –(i) Oils (triglycerides of fatty acids)
 - (ii) resins
 - (iii) Dryers
 - (iv) additives

- (b) Volatile—aromatics, chem and industrial solvents and lacquer solvents, ketones, esters and acetates.
 - **2.1.2 Pigments.** (A) Opaque
 - (B) Transparant
 - (C) Special purpose.
 - **2.1.3 Oils.** Alkali refined Kettle bodying linseed oils are mostly used. Soyabean oil, Tung oil, (china wood oil Kettle bodying) Tall oil (combination of fatty acids and resins) are used in some types.

2.1.4 Synthetic resins – (a) Phenolic resins

- (b) modified phenolic resins (ester gum and pure phenolics).
- (c) maleic resins used in shorter oil lengths (made by reacting maleic acid or anhydrite with a poly-hydric alcohol such as glycerine in presence of rosin or ester gum).
- (d) Alkyd resins (made by reacting phthalic acid or anhydrite with glycerine and pentaerythritol which are further modified with drying or nondrying oils which are mostly used in synthetic enamel paints or industrial paints.
- (e) Urea resins (Urea formaldehyde). It is usually combined with alkyd resins or plasticisers (suitable for metal painting).
- (f) Melamine resins (made from malemine and formaldehyde and give better finish than urea formaldehyde-expensive paint for colour retention.
- (g) Vinyl resins (co-polymers PVC and PVA). available as white powder to be dissolved in strong solvents such as esters or ketones Paint has maximum resistance to chemicals, acids, alkalies, solvents and water. Used in cables, swimming pools, cars, masonry etc.
- (h) epoxy resins (These are epichorohydrin bis-phenol resins, have chain structure compound of aromatic groups, made from aromatic groups and glycerol. Various modifying agents are used to give epoxies of different properties.
- (i) Polyester resins (made by Polymerisation of styrene and lower m.p. resins which are used in paint suitable for use including, varnishes and water proofing paper etc.).
- (j) Polyester resins (polyester polymer with oils have good adhesive to metals used in industrial type paints.
- (k) Silicone resins (Polymerised resins of organic polysiloxanes have excellent chem. resistance with high heat or electrical resistance—a very expensive paint.
- (1) Rubber brand resins (Synthtic rubber paints have high resistance to water and corrosion and used in swimming pool concrete floor, asbestos sheeting, exterior structures.
- (m) Urethanes (resins with alkyds type which are widely used as floor finishes and exterior clear finishes on wood.
- **2.1.5 Dryers.** Facilitate drying of paints. Mostly dryers are metallic soaps that act as a polymerisation or oxidation agents or both. Soaps must be soluble in paint vehicle. Tall oil dryers are less soluble than napthenate based on naphthenic acids. Other dryer normally used are:

PAINTS AND PAINTING 219

1. Cobalt drier – 6 – 12% cobalt metal in most powerful drier used in industry. It has an oxidation catalyst. Excessive amount of cobalt drier can result in wrinkling. It is purple in colour and shall not discolour paint.

- 2. Lead drier 24 or 36% lead metal. This drier has been replaced by calcium or zircomium based drier.
- 3. Calcium drier acts as a polymerisation agent and sold as 4,5 or 6% calcium. It is more popular.
- 4. Zirconium 6, 12, 18% Zirconium often used in combination with cobalt and calcium drier.
- **2.1.6 Additives.** Used in a small quantity, its name and percentage are kept secret by manufacturers. They belong to the following trade names.
 - (i) Antisetting agents (gives a gel structure with the vehicle).
 - (ii) Antiskinning agent Common name methyl ethyl ketone (used in alkyd paint).
 - (iii) Bodying and puffing agent used to increase viscosity.
 - (iv) Antifloating agent used to supress separation of colours when two or more colours are used.
 - (v) Loss of dry inhibitors certain colours (black, organic red or TiO₂) tend to activate the drier and paint looses drying agent on ageing. Agents added, try to react slowly with vehicle and additional drier added to replace what was lost. Now cobalt base agents are used.
 - (vi) Levelling agents special wetting agent is used to cause vehicle to net the pigment which will not leave any brush or roller mark.
 - (vii) Foaming prevention Found in water based paint and debubbling agent is added.Grinding of pigments Additives are added during grinding of pigments which help in melting.

Fungicides – added to prevent its development in exterior paints.

Antisagging agent – to prevent runs or sags of paints.

Glossing agent – to increase gloss.

- **2.1.7 Lacquers.** Dry by evaporation of the solvent they are either cellulosics, resinous and plasticizers (non volatile). A combination of cellulosics and resins based lacquers is used.
- **2.1.8 Solvents.** (*i*) Commonly used petroleum solvents as, for example, white spirit distilation range, 149–204°C, also called thinner or terpentine; faster evaporation rate is suitable for all paints except for flat finishes where heavy mineral oils are used. Even faster evaporation mineral oil (distillation range 93–112°C) is used and often called as VM and p. naphtha is also used as all purpose thinner, EPA (U.S.) limit is 250 gm of volatile solvent/litre of paint. Special purpose naphtha with aromatic content reduced is used as thinner for cleaning. (*ii*) Paraffinic hydrocarbons BP 40–60°C, 60–80°C and 80–120°C and specific gravity 0.645–0.676 and aromatic content 1–5% are also used. (*iii*) Aromatic solvents from coal tar distillation are also used in industrial and chemical coatings. They are having low boiling point chemical. Solvent power increases with increase in aromatic content.

- (a) Benzol C₆H₆ BP 79°C
- (b) Toluol C₆H₃(CH₃)- BP 110°C
- (c) Xylol (Type-1) C_6H_4 (CH₃) (BR 138 144. 5°C). These are three types of Xylenes 23°C xylene, 5°C xylene and 10°C xylene (o.m. and para), and naphtha (BR 149 –177°C) it has slow evaporation rate.
- (e) Trimethyl Benzene, high aromatic petroleum fraction having 80–93% aromatic (BR 100–211°C), FP> 32 °C.
- (iv) Alcohols Acetone CH₃COCH₃ fast evaporating.

Ethyl Acetate, CH₃COO C₂H₃ - fast evaporating and low cut.

Butyl Acetate, $CH_3COOC_4H_9$ – good medium boiling solvent for lacquers. It has good blush resistance.

Isopropyl Alcohol - BP 82.4°C, FP 12°C, S.P. Gravity 0.7925.

Its property is similar to ethyl alcohol.

n-Propyl Alcohol – Azeotrope Compound, 71.7% alcohol and 28.3% water. It dissolves resin, shellac and Castor oil.

Ethyl Alcohol – C_2H_5OH containing 5% methanol. – Good latest solvent for lacquers and also used for dissolving shellac. Methanol added to prevent consumption.

n- Butyl Alcohol - Medium boiling – popular latest solvent for lacquers. BP 118° C, FP 37° C and SP. Grv. 0.811.

2.1.9 Pigments

It gives hiding or obliterating power of paints i.e., coat's property in covering the surface being painted. It also gives decorative effect of paints.

Relative hiding power of white pigments.

		Hiding Unit
Lead Carbonate	_	15
Lead Sulphate	_	15
ZnO_2	_	20
Lithophone	_	25
Antimony Oxide	_	28
Anatase titanium di-oxide		100
(Crystalline form very less used	l).	
Rutile titanium di-oxide		125 - 135
(Crystaline form mostly used ha	ving	
density of 240–250 kg/m ³).		

2.1.10 Extender Pigments

Low cost raw material (RMC) and they are nonhiding pigments such as Calcium Carbonate, talc and clay; percentage used is more if hiding property is to be imparted. Talc is magnesium silicate. China clay (Aluminium silicate) – mostly used in water based paint. Other extender is diatomacius silica used to reduce sheen or gloss.

PAINTS AND PAINTING 221

2.1.10 Protective Paints

Another use of pigments apart from decorative purpose is protection of metal or wood surface (e.g. Cuprous Oxide and tributyl oxide to give ship's bottom property to kill barnacles and antimony oxide gives fire retardant property. Higher the pigment power higher is the gloss property. Other properties are to control viscosity and to give very specific property of flourescence, phosphorescence and electrical conductance.

3. TYPES OF PIGMENTS

Apart from white pigments, extender pigments (whiting calcium carbonate (most important), Talc (magnasium silicate commonly used to give low sheen), China clay (solvent base coating) and other extenders (silica. diatomacious), black pigments (Carbon black and Lamp black) etc. are made. The pigment colours are given in table 170 vol IIA.

Metallic Pigments – Aluminium powder; non leafing type used to give high metallic look and leafing type for silvery look Aluminium paint should not be in acid or alkaline atmosphere. Zinc oxide and red lead are used as primers.

3.1 Colour wheel

This wheel as given in Fig.1 gives complimentary colour at diametrically opposite to each other.

4. INDUSTRIAL PAINTS

There are three generic types of resinous paints.

(i) Alkyds (ii) epoxies and (iii) Vinyls.

4.1 Industrial Usage

Alkyds – When a polyhydric alcohol reacts with a poly basic acid, an alkyd resin is formed. In refinery, alkyd paints are used.

Epoxyes – It is made by reacting epichlorhydrin with poly phenolic compounds or mono/diamines or other compounds, when epoxy resin is formed. It is suitable for solvent atmosphere and certain types of caustic atmosphere.

Vinyls – Suitable for highly alkaline and acid atmospheres as well as areas subjected to extreme moisture and condensate.

4.2 Paint Thickness

Paint thickness on applications: Minimum dry coating thickness required, is 2–3 coats of thickness, 4–5 mils. The instrument is called elcometer.

4.3 Cleaning for Painting

- (i) Thorough cleaning of paint surfaces by sand blasting (costly), wire brushes, knives and emery papers are suitable and solvents are used for oils and grease removal.
- (ii) Application of paints is by hand brushes or spray guns, whenever required, in industry. After 1st coat application, the coating is to be given time for drying so that 2nd coat could be applied, 3rd coat is required in special equipment.
- (iii) A good thinner is to be topped up on paints occasionally to restore paint consistency for the consumption of paints in containers.

- (iv) Atmosphere for painting In humid atmosphere which hampers evaporation of paint vehicle. Also no painting when the ambient temperature is low.
- (v) After each coat of painting application, check for holidays, thin spots, Pinholes, missed area and general appearance.
 - (vi) Without proper cleaning of surface, painting will be poor.
- **4.4** Major cost in painting is cleaning operation which is of the order of 50–60% of cost of paints.

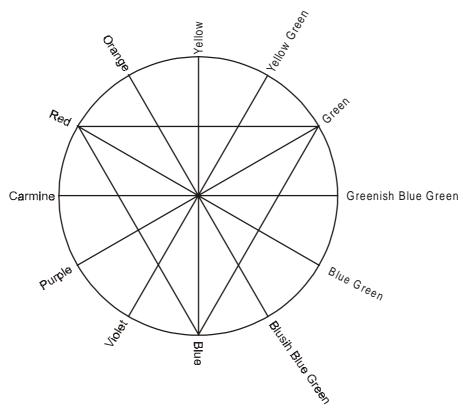


Fig. 1. Colour Wheel. Complementary Colours are at Diametrically Opposite to each other.



BIOGAS PLANT (DOMESTIC USE)

Capacity range = 60–3000 cft/day methane gas

A. MAZOR EQUIPMENT

1. Digestor

1. This is the main equipment where bio gas (methane) is produced from cow dung and water slurry by methanococcus micro organism. It is constructed by brick and cement mortar as a square or rectangular shaped box of size : $2.50 \text{ mH} \times 2.5 \text{ mL} \times 2.0 \text{ mW}$ (suitable for a family of 6–7 persons) with neat cement finish on floor.

The
$$\frac{\text{Ht}}{\text{depth of slurry}}$$
 ratio is kept at 5–6.

Digestor bottom level should be about 0.5m from grade level. The digestor top is to be covered with wooden top cover to prevant escape of methane. Gas outlet pipe (pvc) of 1" I.D. to methane gas holder, where, an inlet valve is to be provided at digestor side near top edge.

2. Drying Tank (1+1)

A small tank of capacity $3m^3$ of brick and cement mortar at below digestor slurry ht. is to be made so that spent slurry from digestor falls through a $3^{''}$ PVC pipe. The tank should have a drain provision of $2.5^{''}$ pvc pipe with closure by wooden circular wedge. The spent slurry tank bottom is to be made by brick work without neat cementing.

3. Gas Holder

1. Circular steel gas holder of size 2 m dia. and ht. 3 m, has a capacity of $9.5 \, \text{m}^3$ (7–10 days consumption) for a family of 6–7 adults. The gas holder foundation (circular) is to be constructed by brick and cement mortar at 1 m above grade level and dia of foundation should be $6^{''}$ more than holder dia with 3 equal pockets for bolting of gas holder foundation bolts of 25 mm dia \times 300 mm long with 1:2:4 concrete with the support plate of gas holder. A 1 G.I. vent valve for purging at top of gas holder and a $1/2^{''}$ G.I. valve at bottom of gas holder for gas outlet, is to kitchen to be provided; and earthing wire (GI – 6 mm dia.) is to be connected from gas holder bottom plate to a 3 feet deep earthing pit.

B. PROCESS

A slurry of cow dung and water is to be made first by putting 30-35 kg/day cowdung into digestor in 1-2 days and then made into a slurry at a ratio of 1:1 (cowdung-water) by adding water;

some cut straw is to uniformly mixed with slurry for better composition of spent slurry in drying tank. Also pH is adjusted by adding alkali to slurry to make pH 6.8–7.2 maintain slurry level at 0.4–0.5 m in the digestor. If necessary, more cow dung is to be added. Cover the digestor with the wooden cover. The total hold up time in the digestor is 20–40 days. Aerobic fermentation first starts with air inside the digestor for 3–4 days, followed by anaerobic fermentation which continues for 17–35 days when methane gas, along with CO₂, is generated in the digestor and is led into gas holder through outlet pipe. Methanococcus micro organism breaks the cowdung cellulose, generating methane (CH₄) gas with some CO₂ The top cover edge is to sealed by mud to prevent gas leakage.

The air inside the gas holder is to be purged out initially as methane enters the gas holder with open purge value in the gas holder top and keeping the gas outlet valve in the gas holder closed after purging. Purging is to be done for a considerable period of time to prevent explosion, (explosion range 5–15%). The gas holder outlet line to kitchen is also to be purged for 5–6 mins. After gas holder is purged and top valve closed, methane pressure develops in the gas holder.

$$\begin{array}{c} C_6 \, H_{10} \, O_5 \, + n \, \, H_2 O \xrightarrow{hydrolysis} n \, C_6 \, H_{12} \, O_6 & \longrightarrow \text{acidification} \longrightarrow \\ \text{cowdung} & \text{by acid bacteria} \end{array}$$

$$\begin{array}{c} 3n\,CH_{3}COOH \xrightarrow{\hspace*{1cm} \text{Methanation} \\ \hspace*{1cm} \text{by bacteria} \end{array}} 3n\,CH_{4} \; + \; 3n\,CO_{2}.$$
 carboxylic acid

Thermal efficiency is 30–50%. The calorific value of bio methane gas (with CO_2) is 500. BTU per SCF or 4450 kcal/m³. Some recycling of spent biomass can also be done.

After methane gas generation stops, close the gas inlet from digestor; open spent slurry to drying tank. One drying tank is to be used and other are kept stand by. The compost manure removed from drying tank is used for agriculture. Finally the digestor top cover is opened and spent biomass cleaned – a part of which can be recycled. About 2 months time is required for proper composting of spent slurry. The methane gas generation rate is about 0.23 m³ per kg of cow dung.



SUGARS

A. MANUFACTURE OF CANE SUGAR

(i) Preliminary Crushing and Extraction of Juice

The sugar cane is weighed and subjected to crushing to extract juice. Crushing is done in two stages in juice extractors or roller mills. The roller mills contain 9 rolls in sets of 3. In the beginning sugar cane is first lebelled and then cut into small pieces followed by crushing in 1st rollers when 50% of juice is extracted. This is followed by crushing in 2nd and 3rd sets of rollers. The composition of raw cane juice.

Water	Sucrose	Reducing	Other organic	Inorganic
		sugars	compounds	compounds
77-88%	7–21	0.3 - 3	0.5-1	

(ii) Screening of Sugar Juices

The raw juice, as it comes from the mills, is contaminated with suspended matter, mainly bagasse fibres and mud. Separation is carried out by screening either in stationery drags screening or in vibrating screens, made of brass. The drags screens is a perforated plate (260 – 400 perforations per sq. inch) screen fitted with a movable rubber scrapper which recycles the bagasse particles to the crushers through a conveyor. In vibrating screen the openings are smaller usually 0.1mm but oscillations are more than 600 per minimum. The amount of bagasse that can be separated by screening varies from 1–10 gms/per litre.

(iii) Removal of Suspended Matter from Screened Juice

The screened juice still contains about 1-10% suspended impurities (non-sugars) which consist of waxy matter (lipids), pentosans, protein matter (non sugars) and Inorganic oxides (CaO, MgO, Fe₂O₃, Al₂O₃, P₂O₅, SiO₂) and insolubles. These are partly filtered out by heating the juice to its B.P. followed by centrifugation in a high speed centrifuge. About 0.05–0.1 gm/lit. of suspended matter is removed by this method. Heating removes the dissolved air, coagulates the proteinic nonsugars and pentosans. Fe₂O₃ and Al₂O₃ are partly precipitated and SiO₂ is precipited partly in combination with sesquioxides.

(iv) Clarification of the Raw Sugar Juices

The residual suspended impurities and ionic dispersoids in the raw juice are separated by clarification with lime. The non-sugar dispersoids, present in the sugar juice, are listed below.

		% non-Sugars
(a)	Hemicelluloses, pentosans (gums) and pectin.	8.5
(<i>b</i>)	Proteinic compounds.	
	(a) Albumin	7.0
	(b) Albuminoges and Pectoges	2.0
	(c) Asparagine and Glutomin	9.5
	(d) Glycine and Aspartic acid	15.5
(c)	Organic Acid (Except Amino)	
	(a) Aconitic, Oxalic, Succinic, Glycolic and Malic	13.0
(<i>d</i>)	Colouring matter	
	(a) Chlorophyl, Saccharetin, tannin etc.	17.0
(<i>e</i>)	Waxy material (cane wax)	17.0
(<i>f</i>)	Inorganic Salt	
	Phosphates, Chlorides, Sulphates, Silicates, Nitrates of Na, K, Ca, Mg, Al and iron	7.0
(g)	Silica	2.0

Item (a) to (f) are present as collodial dispersion. Item (g) is present as molecular and ionic dispersion. Out of the above dispersoids some are removed in the heating and centrifugation operations mentioned in step (III) above and remaining dispersoids are separated by liming process.

There are several clarification processes available, as stated below.

Lime Clarification Process

Lime clarification process is the oldest process using lime as the clarifying agent. There are several modification of the process.

- (1) Cold liming process
- (2) Hot liming process
- (3) Fractional liming process
- (4) Fractional liming and double heating process

The other two clarification processes viz (5) Carbonation process and (6) Sulphitation process, are basically similar to lime clarification process since in the above two processes lime is also used as the clarifying agent.

(i) Cold Liming Process

Lime is made into a slurry with condensate in a rotary slaking machine, or other types of machine. The rotary slakes consist of slowly revolving, nearly horizontal cylindrical vessel, fitted with baffles. Lime and water are fed at one end while the milk of lime is discharged from the other end which is transferred to a settling tank where undissolved impurities collect at the bottom. The slurry of lime over flows into a sieve (13 mesh) which is constantly sprayed with water.

The filtered milk of lime is stored in a tank, diluted to proper concentration and pumped to feed tank in the clarification section. The concentration produced depends on the process used - in Sulphitation process it is $10-15^{\circ}$ Be' or less and in carbonation process it is 20° Be'.

SUGARS 227

Measured quantity of milk of lime is added to the cold raw sugar solution in the mixing tank provided with agitator with manual, automatic or electric metered feeding device.

Some Phosphates are also added. The process is either batch or continuous as in a modern process. Lime addition is adjusted so that pH is maintained at 7.2–8.6 with constant stirring. Lime, Ca(OH)₂ reacts with the non-sugars in the raw juice so as to (*i*) precipitate some of them as insoluble Ca compounds or complexes (*ii*) Coagulation of the colloidal and coarse dispersoids and (*iii*) form soluble Ca compounds and complexes.

The magma is heated in a heater and transferred to classifiers to flocculate and settle the insoluble reaction product. The quality of phosphate in the raw juice measures the amount of precipitate to be formed in clarification process since more the phosphate contact, more will be the amount of precipitate. pH is an important factor in the liming process and the volume of precipitated mass increased with increasing pH.

The insoluble solids settle to the bottom of the clarifier and are removed as dark coloured matter (due to tannins). Clear sugar juice from the clarifier is then transferred to carbonation tank.

Feed to clarifier is either at centre of periphery and the flow is also either counter current or parallel current.

The clarifier used, are of multiple shallow tray types, having capacities ranging from 50–120 cft per short ton of cane per hour.

- (ii) In hot liming process the raw juice is first heated to 100–102°C and milk of lime is then added to maintain a pH of 6–8.0 and the juice is allowed to settle.
- (iii) In the fractional liming process, pH level is raised to 7.6-7.8 in two stages-first liming at 6.0 6.4 pH and then heated to 100 102°c and second liming at 7.6-7.8 pH, followed by settling.
- (*iv*) Fractional liming and double heating process, which is similar to fractional liming process with the exception that the magma is given a post heating operation after second liming, followed by settling. The first heating is also done at 93°C.
- (ν) **Carbonation process:** The excess lime present in the clarifier as dark coloured sugar juice, is removed by carbonation since it imparts syrups and molasses a very dark colour and also increases their viscosities, resulting in difficult crystallization operation, and also, the sugar that is produced, is of brown in colour.

The carbonation process is carried out either in a single stage or in two stages and consists of bubbling $\rm CO_2$ through magma. The residual non-sugars are precipitated or adsorbed on the $\rm CaCO_3$ crystals.

In single carbonation process, the sugar juice is mixed with 70 liter of 20° Be' lime per 1000 liter of juice in the carbonator so as to make this sugar juice extremely alkaline. CO_2 gas, from lime kiln, is then bubbled through the mass till the solution shows a neutral reaction of Phenolphthalein. Carbonation time is 40–60 minutes. The juice is then filtered in filter presses.

In double carbonation process, the juice is heated to 55° C and 100 liter of 20° Be' lime is added to 1000 liter of juice and the CO_2 is then bubbled to the juice till the alkalinity of 400–600 mg CaO is attained. Most of the non-sugars are precipited in this stage, and filtered in filter presses. The filtrate is again carbonated till a slight alkaline reaction is observed on Phenolphthalein. Residual CaO along with some non-sugars are precipitated as Calcium Carbonate in the second carbonation process. In second carbonation there is no foaming of the juice. The raw juice is again filtered in filter presses.

(vi) Sulphitation Process

The process consists of adding excess lime as the clarification agent, followed by precipitation of excess lime by SO_2 , SO_2 is dissolved to form Sulphurous acid which reacts with $Ca(OH)_2$ to give $Ca_2(SO_3)_2$ precipitate.

There are two modifications in the process viz (i) single Sulphitation and (ii) Double Sulphitation. The process is either batch or continuous. In (i) mixed sugar juice is heated to 75° C and taken in a preliming tank and milk of lime at a concentration of $6-15^{\circ}$ Be' is added so as to make the pH 7.4. The mixture is transferred to Sulphitation tank where SO_2 is bubbled from the bottom of the tank which also gives the desired mixing effect. Some provision is made in the tank for circulation of the mass for good absorption and mixing.

The total filtering area required in single sulphitation process is 35 square metre per 100 ton of cane per day.

SO₂ gas is produced by burning Sulphur in Sulphur burners using excess compressed air.

From prelimer, the juice is pumped to the sulphitation tank by a recirculation pump whose function is to circulate the juice in the sulphitation tank and to reduce the pH level in the preliming tank by returning a portion of the limed juice to the preliming tank. pH control in sulphitation tank is done either by lime control or by SO_2 flow adjustment. It is then filtered by sedimentation – the muddy juice is filtered in filter presses.

The double sulphitation process is a new development and consists of second liming to pH 10.5 after first sulphitation. The juice is then heated to 65°C and filtered. The filtrate is again Sulphited to neutral reaction followed by second filtration. The total filtration area required in this process is 65 square metre per 100 ton of cane per 24 hour.

Comparison of the different clarification processes:

(A) No-sugars are removed more completely in carbonation process than in sulphitation process and lime clarification processes. (B) Sugar crystals obtained from carbonation process is more white than in other processes (C) Out put of sugar is more in carbonation process (D) sulphitation process requires improvement.

(vii) Evaporation for Crystalization

The classified sugar juices from the sedimentation tanks, as well as from the filter presses, are screened in a bronze wire mesh having 2000 meshes per cm square. The juice, having a pH of about 7.1, is now concentrated in triple effect vacuum evaporaters with natural circulation and fitted with down comer at a temperature of 103°C. The concentrated juice or syrup crystallises in U type crystallizers (Swenson Walker Crystalliser) using fine sugar as seeds. Heat of crystallisation is removed by circulating cooling water to the crystalliser. The magma is then centrifuged and washed to separate the sugar crystals. The separated mother liquor or molasses sent to vacuum pan feed tank. The primary molasses is then mixed with syrup and crystallised, followed by centrifugation. The separated mother liquor or molasses is sent to the storage tank via weighing scale for storage and sold as a by product. Sugar crystals are dried in a rotary drier, cooled and directly bagged.

B. MANUFACTURE OF BEET SUGAR

The important steps in the manufacture of beet sugar are.

(1) Extraction of juice from beet roots by diffusion

SUGARS 229

(2) Clarification in two stages: First by double carbonation followed by Single Sulphitation

- (3) Evaporation of clarified juice in five effect evaporators.
- (4) Post clarification of syrup by single sulphitation
- (5) Crystallization of beet sugar from syrup
- (6) Separation of beet sugar from the slurry (beet molasses)

1. The Extration of Sugar Juice from Beet Roots by Diffusion

The beet roots containing sucrose in the cells, are washed and sliced into V shaped pieces, called cossetes. The freshly cut pieces are put in the last cells of diffusion battery. The battery consists of 8–16 diffusions cells and work on counter current principle. Hot water is added on the first vessel and almost exhausted cosset are put into it. The residual sugar in cossetes diffuse into the hot water and the weak sugar solution thus produced is sent to the second vessel after it is heated up in a heater. The stronger solution from the second cell is then passed into the remaining vessels in turns and in the last vessel, the rich solution is contacted with the fresh beet slices. The juice leaving the last cell is having almost the same concentration as that in the beet itself and is sent for clarification. The juice obtained is purer than that obtained from cane sugar since gums and albumin etc., do not pass through the cell wall.

Diffusion process for cane sugar extraction is not possible due to deterrioration on long standing.

2. Refining of Raw Beet Sugar

The raw beet sugar obtained is not perfectly white due to presence of impurities which are removed by further clarification and recrystallization. The refining process of beet sugar consists of.

- (a) Affination
- (b) Re-melting
- (c) Clarification treatments (i) liming (ii) Adsorption on bone charcoal.
- (d) Re-crystallization
- (e) Centrifugation
- (f) Drying.

Uses. By product molasses is mainly used for fermentation for alcohol – It is also used in refractory to increase green strength, and as paste for charge chrome.



PHENOLS FOR DISINFECTION

Phenols are antiseptics and disinfectants containing phenols (cresylic acid) and cresols.

Black Phenyls are cheap products whose specification is given in BS 2462–1961 (modified black phenyl and modified white phenyl)

Black Phenyl: Homogeneous solutions of coal tar acids or similar acids derived from petrolium or any mix. of these with or without hydrocarbons and with a suitable emulsifining agent. Black fluids are miscible, yielding stable emulsions with artificial hard water in all proportions from 1–5%.

White Phenyl: Finely dispersed emulsions of coal tar acids or any mix. of these, with or without hydrocarbons.

UK Brand names of white Phenyl: Sal-Hycol, Printol, Pacolin and R Crolin.

Modified black and white fluids may contain, in addition to above, any other ingredients, but if these are made the type and amount must be disclosed.

Classification as per germicidal value and method of testing employed. There are 6 designations of black fluids.

- (i) BA (Rideal-walker, R-W coefficient not less than 4)
- (ii) BB (R-W coefficient not less than 10)
- (iii) BC (R-W coefficient not less than 18)
- (iv) BE (Chicks Martin, C-M coefficient not less than 1)
- (v) BF (C-M coefficient not less than 3)
- (vi) BG (C-M coefficient not less than 4.4)

There are 7 designations of white fluids, 6 of these groups WA, WB, WC, WD, WE, WF and WG has the same minimum R–W or C–M coefficient as the corresponding black fluids and the 7th white fluid group WD has a minimum crown Agent coefficient of 10 and minimum R–W co-eff. of 18. For modified Black and White fluids, the Phenol co-eff. (Staphylococcus) determined by a specified method, must be stated by the manufacturer in addition to R–W co-eff.

Procedure

Test norms

1. R-W test - BS - 541 Broth culture of specific micro organism.

2. Chick Martin test, BS 808 Yeast culture

3. Crown Agent's test, BS 2462 For white variety only, requires sterile artificial sea

water dilution of disinfectant in presence of soluble and insoluble organic matter.

This test is for ensuring that modified black and modified white phenols are not unduly selective in their bactericidal activity.

There are two important processes -

(1) Cumene oxidation (Hock's Process) and

(2) Toluene oxidation process.

It produces skin irritation and causes nervous system breakdown. LD_{50} human = 140 mg/kg body weight.

TLV limit is 5 ppm (CIS = 1.5 ppm)

1–3% phenol is removed from waste water by cumene and acetophane extraction.

4. Phenol co-efficient test, BS 2462

5. Manufacture

6. Toxicity

7. Waste water treatment for phenol recovery



FERROUS ALLOYS

The Ferro alloys have higher percentage of iron. Usual ferro alloys are Ferro-silicon, ferro-manganese, ferro-chromium, Ferro-titanium, ferro-nickel, ferro-boron, and ferro-molybdenum etc.

These alloys are prepared by direct reduction of respective oxides or technical grade oxides or concentrates with carbon (carbothermic process) or with Aluminium (alumino thermic process). Ferro-manganese, ferro chromium and ferro silicon are prepared by carbothermic reduction of particular oxides in submerged arc electric furnaces. Other raw materials, apart from corresponding oxides, is metallurgical coke and power requirement for the electric furnace varies from 15–100 MVA.

Ferro-manganese can also be produced in Blast furnace. Ferro-chrome and ferro-manganese have high affinity for carbon and these alloys contain 7–8% carbon, while Ferro-silicon of 25% Si, contains 1% C and that containing 75% Si has 0.1% C.

Low carbon ferro-manganese (0.1–2% C) or ferro-chromium (0.02–2% C) is produced first as a silicon containing ferro alloy using quartzite and coke in a submerged arc electric furnace. These silicon containing alloys are then used for silicon thermic reduction process using an appropriate oxide ore in an arc refining furnace to get low carbon ferro-manganese or ferro-chromium.

Silico thermic direct reduction process with addition of Aluminium is used to manufacture ferro-molybdenum and ferro-nickel. The energy released in the reaction is adequate to melt both metal and slag. Solidified block of ferro molybdenum or ferro-nickel can be recovered easily.

Ferro-vanadium is produced by using vanadium oxide, iron turning, stampings or rail bits and Aluminium in a refractory lined open hearth furnace where heat of reaction melts both metal and slag. Often inert materials are added to lower the peak temperature. Ferro boron and ferro titanium is produced in a manner similar to Ferro-titanium which contains 70% Titanium and 30% iron; using scrap Titanium and iron apart from Aluminium and so also Ferro-Zirconium. Ferro-selenium is produced by exothermic reaction of iron and selenium powder.

Steel industry uses these ferro-alloys to produce particular steel or alloy, containing the alloying metal with iron in ferro-alloys.

FERROUS ALLOYS 233

Table 1 Composition of ferro-alloys

Item	Alloying metal	Iron	Carbon
Ferro-manganese	Manganese - 75-92%	25–8%	
Ferro-Chromium	Chromium - 45-95%	55–5%	
Ferro-Titanium	Titanium - 20-75%	80–25%	
Ferro-Nickel	Nickel - 20-60%	80-40%	
Ferro-Silicon	Silicon - 8-9.5%	92-91%	
Ferro-Silicon	Silicon - 25%	75%	1%
Ferro-Molybdenum	Molybdenum - 62-70%	38–30%	
Ferro-Selenium	Selenium - 50%	50%	



HIGH CARBON CHARGE CHROME

1. Charge chrome containing carbon and 50–60% chromium, is required for alloys like stainless steels. Typical analysis of charge chrome :

Cr = 50-56% or 56-60% wt%

C = 6-8% (max)

Si = 4% (max)

P = 0.03 (max)

S = 0.035 (max)

Size of product: 10-150 mm lumps; standard = IS 11945 (1987)

High carbon charge chrome is required for introduction of chromium in S.S. and special alloys; raw materials and utilities required are :

Chromite Ore = 2200-2500 kg/Te

Briquette Coke = 330 kg/Te

Lime = 156 kg/Te

Quartzite = 142 kg/Te

Molasses = 600 kg/Te (binder)

(Sugar = 85.5%)

Paste for electrode = 60 kg/Te (molasses)

and power (a) 3000-3100 kwh/Te (for Pelletising and preheating route)

(b) 3800-4100 kwh/Te

2. There are two routes for manufacture – by pellestising and preheating or by Briquette charge without preheating.

Charge Pelletising Process

Chromite Ore materials as per calculation is ground in ball mills to 80% below 200 mesh and then formed into 15–20 mm balls in dicc pelletiser, for agglomeration, is used after adding coke and flux (bentonite 1%) in the charge. The balls are then preheated in a rotary static vertical klin with

off gases from smelting furnace (to save energy in electric smelting furnace as much as 0.7–0.8 kwh/Te). Preheating of pellets makes it hard. The preheated pellets are then melted at 1600°C in an electric submerged arc furnace of capacity 30–45 MVA and voltage 150–160 V with circular stationery hearth with self baking continuous soldering electrode holder assembly as well as electrode stripping mechanism, copper contact clamps for holding electrodes, water cooled copper bus bars with copper tubing. Coke reduces the chromite ore at high temperature.

$$3Cr_2O_3 + 18/7 C = 4/25 Cr_7C_3 + 2CO$$

 $FeO + C = Fe + CO$
 $1/3 Cr_7C_3 + 1/3 Cr_2O_3 = Cr + 3CO$

The cast housing provides metals and slag draw outs with guns for closing of tap holes and refractory lined laddles for holding tapped molten metal and slag.

Slag granulation plant, crushers are available in the facility along with raw material handling and warehouses. Slag volume is 1.2 to 1.4 times to that of metal. The chromium metal on cooling is crushed into 10–150 mm lumps for use in alloy steel furnace for chromium addition.

Off gase from submerged arc furnace, after it is used to preheat the pellets, is scrubbed in a venturi scrubber with alkaline water.

3. FLEXIBILITY

High carbon charge chrome plants are usually designed for flexibility to produce ferro manganese or ferro silicon.

Power saving

By plasma technology in electric smelter furnace of capacity 30 MW or more. Other power saving processes by Kwasaki, In-metco and Krupp codir.

Lower capacity 2.5-5 MVA plants are also in use.

4. BREQUETTING OF RAW MATERIALS

The grounded ores, after benificiation, are mixed with binders (molasses and lime) and fed to a double roll briquetting press to form $50 \times 40 \times 25$ mm shaped bricks.

In the west, molasses binding material is not used for obvious reasons. Beneficiated ores give better quality charge chrome.



CHARACTERISTICS OF VALVES USED IN CHEMICAL PROCESS INDUSTRY

1. CRITERIA FOR USE

- (i) Material of construction; for body and trim (Stem, seat ring, disk)
- (ii) Valve standard codes and type-rising stem or non rising stem.
- (iii) Connecting flanges Flat, raised face and grooved flange.
- (iv) Valve functions, on-off, throttling, pressure regulation or relief, preventing back flow or combination.
- (v) Press. drop consideration.
- **2.** (a) Gate valve, if used, in throttling service, produce wire drawing.
 - (b) Globe valve throttling efficiency is more due to increased resistance to flow for size upto 6".
 - (c) Plug cock valves are more +ve shut-off than gate valve and can be used for throttling but characteristics are not as satisfactory as glove valve for such service, with lower pressure drop. Non-lubricated plug valves work by cam-crank mechanism. Excellent service, for corrosive service which requires special lining or alloys.
 - (d) Swing check valves have minimum pressure drops and suitable for liquids and for larger line size. It is not suitable for pulsating flows. Some types work only in horizontal lines.
 - (e) Piston check or drop check valves are suitable for vapours, steam, water and pulsating flows.
 - (f) Y-type valves produces lower pressure drop and turbulance than globe valve and is preferred for erosive services.
- 3. Usually globe valve for flow control is used for sizes upto $2\frac{1}{2}$ " to 3" and beyond these sizes, gate valves are used.
- **4.** ASTM A 351 material valves of Ferrite and Austenitic steel castings are used for high temperature service. ASTM A 182 material forged or rolled alloy steel, are used for pipe flanges, fittings for high temperature service.
- **5.** Valves in oxygen service use molybdenum disulphide based lubricant to prevent fire hazards.



BOILER FEED PUMPS AND STANDARD VALUES FOR BOILER FEED AND CIRCULATING WATER

BOILER FEED PUMPS

Dimensioning in accordance with the "Technical Regulations for Steam Boilers" governing the equipment and installation of steam generators, edition of September 1964. German regulation.

Every boiler plant must be fitted with at least two feed pumps driven from two mutually independent power-sources. In the case of steamdriven feed pumps, however, all pumps may be connected to the same steam supply system. Electric feed pumps may be driven from the same power source provided that, in the event of power failure, firing is also disconnected.

Where only two feed pumps are used, each pump must be capable of providing: 1.6 times the total steam output of all boilers to which it is connected, in the case of boilers not fitted with automatic feed control up to 32 t/h.

1.25 times of this amount in the case of boilers of above 32 t/h or where there is automatic feed control:

1.0 times the amount stated above in the case of once-through boilers.

Where more than two feed pumps are used, the pumps remaining in operation after the pump having the highest output has failed must be capable of providing at least the quantity of feed-water specified above for one of two pumps.

Feed Pressure

The feed pressure of the pumps must be sufficient, not only in delivering the quantities of feed water required to overcome the maximum safe operating pressure, but also in delivering the feed water quantity corresponding to the steam output, 1.1 times the maximum safe operating pressure, the resistances between feed pump and steam generator to be considered in each case.

In the case of once-through boilers, allowance must also be made for the pressure loss in the steam generator at maximum steam output.

Power required at pump shaft N = 2.72 $\frac{D.P}{\rho.\eta}$ in kW

where D = feed water quantity, kg/h

P = feed water pressure, atm. gauge

 $\rho = \ density \ of \ feed \ water, \ kg/m^3$

 η = pump efficiency, %, namely:

60-80% for direct coupled centrifugal pumps and

80-90% for reciprocating pumps.

Select a motor rating approximately 15% greater than N.

Table 1

2. Standard Values Feed water

Constituent	Unit	Fire-tube boilers	boilers ¹ atm. g bo			boil wa	Once-through-type oilers and spray-water for super-	
		< 20 atm.g	202)	40 ²⁾	64 ²⁾	≥ 80	Heated-steam coolers	
General Requirements	-		clear and colour less					
Hardness	$\frac{mval}{1}$	< 0.04	< 0.02	< 0.01	< 0.01	Not dete	ctabl	le
Total carbondioxide	mg/1	_	< 20	< 20	< 20	< 1		<.1
Oxygen	mg/1	< 0.5	max. 0.03: for continuous < 0.02 operation					
Iron	mg/1		if possible < 0.05 < 0.03				< 0.02	
Copper	mg/1		< 0.01 < 0.005				< 0.005	
Silicic acid Sio2	mg/1		Continuous operation without < 0.0 blow-down, max. 0.02; otherwise only as required for boiler water			< 0.02		
Potassium permanganate (KMnO ₄) consumption	mg/1		If possible < 10 if possible		possible <	: 5	if possible < 5	
Oil	mg/1	< 5	If possible < 1 < 0.5			< 0.3		
ph.value at 20 °C	_		For all pressures 7 9.5			7 9.5		
			Continuous operation without blow-down					
Conductivity at 20 °C	μS cm		< 0.3 otherwise only as required for boiler water			<0.2		

⁽¹⁾ Source: VGB Reports 1962. No. 76. pp. 1-3.

⁽²⁾ With local heat transfers $> 2.10^5$ kcal/m²h, the standard values for pressures 80 atm.g should be used.

Table 2

3. Standard Values for Boiler Water

Constituent	Unit	Fire-tube						
		boilers < 20 atm.g	20 ²	40 ²	64 ²	80 ²	125 ²	160
P value	mval/1	5.25	< 10	< 6	< 3	< 1	< 0.3"	< 0.1
	= 50mg CaCo ₃ /lit.						< 15	< 5
Silicic acid SiO ₂	mg/1	No restriction if P value and P ₂ O ₅ as specified	3 < 70 + 7p ³⁾	3 < 30 + 3p ³⁾	<10	< 4	< 1.2	< 0.4
Phosphate P ₂ O ₅ ⁴⁾	mg/1	< 25	< 25	< 10			< 3	
Conductivity at 20 °C	µs/cm	< 8000	< 8000	< 5000	< 2500	< 1500	< 250	< 50

- (1) See page 238.
- (2) With local heat transfers.....> 2.10^5 kcal/m²h it is recommended that the standard values for 160 atm. g (apert from SiO_2 and p value) be used in all pressure ranges.
 - (3) p = p value
 - (4) May even be entirely omitted where the sudden appearance of hardness is reliably prevented.
 - (5) 1000 µs/cm is equivalent is approx. 500 mg NaC1/1 $\underline{\Delta}$ approximately 0.05° Be'.



CRYSTALLIZER CLASSIFICATION

Table A

Mode of operation co	ntinuous Batchwise
----------------------	--------------------

Method of crystal suspention Hydraulic, Mechanical Buoyancy, Fixed support

Method of crystal size control Nucleation rate, Intermediate seed rate

Method of growth inducement Evaporation, Cooling, Salting out effect

Table B Equipment Type and Temperature – Solubility Relationships

Effect of temp. rise on	Equipment reqd.	Example
solubility in water		
Small increase in solubility	Evaporator-crystallizer Salting out evaporator	Sodium chloride
Decrease in solubility	Modified evaporator-crystallizer	Anhy. sodium sulphate, Gypsum, Iron sulphate mono hydrate
Substantial increase in solubility	Vacuum crystallizer Water or brine cooling crystallizer	Potash alum, Glauber salt, Coppers, Potassium nitrate
Moderate increase in solubility	Modified vacuum or Evaporator- crystallizer	Pot. carbonate, Sodium nitrite, Pot. chloride

Source: Chemical Engineering, Dec. 6 1965

Solubility curves of various inorganic salts are given in Fig. 1 and Fig.2.

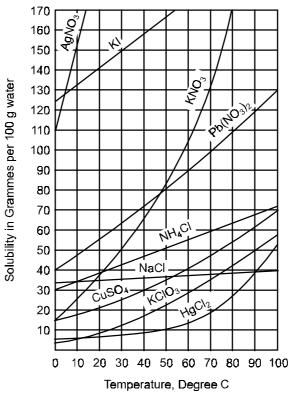


Fig. 1. Solubility curve of various salts.

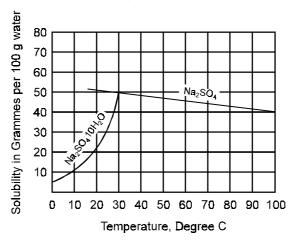


Fig. 2. Solubility curve of Sodium Sulphate.



BRIEF ON OFFSHORE OIL EXPLORATION AND TRANSPORTATION PIPELINE

THE SYSTEM

The two 6.625" O.D. oil/NG lines are fixed inside by spacers (segmented) in a 18" special steel casing pipe. Both the gas/oil pipes as per ASTM standards are provided, with SECT heat tracings tubes, methanol control tubes (1.315" O.D.) and hydraulic control tubes (1.315" O.D.). The gas and oil pipes are provided with 25 mm thick polyurethene foam insulation. The inner pipes are provided with rollers arrangement for free movement due to various factors – winds and waves, tidal currents, breaking waves, seabed topography, hydrostatic head, and sea bed soil resist, horizontal and vertical movements due to environmental forces during installation and operation. The assembled casing pipe is laid on sea bed by pull from shore or pipe pull from lay barge, close to shore (common); cross section of pipe is given in Fig. 1.

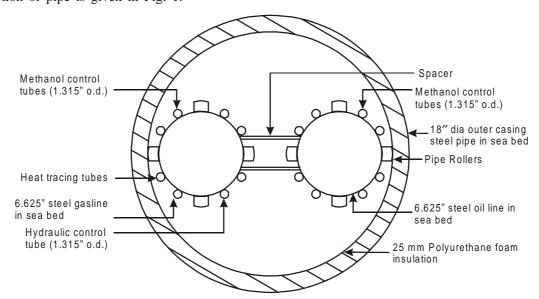


Fig. 1. Offshore Oil/Gas Exploration Pipe line.



INSECTICIDE OR PESTICIDE

GENERAL

- 1. Insecticides or Pesticides are insect destroying substances of chemical, organic extracts from medicinal plants. The insecticide action is through stomach poison, contact poison, systemic and non systemic poison, or act as repellants and attractants. Insecticides are broadly classified into the following groups based on action on the type of pests.
 - 1. Acaricides (Mites destroying)
 - 2. Insecticides (Kill insects)
 - 3. Molluscicides (Action on snails)
 - 4. Nematocides (Action on underground eel worms)
 - 5. Rodenticides (Action on rats or mices and sqirrels)
 - 6. Slimicides (Remove slimes)
 - 7. Fumigants (Prevent deterioration of fruits and cereals)
 - 8. Fungicides (Kill fungus growth)
 - 9. Herbicides (Destroy unwanted vegetation growth)

Insecticides/pesticides can be solid or liquid and natural or synthetic. As per Indian insecticides Act 1986 (Rules 1971) and (ammended in 1995) there were 143 pesticides for registration. Pesticide Board takes about 6 yrs for registration of a new Pesticide molecule. Indian insecticides 1968 Act, goes on changing due to new items or some listed ones deleted due to harmful effects. India is the largest producer of pesticides.

Pesticide formulations are usually made by small scale producing units. Some of the new pesticides, listed in different groups below, have not yet been registered due to old patent Act and exclusively available in the west.

1.1 There are Six Types of Insecticide Grades

E C = Emulsifiable concentrate.

W P = Finely milled powders that form a suspension with water.

W S C = Water soluble concentrate

A S = Alcohol soluble pesticide

W D P = Water dispersible powder.

G R = Granulated formulation.

Powder insecticides are ground with talc or clay with addition of wetting and dispersing agent. Antifungal pesticides are applied either on soil or as folier spray.

2. THE LIST OF VARIOUS PESTICIDES ARE AS FOLLOWS

2.1 Group A - Acaricides

	NY.		
	Name		Area and action
1.	Nimidane	_	
2.	Amitraz	_	Fruit and hops
3.	Apollo 50C	_	Top fruit
4.	Azocyclolim	_	Fruit and Vegetable
5.	Childien	_	Contact poison
6.	Chexalin	_	Mites in fruit
7.	Damfin	_	Stored grain
8.	Dicofol	_	Mites killer
9.	Dieno-chlor	_	Ornamental trees
10.	Dimethoate	_	Insecticide and acaricide
11.	Devipan	_	Agri. insecticide
12.	Fen properthrin	_	Fruits and Vegetables
13.	Malathion	_	Non systemic, contact poision and respiratory system attack.
14.	Mesurd	_	Foliar feeding caterpillars and sucking pests.
15.	Aqualin/cu. sulphate	_	Water body application
16.	Methamidophos	_	Sucking and chewing insects.
17.	Methomyl	_	Wide range and spider mite control.
18.	Parathion	-	Systemic insecticide with contact and stomach action. Highly poisions; suitable for wide range of insects.
19.	Quinomethriorate	_	Fungicidal action
20.	Fenovalerate	_	Termite killer
21.	Dichlorophene		
22.	Fenithrion	_	
23.	Suxon	_	
24.	Para-quate	_	
25.	d-allethrin (4%)	_	Mosquito repellant.
26.	Hexachlorophenol	_	
27.	Sisystox	_	Seed treatment and foliar spray, systemic.

2.2 Group B-Insecticides

- 1. Arsenic trioxide
- 2. Alachlor

INSECTICIDE OR PESTICIDE 245

3. CaO 4. Carbaryl Contact insecticide for apples. 5. Chlor-fenvinphos Seed treatment and soil application. Confidor 6. Systemic, contact and stomach poison. 7. Cupermethrin/ Non systemic, contact and stomach poison. Cypermethrin Cupric acetate 8. Fungicide and insecticide. 9. Diazivon (liquid) 10. **Imidazole** Fabric eating pests and contact poison. 11. Ethion Cattle lice abatement, non systemic insecticide for citrus, decidous fruits, cotton and ornamental plants. 12. Kafil Smoke insecticide (closed space) for white fly, cockroaches and domestic insects. 13. Systemic, with contact stomach poison and also Oxytheoate spidermite. For fruits and vegetable. 14. Propoxur Nonsystemic, for action on sucking and biting insects (aphids, mealy bugs, leaf hoppers, caterpiller on cocoa, rice, oil Palms and others. 15. Rampant Soil applied for seedling pests and cabbage. 16. Reldon-50 Organophosphate insecticide for stored grain and rape seeds. 17. Terbufo S Soil insecticide for vegetable and food crops and nematicide with stomach and contact poison. 18. Terraour P Nematicide and soil dweling insects. 19. Terrathinon Organophosphorous insecticide. 20. Endosulfan/Thioclan For control of sucking, chewing and boring insects and (liquid) mites in a wide variety of crops. 21. Thripstick Pyrethroid insecticide-non systemic for control of many crops. 22. Dichlorovas/Vapona 23. Volathion Foliage and soil application for control of lepido-plerous larvae, bettles and its larvae and locust on large variety of crops. 24. Fungi in fruits and vegetables and ornamental trees. Zind 25. Zolone Organophosphrous insecticide - for insects and spiders on fruits and vegetables. 26. For mosquito killing. Deltamethrin 27. B.H.C. Insecticide 28. DDT Used in public health sanitation

29.

Methyl parathion

63. Prallethrin

30.	Monochrotophos (liquid)		
31.	DDVP (Dichlorovos)	_	Liquid
32.	Diuron		
33.	Canbaryl/Sevin	_	DDT equivalent
34.	Dimethoate	_	
35.	Meta sytox	_	
36.	Al phosphide	_	
37.	Zinc phosphide	_	
38.	Phorate	_	
39.	Chlorobenzilate		
40.	Cupric pyriphosphate	_	
41.	Butachlor	_	Liquid
42.	Data pon	_	
43.	TEPP	_	
44.	Lindane (Y BHC)		
45.	Thiram		
46.	Fenthion		
47.	Endosulphun		
48.	Pyrethrun extract		
49.	Quinal phos		
50.	Aldrin	_	For soil bound pests (termites, cut worms, grass hoppers etc.). Contact and stomach poison – used as dust spray, WDP.
51.	Warfarin	_	Safer insecticide.
52.	Clordane	-	For crickets, locusts, cockroches, ants and leaf eating insects.
53.	Nicotine sulphate	_	Plant insecticide active component containing (0.5%)
54.	Nim oil	_	Vegetable tree origin active component (0.5%)
55.	Methoxyclor	_	Safe for plants.
56.	Chloropyriphos	_	
57.	B.T.	_	Bio insecticide.
58.	Datopon	_	
59.	Allethrin	_	Mosquito repellant
60.	Malthion	_	
61.	Phosphomidon	_	
62.	Deltamethrin	_	Mosquito killer

Mosquito killer.

INSECTICIDE OR PESTICIDE 247

2.3 Group C - Molluscicides

- 1. Calcium arsenate
- 2. Melaldehyde
- 3. Clonitritide
- 4. Methio-can
- 5. Mini Slugit pellets

2.4 Group D - Fumigants

- 1. Al phosphide
- 2. Ethylene dibromide/dichloride.
- 3. Ethylene oxide gas (B.P. 12°C) Cereals, empty building and plant disinfection.
- 4. Tetrachloromethane Green house fumigant

2.5 Group E - Fungicides

1. Copper oxychloride

Aaterra W P – Soil based or compost
 Acticide PMA 100 – Has herbicide action also.

4. Afugan

5. Aliette – For horticulture crop

6. Anildazine – Nonsystemic, foliar aplication for potato, tomatoes and

leaf spot.

7. Antifungin -

8. Arsenic trioxide -

9. Akiran – For cereals, rice, cotton and vegetables.

10. Ashlade TCNB – Additionally potato sprouting prevention.

11. Bitertanvol – Control of scab on appel and black spot on roses.

12. Butyl Paraben – Food preservation and in pharma control of powdery

mildew.

13. CaO -

14. Calixin – For cereals and vegetables.

15. Captafol -

16. Carbendazim – For wide variety of cereals, fruits and vegetables.

17. Carboxin – For cereals.

18. Chlorothalonil - Non systemic, wide variety of crop and additives for

marine coating.

19. Mancozeb -

20. Nickel chloride -

21. Sulphur (Collidal) – WDP and Dust.

- 22. Thiram23. Zineb24. Ziram
- 25. Aurcofungin –
 26. Ferbam –
 27. Copper (++) bydrovide
- 27. Copper (++) hydroxide -
- 28. Dichlorophen Moss controlling
- 29. Diphenyl –
 30. Folicor –
- 31. Fera thinosulf Soil fungi-cide.
- 32. Carbendazim -
- 33. 40% formaldehyde solution with water Soil fumigation

2.6 Group F - Herbicides

- 1. Acifluorfen $(LD_{50} = 1300 \text{ mg/kg})$
- 2. Agriphalan –
- 3. Alachlor $(LD_{50} = 1200 \text{ mg/kg})$
- 4. Amcide –
- 5. Arsenic trioxide $(LD_{50} = 1.46 \text{ mg/kg})$
- 6. Aresin $(LD_{50} = 1660 \text{ mg/kg})$ 7. Atrazin $(LD_{50} = 1100 \text{ mg/kg})$
- 8. Benzolin $(LD_{50} = 4800 \text{ mg/kg})$
- 9. Benlazon –
- 10. Bifenthrin (LD₅₀ = 1740 mg/kg) 11. Chlorovyron (LD = 2700 mg/kg)
- 11. Chloroxuron $(LD_{50} = 3700 \text{ mg/kg})$ 12. Datapon $(LD_{50} = (7126 \text{ mg/kg})$
- 12. Datapon $(LD_{50} = (7126 \text{ mg/kg}) \text{For control of grass in crop}$ 13. Diuron - For control of weeds in non crop area.
- 14. Dowpon $(LD_{50} = 9330 \text{ mg/kg})$ For control of weeds and mosses in non-crop areas viz rail roads and rubber plantations.
- 15. Butachlor -
- 16. Isoproturon
- 17. Paraquat dichloride
- 18. Granoxone
- 19. Fluroxypyr Broad leaf weeds.
- 20. MEPA -

INSECTICIDE OR PESTICIDE 249

	21.	Propanil	_
	22.	Benzonitrates	-
2.7	Group	G - Slimicides	
	1.	Dodecyl Dimonium chloride	- For swiming pool and water treatment plant.
	2.	Drewbrom	_
	3.	Vanicide	 For petrol tanks, C.W. basins, paper plants and cotton fabrics.
	4.	Mycocide	_
2.8	Group	H - Rodenticides	
	1.	Barium carbonate (15–20%)	_
	2.	Comafuryl	_
	3.	Zinc. Phosphide	_
	4.	Alpha Chloralose	_
	5.	Bromediolone	-
	6.	Cupric arsenite	-
	7.	Difenacoum	_
	8.	Drat	-
	9.	Killgerm, Sewarin	_
	10.	Malla – dnite.	_
	11.	Phostoxin	_
	12.	Photo phor	_
	13.	Hydrocyanic acid (prusic acid	id)–
	14.	Racumin	_
	15.	Warfarin – 3	_
	16.	Thallium Sulphates	-
	17.	Aldichlor	_
	18.	Arsenic oxide.	-
2.9	Group	I - Nemoticides	
	1.	Chloropicrin	_
	2.	Cloetho carb	_
	3.	Etho prophos	-
	4	DCIP	_

5. 1, 3 dichloropropane – Has fumigant action to control nematodes.

Soil application.

6.

7.

Dizomel

Fenamiphos Fensulphothrin

- 9. Iozofos Root nematodes control in rice, maize, sugar and vegetables.
- 10. Phorate For sour fruits, vegetables, and grain
- 11. Oxamyl For fruit trees, vegetables, beat and bananas.
- 12. Triazophos For straw-berries, tulips and garlic.
- 13. CS₂
- 14. Carbofuran –
- **N.B.** Banned pesticides are Aldrin, Chlordane, DDT, Heptachlorendin, Taxo-phane and dibromopropane. DDT can be used for public health only. Pesticide act does not enlist all the modern pesticides listed above.

The unit of toxicity of pesticides is usually expressed as LD_{50} which means, it is lethal to 50% of test animals, followed by the dose expressed as mg/kg body weight. The test animals are usually rats and oral (orl.) dose is given. Example $LD_{50} = 1100$ mg/kg for Atrazin (herbicides).

3. Pesticides are complex organic molecules, usually chlorinated hydrocarbons and organo phosphorus compounds which are more toxic than carbamates. There are some inorganic pesticides also usually of copper, arsenic, barium and calcium compounds. There are some plant based insecticides, viz neem (margosa) oil from neem seeds, kernel and leaves contg. active component, Azadiractin Indica and ether extract of which (1.5%) is very effective against locust and white cotton fly. Plant based insidcides are biodegradeable and insects do not develop resistance to the insecticide. The residue, neem cake after neem oil extraction, is used as a bio fertilizer.

Emulsifiable concentrate is one liquid, dispersed in another liquid, each maintaining its original identity and the two liquids are prevented from reacting with each other by the addition of an emulsifier. Emulsions are milky. Herbicides are generally soluble in water. There are powder insecticides also.

4. SOLVENTS FOR PESTICIDES/INSECTICIDES

For application of pesticides, not soluble in water , or plants, crops etc. To form a water system, it requires the use of an emulsifier (nonionic, cationic/anionic, inorganic and natural). Except inorganic emulsifier, all other types of emulsifiers are biodegradeable.

An emulsifer (surface active agent) is having a chemical structure in which the molecule is divided into two moieties—one part of which is hydrophilic (water soluble) and the other part is hydrophobic (water insoluble), usually hydrophobic part is soluble in organic solvents. Emulsifer effects wettability by influenoing both surface tension and contact angle. For longer storage of pesticides, stability of emulsifier is important. Emulsifier pesticides are important because of being more biologically effective and application is easier and economic. Other dispersal system are also used. Wet-able pesticides powder also contain surface active agents.

The emulsifier molecule's hydrophobic moiety is always nonpoliar alephatic and/or aromatic hydrocarbons group, where as the hydrophilic section contents either an ionic group or an accumulation of OH^- group or a poly (Alkenyl Oxide) group e.g., $(-CH_2 - CH_2 - O_-)_n$. The emulsifiers in the first group above are called anionic surfactants and the second group is called polar surfactants. Classification is determined based on whether the main moiety that is left behind after disolution, is negatively charged or positively charged.

Emulsifiers are numbered with a prefix alphabet denoting the type.

INSECTICIDE OR PESTICIDE 251

Table 1

Nonionic emulsifiers

Aliphatic alcohols (-COO) Sorbitol

 $\begin{array}{ll} \mbox{Ethylene Glycol (-COOCH$_2$CH$_2$OH)} & \mbox{Penta erithritol} \\ \mbox{Polyethylene glycol} & \mbox{Saccharose} \end{array}$

Polypropylene glycol Polyglycol ethers.
Glycerol/Polyglycerol Condensed Phenols

Table 2

Cationic emulsifiers

Fatty amine salts,

Salts of alkaline diamine, e.g., alkyl benzyl ammonium

Salts of alkaline, Polyamines

Table 3

Anionic emulsifiers

Alkyl Carboxylates

Alkyl Sulphonates

Alkyl Benzene Sulphonates (Sparingly soluble)

Sulphated alkylamides

Phosphates of phenols

Organic compounds of H₃PO₄

Table 4

Solid Inorganic emulsifier

Bentonite

Fuller's earth (non plastic clay mainly mineral montrorillo nitrite)

Aluminium salts

Ferric hydroxide

Water glass.

Natural emulsifier (Partially surface active lanolin)

Egg Yolk (cholesterols), Gelatine and casin.

Additives (Promoters) for pesticides: Aliphatic alcohols (2-ethylhexanol), urea and xylene.

Emulsion preservatives – Glyoxal (not biodegradable). Emulsion stabilisers – polyglycol, ethers of alcohols, fatty acids, glycerides and alkyl phenols.

5. CRITERIA OF SELECTION SPECIFIC EMULSIFIER FOR A PESTICIDE

(i) Solubility: Emulsifier should be sparingly soluble in internal phase and soluble as in external phase oil. Soluble emulsifiers form w/o emulsions and water soluble emulsifiers tend to form o/w emulsions as per Bancroft rule.

- (ii) Chemical Structure: It should match the chemical structure of internal phase (similar chemical structure of pesticide desirable).
- (iii) Phase volume ratio: It determines the external phase type of emulsion. Excess of oil proceduces w/o (water in oil) emulsion which requires oil soluble emulsifiers; With excess of water, o/w (oil in water) emulsion is produced for which water soluble emulsifier is used.
- (iv) Nonionic emulsifiers are required for preparation of w/o emulsion. Addition of anionic emulsifiers gives rise to mixed emulsifiers which are widespread in use.
- (ν) H.L.B. values: Emulsions are prepared with either one, two or more emulsifiers, usually with different H.L.B. value (hydrophilic lipophilic balance). Hydrophilic emulsifiers with high H.L.B value, gives formation of o/w emulsion. On the other hand, hydrophobic emulsion, with low H.L.B. value, are more used for preparation of w/o emulsions. H.L.B. values of emulsifiers are given in table-below

Table 5
H.L.B. value of emulsifiers (non ionic)

Fatty Acid esters of	H.L.B. value
Ethylene glycol	1.5-2.9
Polyethylene glycol	1.8-18
Glycerol and polyglycol	0.8-4.5
Sorbitol	1.8-8.6
Saccharose	7–15
Polyglycol ethers of	
Alcohols	8.2-16.9
Fatty Acids	8.1–15
Glycerides	8.0-18
Alkil Phenols	9.92-16.5

Trial and error: Based on above stipulations, one/more emulsifiers are selected and a trial sample of emulsifiers with particulars of pesticide is selected for further test. Quantity of solvent (emulsifier and others if any) varies from type of pesticides emulsion. The following table gives the percentage of solvents required for liquid pesticides.

Table 6

Pesticides	Solvent % wt.
Endosulfan, 35%	
E. C.	62
Butachlor	44
DDVP, 76%	16
Monocrotophos W.S.C.	48

6. WOOD INSECTS

Common insects, which destroy wood, are termed as termites and wood worms (Arobium pumctalum, teredo, long worm banberia, monteria beetle, lyctus and xeslabium and rufovillo – san).

INSECTICIDE OR PESTICIDE 253

7. MANUFACTURE OF NEEM BASED PESTICIDES

A. Neem seeds are crushed and extracted by Soxhlet extraction using petroleum ether. The extract is concentrated to yield paste type residue which is then mixed with more ether. Oil is kept for about a month when fatty solid matter settles down and separated by decantation. The yellow coloured liquid is called Neem oil or neemol. Neemol protects about 94.7% of leaf area at concentration of 1000 ppm.

B. For Nimidin manufacture, crushed seed of neem, and ethyl alcohol are used in Soxhtlet extractor which yields vermidin. It is then mixed with ethyl acetate and water. The ethyl acetate soluble part is then concentrated and the resultant residue is again partitioned between a mixture of petroleum ether and aqua methanol soln (5:95). The aqua methanol soln is concentrated to get brown semisolid residue called Nimidin. The solid residue obtained from both of these processes is used as organic manure.



CRITICAL PATH METHOD (CPM)

It is a systematic procedure in Industrial engineering for scheduling and managing complicated projects. The basic factors for CPM are.

- (i) A large project consists of a long list of smaller tasks.
- (ii) Some of these tasks are of such nature that the next task cannot be done unless some other one is finished.
 - (iii) The manpower available at any given period is limited.
- (iv) A careful planning can device a system of priorities which ensures that most important task is always being worked upon by the largest number of people of the project. The manpower deployed will be as uniform as possible.
- (v) The sequence of tasks which is done at least time period one after another without any interuption is the critical path.
- (vi) The procedure is set in diagram depicting all tasks with time periods for completion, floats if any etc. The shortest route time period for completion of the project is called the critical path for the project scheduling. The CPM chart is made with the aid of a computer.
 - **N.B.** PERT Evaluation and Reviewing

Technique It is slightly different from CPM technique.



PSYCHROMETRY

The properties of moist air viz. humidity, relative humidity, wet bulb temperature, enthalpy, humid vol. and saturated volume are dealt in psychrometry. In humidification, evaporation of water or other liq. takes place in contact with air and dehudification means condensation of water in air water mixture or a mixture of non condensible gas and a liquid. Specific humidity of an air water mixture is the lb/kg of water vapour carried by 1 lb/ 1 kg of dry air and it is dependant on partial pressure of vapour.

Percentage humidity is the ratio of actual humidity to the saturation humidity at the air/gas temperature. At all humidities except 0 and 100 percent, the percentage humidity is less than relative humidity. Percentage R.H. is the ratio of partial pressure of water vapour in air water mixture at existing temperature to the vapour pressure of water at dry bulb temperature. Dew point temp is the temp at which a given mixture of air and water) (or a non condensing gas and a liquid) is cooled at, constant humidity, to become saturated. It is also called adiabatic saturation temperature. Total enthalpy is the heat content of air water or gas—liquid mixture. Wet bulb temperature is the equilibrium temp. attained by a water surface in contact with air (or a non condensing gas) such that the latent heat of evaporation of water or liquid in the interface is equal to sensible heat transferred from air water mixture to the water surface. Dry bulb temperature is the ambient temperature. The difference between D.B. temperature and W.B temperature is called wet bulb depression.

Humid volume is the total volume of a unit mass of vapour free gas and that of water vapour in it at 1 atm and existing temperature of gas. For a saturated gas, humid volume is saturated volume. From psychrometric chart (Fig.1), humidity, enthalpy, dew point, D.B./W.B. temperatures, enthalpy etc., can be found when any two of above factors are known. Humid heat is the heat necessary to increase the temperature of 1 lb or 1 kg of gas and vapour it may contain in it by 1°F or 1°C.

Moisture content of air and its temperature is not only important for human comfort but also in industry for processing and storage of various products including food and some pharma products and is the basis of air conditioning. In the process of humidification, cooling of liquid takes place due to evaporation and this principle is used in cooling towers.

Calculation of various properties of air can be made when some factors are known.

Wet bulb temperature

$$t_w = t - \frac{kw}{hfg} \times h'_{fg} (w_w - w)$$

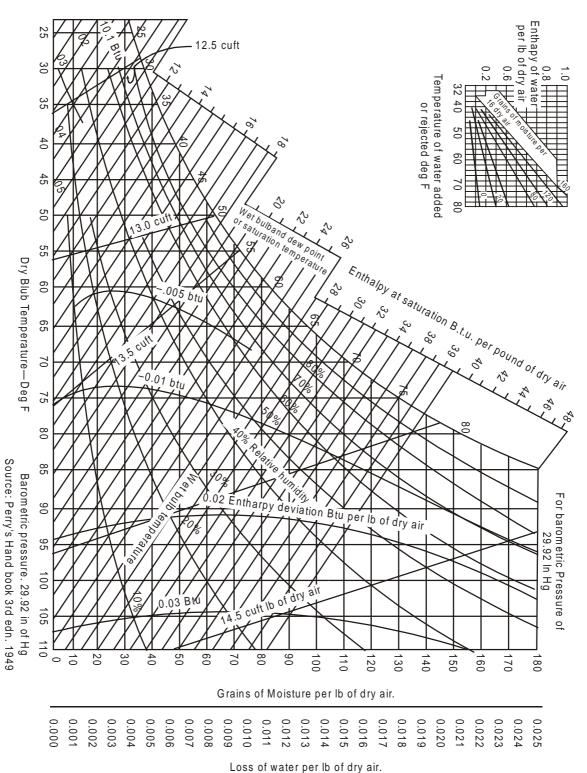


Fig. 1 Psychrometric chart at atmospheric pressure.

PSYCHROMETRY 257

where $t = D.B. \text{ temp } ^{\circ}C$

 $t_w = \text{ wet bulb temp } ^{\circ}\text{C}$

 $k_w =$ diffusion co-eff. of water vapour through film of air water vapour mixture, kg/m²

 $h'^{f}\underline{g}$ = Enthalpy of vaporisation at wet bulb temperature kcal/kg

 h_{fg} = Enthalpy of vaporisation at dry bulb temperature kcal/kg

 $w_w =$ Specific humidity at wet bulb temp.

w =Specific humidity at dry bulb temp.

If the coefficient, kw is not known, dew point can also be calculated as per the modified A.P. Jhon equation or carrier equation.

Specific humidity

$$w = \frac{M_v P_v}{M_a P_a} = \frac{18.016}{28.966} \times \frac{P_v}{P_a} \text{ or } 0.622 \frac{P_v}{P_a}$$

where, w = specific humidity

 P_{v} = partial pressure of moist air, mm Hg

 P_a = partial pressure of dry air, mm Hg

 M_v , $M_a = Mol.$ wts of water and air respectively

Dew Point

Modified A.P. Jhon equation for dew point temp. calculation

$$P_v = P_{v'} - \frac{1.8P(t - t_w)}{2700}$$

where, $P_{\nu'}=$ satn. press. at wet bulb temp, mm Hg

P_v = partial pressure of water vapour in air, mm Hg

 $t = D.B. \text{ temp } ^{\circ}\text{C}$

 $t_w = \text{wet. bulb temp } ^{\circ}\text{C}$

 $P = \text{total pressure } (P_{air} + P_v), \text{ mm Hg}$

Carrier equation for dew point calculation

$$P_v = P_{v'} - \frac{(P - P_{v'})(t - t_w) \times 1.8}{2800 - 1.3(1.80 t + 32)}$$



GLASSES AND TEXTILE GLASS FIBRES

A. CLASSIFICATION

Glass		Type	Uses
E Glass	_	Alumino borosilicate	For GRP and including
		glass containing alkali	use in other appliances.
		1% (wt)	
C Glass	_	Alkali-lime glass with	High acid resistance
		high borontrioxide	appliances use and
		(B_2O_3)	staple fibres.
A Glass	_	Alkali-lime glass with	Spl. applications/acid
		little or no B_2O_3 and	resistant, and cement
		alkali 1%(wt)	reinforcement.
E-CR Glass	_	Alumino-lime silicate	For G R P and flue
		glass with alkali 1%.	gases pipes.
		High acid resistant	
R Glass	_	Alumino-silicate glass	Spl. use in G R P
		without Ca and Mg oxides-	boats of high power.
		high much properties.	
D Glass	_	Borosilicate glass-speciality	Micro wave heating
		glass with high	plates and special uses.
		dielectric properties.	
S Glass	_	Alumino silicate glass	Used in G R P boats of
		with $MgO = 10\%$ good	high power.
		tensile strength.	

B. DIELECTRIC CONSTANTS OF TEXTILE GLASSES AT 1 MH,

E glass = 5.8 - 6.4

C glass = 6.8

E–CR glass = 7

R glass = 5.6 - 6.2

S glass = 4.8 - 8.3

D glass = 3.85

Quartz glass = 3.78

C. TEXTILE GLASS FIBRES ARE MADE FROM DIFFERENT GLASSES AS ABOVE BY FIBERISATION PROCESS DESCRIBED IN CHAPTER 26

- N.B. 1. Glass filament yarn ISO 2078 and ISO 3599 EC–9–34 where E glass and C glass contain 9 filament diametres in μm
 - 2. 34 tex (1 tex = 1 gm/1000m)

D. USES OF TEXTILE GLASS FIBRES

Textile glass fibres of different glasses is available as glass filament and glass staple fibres of limited length (spun fibres) of dia. $9-13~\mu m$. Uses involve insulation, textile purposes viz decoration, filtration, reinforcement of a matrix to make a composite. Matrix can be plastics (thermo or thermosets), bitumen, rubber, cement, gypsum and other materials.

Textile yarns and plied yarns with filament dia of 5–13 μ m are mostly woven into fabrics. The plastic admix products viz mats, rovings etc are made from glass filaments of 9–24 μ m dia. Tensile strength of E glass filament = 3400.Mp_a and that of R glass filament is 4400 Mp_a.

E. COMPOSITION OF GLASSES

	Multi– purpose	A glass	C glass	E–CR glass	Alkali resistance glass	R Glass	S Glass	D Glass
SiO ₂	53–55	70 – 72	60–65	58	60	60	60–65	73–74
Al_2O_3	14-15.5	0 - 2.5	2-5.5	12-13	0.7	24.5	20–25	_
CaO	20–25	5 – 9	14	21	5	6	_	0.5-0.6
MgO	20–25	1 – 4	1–3	4.5	_	9	10	-
B_2O_3	6.5–9	0 - 0.5	2–7	<0.1	_	_	0-1.2	20–23
F	0-0.07			0.15				
Na ₂ O ₁								
ZrO ₂	<1	1	0.4			0.1		
K ₂ O			0.3					
Fe ₂ O ₃			2.1					
TiO ₂								



ENVIRONMENT AND POLLUTION AIR AND WATER

1. SOLAR ENERGY

About 20% of total solar energy transmitted by sun is lost through space until it reaches about 3–5 km above a city. A polluted city atmosphere can reduce further about 10–20% of sun's energy out of 80% reaching on the earth. The solar energy thus reaching is sufficient to initiate photochemical process resulting in smog formation due to complex reactions between oxides of nitrogen and hydrocarbons present in city air in presence of solar radiation.

The remaining solar energy (short wave radiation) is then absorbed by the earth's surface and re-emitted as long wave or heat wave radiation. The air layers, close to the radiating surface, soil, building structures or any other objects, are heated and start to rise as convection air stream. The air motion thus produced will disperse and dilute air pollutants. The two metrological phenomena, responsible for high or low pollutants levels in air, are due to atmospheric stability and air flow is determined by sun's energy reaching the earth.

1.1 Atmospheric Stability

The ground surface heating and resulting in heating of air adjacent to it, produces change in temperature with height above sea level which is called adiabatic lapse rate @ 5–4 °F per 1000 ft. When the temp. decreases with height, the lapse rate is +ve and a good dispersion and vertical transport of pollulants can be expected under this unstable weather condition; conversely, the air is stable when the adiabatic lapse rate is -ve when the air temperature increases with height. When lapse rate becomes -ve it is also called an inversion and under this condition no vertical dispersion of pollutant in air can take place and thus the pollutants remain trapped within the inversion layer of air at the particular ht. In table 1 temperature above sea level at different zones are given.

1.2 Greenhouse Effect

Earth atmosphere act as a greenhouse in trapping heat from sun after it is reflected from earth surface as a long wave (infra red) radiation. The absorption of long wave is effected by small amounts of water vapour. CO_2 and ozone gases are called greenhouse gases in the air. The clouds are opaque to too long wave radiation unless they are extremely thin and cirrous clouds, after clear sky can increase surface air temp. by a few degrees. The green house gases affect the surface air temperature which causes unstable weather condition. The burning of fossil fuels, auto emission, and other combustions increase the CO_2 conc. in air. Under Kyoto Protocol (1997), six greenhouse gases

have been identified which are, a part from CO₂, CH₄, Nitrous oxide, HICs, CFCs and Sulphur hexafluoride. Also ozone layer over earth atmosphere if broken by greenhouse gases, the natural protection against ultraviolet rays is removed which pass through ozone hole. This causes more increase in air temperature with the possibility of more melting of ice and increase in sea water level.

1.3 Composition of Clean Dry Air at Sea Level

 $N_2 = 78\% \text{ vol.}$ $O_2 = 20.94$ Argon = 0.93 $CO_2 = 318 \text{ ppm}$ Neon = 18 ppm $H_2 = 0.5-1 \text{ ppm}$ CO = 0.1 ppm $CH_4 = 1.5 \text{ ppm}$ Ozone = 0.02 ppm $SO_2 = 0.0002 \text{ ppm}$

 $NO_x = 0.001 \text{ ppm}$

2. METHODS OF CONTROL OF LIQUID EFFLUENTS FROM INDUSTRY

There are three main methods of handling liquid effluents.

- (i) Chemical treatments
- (ii) Mechanical treatments
- (iii) Biological treatments

These methods are further subdivided into following categories of treatments:

- (a) Various chemical treatment methods available.
- (b) Biological treatment to reduce BOD. A high $\frac{\text{COD}}{\text{BOD}}$ ratio indicates that the effluents are not biodegradable which can not be converted to biodegradable even by bacteria.
 - (c) Air filtration/ pressure filtration
 - (d) Sedimentation in clarifiers with coagulating agents.
 - (e) Forced aeration by aerators in lagoons.
 - (f) Pure oxygen activated sludge process or wet oxidation process.
 - (g) Activated sludge cum carbon activated process.
 - (h) Electrodialysis
 - (i) Semipermeable membrane process.
 - (j) Dissolved air flotation process.
 - (k) Biotechnology method.
 - (l) Anarobic fermentation process using microorganism (bacterial strains)
 - (m) Ion exchangers

- (n) Flocculators
- (o) Floating aeration in ponds
- (p) Storage of treated effluents in delay ponds (1+1) and slow discharge to outfall through storm water drains.
 - (q) Molten Metal Technology.

2.1 Biological Treatment Methods

- (i) Special bacteriological strains/cultures (viz thermobac, polybac) which can make metabolic conversion of poisonous into non-poisonous materials. The cultures are available for HCN, nitrite, Phenolics, aldehydes, petroleum oils and other organic toxic materials.
- (ii) Pure oxygen activated sludge can simultaneously cause biodegradation and chemical conversion of wastes containing high $\frac{\text{COD}}{\text{BOD}}$ ratio.
- (iii) Wet oxygen process can destroy wastes from too dilute a stream for incineration and too concentrated effluent for conventional treatment.
- (iv) Activated sludge cum activated carbon process can handle wastes, containing both biodegradeable materials and wastes, having very high chemicals.
 - (v) Ion exchange and electrodialysis methods are for removal of ionic wastes.
- (vi) Dissolved air floatation process for removal of oil and emulsion wastes. Fine air bubbles are sparged at the bottom of wastes which carry both oil and emulsions to top as scum which are periodically removed. Efficiency is over 95%. Suitable also for fine solids and colloids.
- (vii) In biotechnology method high and low toxic materials from pesticide units are separately stored in polythene lined solar evaporation pond. Sun's rays evaporate water from high and low toxic tanks. In the high toxic tanks, on concentration, the pollutants become harmless. The technique is not very convincing. This process is usually used in pesticide plant wastes. The water from pesticide free tank can be used for land fill after neutralisation with lime, aeration and flocculation. The low concentrated pond similarly gets pollutant free or the pollutants within limit.
- (viii) Floating aeration in lagoons—The process has several floating aerators in lagoons, handling obnoxious wastes, usually from paper mill, after lime dosing. Oxygen is supplied to wastes by aereators.
- (ix) Anaerobic fermentation of brewery/distillery wastes, containing alcohol are usually carried out by methanococcus bacteria in a closed fermenter when alcohol is degraded by bacteria to CH_4 and CO_2 gases which can be used for fuel purpose in the plant.

Methane bacteria has 9 types of strains, each for different substrates (food for bacteria). Sewage sludge can also be digested by anaerobic treatment.

According to Barker, the 9 strains of methane bacteria are as follows.

Products

(a) Methanobacterium formicicum – Formate, CO₂ and H₂

(b) – Do – meliaanski – Primary and secondary alcohols, H₂

(c) – Do – propionicum – Propionate salt.

(d) – Do – Sohngenii – Acetate and butyrate

(e) - Do - Suboxydans
 (f) Methanococcus mazei
 (g) - Do - Vanielli
 Butyrate, Valerate
 Acetate, butyrate
 Formate, H₂.

(h) Methanosancina methanica

(x) Molten Metal Technology

This was developed in USA. The process disintegrates hazardous wastes into elemental form in a hermitically sealed unit when wastes are separated into elemental from which can be converted to useful by products. The details are not available.

(xi) Solid Wastes Disposal

- A. Hazardous solids are disposed of by putting in sealed drums which are dumped in concrete underground tanks.
- B. Overground dumping of hazardous wastes on concrete floors.
- C. Sedimentation in ponds/lagoons
- D. Incineration-mainly for hospital garbage and domestic refuge.
- E. Chemical treatment method.

Stipulation of Hazardous wastes, limits of hazardous wastes generation and disposal methods are elaborated in statutory Hazardous wastes (management and handling) Act 1989. Radio active wastes are covered under Atomic energy Act 1962.

Water pollution from industrial effluents are covered under the water (prevention and control) of pollution Act, 1974. Disposal of treated industrial effluents are also controlled by MINAS or State Pollution control board standards.

In table 2 limits of pollutants as per MINAS/ IS 2490/Assam pollution control board (for Namrup fertiliser plant) for final discharge of effluents to river is given.

3. WASTE WATER STREAMS

From large chemical processing plants can be grouped as follows

- (a) Chemical effluents sewers from process plants
- (b) Oil water effluent sewers from compressors.
- (c) Cooling water purge sewers.
- (d) Steam-water sewers from plant sewers.
- (e) Water treatment plant sludge disposal sewer.
- (f) Sanitary sewers.
- (g) Solid wastes disposal.

3 (a) Chemical Effluent Sewers

The sewers from process plants should be designed to collect contaminated process chemicals wastes which occur as discharges from process equipment, leakages from pumps glands, spillages and floor washings. These are separately collected in a pumping pit in the plant through separate lines and from where it is pumped through a properly designed pipe line to effluent treatment plant, designed for treatment of such effluents. In case of ammonical effluents, it is stripped with L.P.

steam when ammonia is removed. The remaining ammonia in stripper outlet water is air stripped in a cooling tower and effluent discharged to delay pond.

Storm water from trenches in the plant goes directly to storm water drains along plant roads as it does not contain any harmful chemical effluent. Acidic and alkaline effluent from D.M. plant are mixed in a pond within the plant B.L and pumped to chromate treatment plant or delay pond. The D.M. plant pond is usually rubber lined and D.M plant floor area, trenches are lined with acid proof tiles.

3 (b) Oil Water Effluent Sewers

The oil water effluent from compressors in a plant, coming through sewers, are usually treated at the API oil trap, containing coke and clear water is discharged into the storm water drains. The operation of oil traps is to be regularly monitored for performance.

3 (c) Purge Cooling Water Sewer

The cooling water is usually treated in chromate treatment plant and contains 10:20 ppm of chromate $CrO_4=(+6)$ and phosphate (TSP) to prevent corrosion of C.W pipelines and equipment using cooling water. Cr(+6) is to be reduced to Cr(+3) before discharge. The purge water from each cooling tower is led into a sewer pipe which flows to adjacent purge cooling water treatment plant using 10% Sodium meta bisulphite solution after C.W is acidified to pH 2.5 and treated with Sod. meta bisulphite, NaHSO $_3$ which reduces Cr(+6) to (Cr+3).

$$\mathrm{H_2SO_4} + \mathrm{NaHSO_3} + \mathrm{Na_2Cr_2O_7} \ \rightarrow \ \mathrm{Na_2SO_4} + \mathrm{Cr_2(SO_4)_3} + 2\mathrm{NaHSO_4}$$

The reaction mass from Sodium meta bisulphite reaction tank, having agitator is transferred to neutraliser, where it is treated with lime solution and pH is brought upto 7.5. Acidic and Alkaline mixed effluent water from DM plant can be mixed here also. The neutrlised effluent is then pumped through sewer line to delay ponds from where it is discharged to treated effluent discharge drain through delay pond overflow point.

3 (d) Steam Condensate Sewer from Plants

The condensate blowdown from boilers are collected in separate sewers as it contains alkaline wastes and pumped from plants to delay pond.

3 (e) Water Treatment Plant (WTP) Sludge Disposal

The sludge, containing 3–5% suspended solid from water treatment plant, usually contains Ca(OH)₂,CaCO₃,A1(OH)₃, mud etc. and is drained by pumping to sludge settling tank when suspended materials settle at the bottom and clear water is discharged to final effluent drain of delay pond.

3 (f) Sanitary Sewers Effluent Treatment

The effluents from septic tanks are taken by 4" lines and combined with other sewer lines to a 8" sewer line and the sewage taken to septic (treatment) plant. usually, a small concrete pit with (+) 6" seal between inlet and outlet sewer lines is provided at direction change points of sewer lines. The pit is covered with concrete grills at top.

3 (g) Solid Wastes Disposal

(i) For hazardous solid wastes, packing etc. are usually put in plastic or metal drums and lids are sealed. The drums are put in underground concreate bunkers and entrance is covered with concrete slabs.

(ii) For other solid wastes, like catalysts containing harmful metal salts etc, are dumped in covered rooms with concrete floor for long storage and if possible, sold to interested parties.

4. SURFACE WATER THROUGH STORM WATER DRAINS

Depending on total area of plant, the run-off water rates from rains are calculated as follows.

- (i) Run-off water as 100% for all paved area inside the plant.
- (ii) Run-off water as 50% for unpaved areas inside the plant-the other 50% is thought to have been absorbed in other soil. Rain water from individual plants are discharged to storm water drains.
- (iii) Rain water accumulation per inch of rainfall per hour per ft² area is 0.014 US gallons per minute (0.0539 lit/min per ft²). In addition consider fire water accumulation of 500 US gallons per minute for reasonable duration and any other uncontaminated water quality which comes from plant to storm water drains which ultimately goes to outfall points along with delay ponds over flow. W.T.P. plant sludge water quantity and individual effluent treatment plant's treated effluent quantity also goes to outfall point.

5. OTHER EFFLUENT TREATMENT PROCESSES FOR SOME INDUSTRIES

5.1 Fertiliser Plant Chemical Effluents

5.1.1 Urea Plant

The plant generates (a) Vacuum condensate from Vacuum concentrators containing urea and NH_3 from prilling tower top where the vacuum concentrators are located. The condensate is treated in urea hydrolyser when urea hydrolyses to NH_3 and CO_2 .

$$NH_2CONH_2 + H_2O \longrightarrow 2NH_3 + CO_2$$

The vacuum condensate is to be first stripped in upper stripper column containing bubble cap plates after preheating to 110°C and taken out from bottom of upper section and fed to urea hydrolyser after preheating to 189°C in feed preheater. Hydrolysis is carried out at 18 ata and 195°C by indirect steam heating in inbuilt steam heater bundle.

The hydrolysed solution from urea hydrolyser is then fed to bottom section of NH_3 stripper with a kettle type reboiler at bottom using 6 ata steam and NH_3 and CO_2 recovered are recycled to process. The Conc. of urea reduces from 0.84% to 380 ppm and that of NH_3 Conc. reduces from 3.82% to 140 ppm. The treated effluent from stripper bottom is stored in a $500m^3$ underground storage tank along with pump spillages and from there it is pumped to a $500m^3$ underground storage tank for air stripping of ammonia after it is made alkaline by adding NaOH solution and pH raised to 9. The stripped solution at bottom of air stripper may contain upto 30 ppm ammonia which is then sent to delay pond for slow discharge.

5.1.2 Ammonia Plant (NG based)

5.1.3 The process condensate, generated in purification section contains NH_3 , CO_2 etc and is stripped in a L.P steam stripper. The condensate contains 500 ppm NH_3 , 4000 ppm CO_2 and 1500 ppm methanol. The condensate is flashed in flash vessel when most of the CO_2 is removed and then stripped to remove NH_3 and methanol. The stripped condensate contain $NH_3 = 10$ ppm, $CO_2 = 10$ ppm and 20 ppm methanol which is sent to D M plant for cation polishing.

The purge water from the recovery section of ammonia plant, containing 1% ammonia, is sent to 500 m³ underground effluent storage tank in urea plant. In Table 2, the analysis of waste water

standards for discharge to Rivers, canal, etc is given for fertilizer plant manufacturing urea and intermediate product of NH₃.

5.1.4 D.M. Plant

The acidic effluent, generated by cation exchanger condensate polishing unit, is to be taken to D M plant neutralisation tank with rubber lined and with epoxy coating. Similarly, alkaline anion exchanger effluent and process water gravity filters are to be taken to neutralisation tank where pH is neutralised and when the tank becomes full, the water from the neutralisation tank is pumped to delay pond. If necessary, the acidic and alkaline effluent can be pumped separately to chromate treatment plant.

5.1.5 API Oil Filters

In each compressor house an API oil filter with coke packing is to be provided to remove oil from condensate and clear water taken to storm water drains.

5.1.6 Steam Utility Plant Effluents

The B F W purge water from boilers is to be separately taken in a header to a pumping pit and from there, it is to be sent to delay pond for slow discharge.

5.1.7 Sewage Treatment By Anaerobic Fermentation

Sewage is usually having high B.O.D value. The sludge is treated in sludge digestor under anaerobic condition with agitation when soluble sludge collects at the bottom and removed. $\mathrm{CH_4}$ and $\mathrm{CO_2}$ gases are removed from top. Time for digestion is 12–50 days. The supernatant liquid from digestor is removed from top. There are 9 species of methane bacteria having different substrates which can be judiciously used for biological effluent treatment. In sludge digestion, percentage of total solids, conductivity, volume of sludge, pH and BOD value are indicators for efficient digestion. The digested sludge is then subjected to elutriation.

The fresh sludge suitable for disgestion may contain other alcohol soluble substances, cellulose, hemi-cellulose, lignin crude protein and ash (24%).

6. PRESSUREISED AIR FLOATATION PROCESS FOR OTHER INDUSTRIAL WASTE WATER TREATMENT FOR

- (i) Removal of pulp and paper fibres from waste water
- (ii) Removal of oil from refinery waste.
- (iii) Primary clarification of sewage and thickening of sewage sludge.
- (iv) Full recovery of coal washery wastes.
- (v) Removing oils from metal processing wastes
- (vi) Removing fatty acids and soaps from wastes water from soap works and processing of edible oils.
- (vii) Removing suspended solids from cannery wastes
- (viii) Clarification of laundry wastes
- (ix) Removal of grease and suspended solids from meat packaging units.
- (x) Waste water treatment from engine cleaning and paint stripping; etc.

The process consists of dissolving the gases in effluent liquid under high pressure and releasing the pressure of liquid suddenly in a separator by taking out the effluent fluid by a horizontal discharge pump at 25-60 psig pressure. Alkali (for pH control) and coagulant is added to mixing tank as well

as to pump discharge. Compressed air is added to pump suction and released from separator top and separator outlet fluid and is slowly fed to the conical floatation unit by a back pressure control valve. The bottom scrapper of floatation unit removes sludge and scum is removed from top of floatation unit and clear treated water over flows from top. About 5–8% free air dissolves.

The process is based on the principle of Henry's law which states that increase of solubility of gases dissolved in water varies with the absolute pressure of gas.

6.1 Food industry Waste Water

Ultrafiltration by membrane method is used to retain organic substances in food industry's waste water. Pressure required is 10–20 m water column and dissolved materials pass through the membrane.

BOD Value	% retention by membrane
(mg/lit)	
18250	99.7
(Carbohydrates)	
Potato starch 12700	85.1
Veg. Proteins 21500	99.6
Cheese whey 45000	99.3

Table 1
Atmospheric Temperature above sealevel.

Height, KM	NAME	Temp°C
250	Thermopause	1027
230	Satellite Level	
210	Thermosphere	27
70	Mesosphere	- 3
30	Stratosphere	- 73
10	Troposphere	
	Sea Level	7

Table 2

1. Limits of Pollutants as per Minas/IS 2490/Assam Pollution Board (For Namrup-III) for Final Discharge Effluents to River

SI. No.			Minas IS2490-74		
1.	рН	6.5 - 8.0	5.5 - 9.0	5.5 to 8.0	
2.	Temperature	_	< 40°C	Shall not exceed 40°C	
3.	Ammonical Nitrogen.	50 mg/lit	50 mg/lit	_	
4.	Total Kjeldahl Nitrogen	100	_	50	

5.	Free Ammonical Nitrogen	4 — — — —	4.12	4.12
6.	Nitrate Nitrogen.	10	-]	20 (Nitrite and
7.	Nitrite Nitrogen.	_	_	Nitrate.)
8.	Cyanide as CN	0.2	0.2	0.2
9.	Venadium as V	0.2	_	-
10.	Arsenic as As	0.2	0.2	0.2
11.	Flouride as F	10	2.0	-
12.	Hexavalent chromium as Cr+6	0.1	0.1	0.2
13.	Total chromium	2	_	2
14.	BOD (5 days at 20°C)	_	30	20
15.	COD	_	250	250
16.	Oil and grease	_	10	10
17.	Total suspended solids	_	100	30
18.	Sulphate as SO ₄	_	_	100
19.	Chloride as Cl.	_	_	600
20.	Dissolved oxygen.	_	_	3
21.	Resedual chlorine	_	1.0	1
22.	Phenolic compound	_	1.0	1
23.	Total Dissolved solids	_	_	2100
24.	Sulphides (as S)	_	2.0	2.0

Table 3
2. Ambient Air Quality Standard as per Air Act. 1981

Γ	Area	Category	SPM	SO ₂	СО	NOX	Remarks
			Unit =	$\mu g/M^3$			
Γ	Α.	Industrial and Mixed use	500	120	5000	120	
	В.	Residential and Rural	200	80	2000	50	
	C.	Sensitive	100	30	1000	30	

AIR POLLUTION ABATEMENT

1. Electrostatic Precipitator

When dust/microbial cells pass through an electrified field (D.C), they become ionised with +ve charge and are collected on a negatively charged plate. The ionising wires are held at 13000 - 14000 volts and the dust collecting plates are kept at 6000 - 7000 volts. The dust removal efficiency is about 90%. The controlling factors are air flow rate, plate loading, electrostatic field intensity, size of dust and its dielectric properties.

Larger foreign particles and increased air humidity can cause severe damage due to sparking. A medium efficiency dust filtration system should precede the electrostatic precipitator and if required

flue gases should be dehumidified. It is mandatory to use E. S. P for large coal based thermal power plant.

2. Greenhouse Gases Fixation in Air

Reaction :
$$CO_2 + H_2O + Sunlight \xrightarrow{chlorophyll} (CH_2O) + O_2$$

For each gm mole of carbon fixed, 470 kj (112 kcal) of energy is absorbed in the biomass.

Dissolved organic substances are usually susceptible to Biological degradation where as refractive substances are not accessible to microbial attack and are characterised by high C O D and contents of organic carbon.

This is usually treated for removal by combined adsorption or flocculation and activated charcoal process. Activated charcoal has surface area of $600-1200 \text{ m}^2/\text{gm}$ and when used for removal of organic matters most of the materials are removed. The active carbon mass is regenerated by heat at $750-950^{\circ}\text{C}$.

6.2 Cement Industry Inorganic Waste Material

Cement dust from clinker kiln and cement grinding are usually removed by electrostatic precipitators. In case of waste water from the dust scrubbing unit the waste water is taken to large lagoons for seepage and sedimentation and clear water is discharged from top of lagoons.

6.3 Porcelain Industry Waste

- (1) Preliminary screening, done to remove large coarse or broken particles.
- (2) Combined chemical–mechanical methods for clarification.

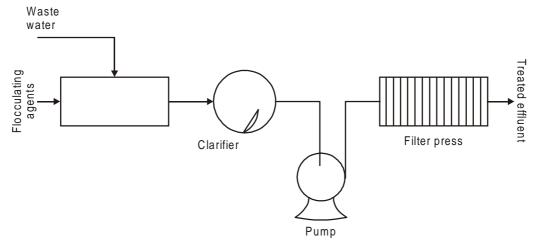


Fig. 1 A Porcelain Industry Waste Treatment.

The process consists of addition of flocculating agents (Al. Sulphate, lime or iron salts) in an additional tank and holding waste for 5–10 mins and then taking into a clarifier or sedimentation tank. The sediments from bottom of tank is pumped to a filter press. The suspended matter is thus removed and clear water after filter press. is discharged. (See Fig. 1)

6.4 Waste Water from Iron and Steel Works

The recirculation water from Blast furnace wet gas treatment, cleaning towers and other

operations like flue gas purge water consists of aeration upstream of sedimentation tanks to blow out carbonic acid followed by sedimentation in tanks. The waste water consists of cyanogen, sulphur, phenol, ashes, iron oxide, silicic acid slag. Ore particles as well as Al, Carbon, Calcium, Mg and Zn compounds. By aeration, Calcium/Zinc hydrogen carbonates are converted to carbonates and precipitated out with addition of flocculating agents—iron or Al salts as well as auxiliary flocculating agent viz an organic polymer.

The sludges which collect at the bottom of sedimentation tanks, are recovered continuously and used for land fills.

Toxic materials like alkali cyanides are formed in B.F. gas and flue gases contain HCN or dicynide. The process of removal of these materials consists addition of formaldehyde to recirculated water to raise pH to 8–10 and keeping in delay pond for long hold up to convert the cyanides to harmless polymers.

6.5 Ttreatment of Waste Water from Picking Plants

For treatment of waste water from metal pickling plants, usually one method is for recovery of Fe^{+2} or Fe (SO_4) $5H_2O$ when HCL or H_2SO_4 is used for pickling and the 2nd method is by neutralisation with alkalies when acid pickling is done. Lime is used as a neutralising agent.

6.6 Waste Water from Electroplating Industries

The waste consists of mainly cyanides occurring as alkali cyanides (very poisonous) or as complex cyanides. The process consists of, reaction with Sodium hypochlorite NaOCl (den.1.21 kg/lit and contains 12.5% active chlorine, corresponding to approximetely 150 gm of active chlorine (per lit) when cyanide is oxidised to chlorine cyanide which is then converted to cyanate at pH at about 9.5 using NaOH. Both the temperature is kept below 38°C. The reactions are exothermic:

$$2CN^{-} + 2OCL^{-} + 2H_{2}O \longrightarrow 2CNCL + 4OH^{-}$$

$$2CNCL + 40H^{-} \longrightarrow 2CNO^{-} + 2CI^{-} + 2H_{2}O$$

$$2CN^{-} + 2OCL^{-} \longrightarrow 2CNO^{-} + 2CI^{-}$$

Excess Hypochlorite @ 1% is used and residence time in reaction bath is about 20 mins. Air above bath is exhausted by an exhauster which push the reaction vapours through a water scrubber.

Iron (Fe⁺²) salts can also be used to form complex salts ferricyanides Fe₂ (Fe(CN)₆.

6.7 Soda Ash Plant Waste Water

It contains CaCl₂ and sludge, containing suspended matters which are treated in a sedimentation tank for 8–9 hrs when conc. of chlorides are reduced.

6. 8 Waste Water from Pharma Industries

Here various methods viz detoxification, deoiling, neutralisation, treatment with precipitating agents, decolorisation, sedimentation, biological treatment etc, are used and exact nature of treatment will depend on specific requirement. When separate treatment methods are to be used for each waste water from a particular type of product, exact waste water treatment method is to be used.

6.9 Waste Water from Inorganic Dye and Colourant Plants' Intermediates

The waste water usually contains lead or arsenic compounds which must be detoxified by using (1) Sodium sulfide to precipitate arsenic sulfide or (2) using (Fe⁺³) in an alkali solution to precipitate Ferrous arsenate or adsorptive co-precipitation (3). In case of lead waste water, uses

Sodium Carbonate to precipitate lead carbonate (4) Similarly for barium containing waste water, use of Sod. Carbonate is to precipitate barium carbonate (5) For chromate containing waste water to reduce Cr^{+6} to Cr^{+3} using Sod. metabisulphite in acid pH and then converting Cr^{+6} to Cr^{+3} followed by neutralisation with lime. (6) For TiO_2 containing waste water, treatment with hydrated iron sulphate is followed by crystallization and reduction to Fe_2O_3 and H_2SO_4 . The dil. acidified effluent is then dumped into sea or sent to delay pond.

In all these processes water after detoxification is stored in delay ponds for sedimentation and slow discharge to surface water.

6.10 Organic Dye and Intermediate Industry

(i) Removal of colours-various methods are used to remove colour viz chlorine, Ferrous chloride, Sodium hydrogen sulphide. Azo dyes are cracked by reducing agent, land filtration and biological purification.

The combined method of chemical precipitation with biological purification gives satisfactory results in some cases of water treatment.

(ii) The waste water, which is more from these industries are first neutralised if necessary. The segregated streams of waste water are treated individually w.r.t. their composition, treatment method required and specific type of waste water. The waste water containing toxic substances—cyanide compounds, arsenic salts, free chlorine, flourine bromine etc are detoxicated by chemical precipitation method. Oils and fats if present are retained in separators. Waste water containing mainly organic substances are treated by extraction, concentration by evaporation and other methods.

Strong odours from waste water are removed by aeration with fixed or floating aerators in tanks, columns etc, by the treatment with Cl_2 . For all types of waste water neutralisation can be carried out together with NaOH or lime in aflocculator with built in stirrer for 15–30 minutes before coarse sludge flakes are sedimented for sludge removal.

For removal of high B. O. D level in waste water the treatment is usually done in digestors followed by degasifiers to remove $\mathrm{CH_4}$ and $\mathrm{CO_2}$ gases under 20" vacuum and then separation of sludge by tickling filtration and finally in clarifiers.

Anaerobic digestion of pulp and paper industry waste is carried out at 0.1 lbBOD/ cft of digestor/day only if sulfides formed are not allowed to accumulate in the digestor.

6.11 Dairy Effluent Treatment

Waste water from Dairy is first removed of oil in a oil trap and sent to equalisation tank from where it is sent to anaerobic tank for fermentation. After anaerobic treatment, the effluent is treated in series in two aeration tanks fitted with air aerator and sent to secondary settling tank. By-pass arrangement is provided for use in either of the aeration tanks. Settling tank clear effluent from top is pumped to sludge draining filter and water is recycled to Aeration tank I or aeration tank—II. Heavy sludge is removed from the bottom of sec. settling tank for disposal.

6.12 Sugar Mill Effluent

The process is similar to above except that lime is added to equalisation tank and a bar screen is provided before oil trap to remove bagasse fibres.

6.13 Waste Water Containing Mercury

Waste water from caustic chlorine plant using Mercury cell and other processes contains small quantities of Mercury. There are 3 processes for removal of mercury.

(i) In chemical process, Mercury compounds are reduced with Hydrazine or by precipitating Mercury as sulphide with thiourea or Sodium sulphide followed by filtration.

$$\frac{1}{2}$$
 O₂ + H₂O + 2Na₂S + Hg \xrightarrow{air} HgS + 2NaOH

(ii) By reacting Mercury with chlorine and adsorption in an ion exchange resin

$$Hg + 2HCl \rightarrow HgCl_2 + 2H^+$$

(iii) By Liq-liq extraction when Mercury conc. is reduced to < 0.01 mg/lit.

7. ENVIRONMENT PROTECTION ACT (EPA) 1986

- **7.1** The prescribed standard for liquid effluents along with parameters for each category of industrial plants and others are given in schedule–1 of the EPA 1986. Often these standards and parameters are based on capacity of the factory. In addition MINAS (Min. national standards) for waste water is applicable for some industries including stack ht. Fertiliser plant treated effluent quality is given in table 2.
- **7.2** The emission standards are also included in the Ambient air quality standard as per Air Act 1981 categorises 3 different areas (industrial and mixed use, residential and rural and sensitive) for SPM, SO₂, CO, NOX as given in table 3. For big projects continuous monitoring of atmospheric air, over the factory and at some distance along prevalent wind direction. E I A/ E M P report is necessary for approval of the project either from central pollution control board or state pollution control board depending on whether the industry is under central govt. or state authority control. There are 23 projects industries which are under central pollution control board schedule I plus all projects with threshold criteria above those specified in schedule II under control of state pollution control board.

The schedule – II of the Act gives a list of 46 projects/industries which require state environment clearance.

In order to get environmental clearance for a big project, it requires submission of E I A (Environment Impact Assessment) report and E M P (Environment Management Plan) along with D P R to concerned clearing authority (central and state). Such EIA/EMP reports are to be prepared by central pollution board approved consultant.

- **7.3** Treated liquid effluents standard parameters are specified by MINAS or state pollution control board limits. Often IS standard is also available. The concerned plant authority is required to maintain these limits, especially SPCB limits. In table–2 these standards for fertilizer plant effluent discharge limits.
- **7.4** Delay ponds (1+1) usually treated effluents from effluent treatment plants are stored in delay ponds (1+1) having 2 months capacity each from where it is discharged at out fall point after the rate of effluent discharge is measured in a weir (vnotch or rectangular). Often dilution water is to be added before discharge to bring the effluent conc. below state pollution board standard or MINAS.
- **7.5** Under CPCB notification number S.O 318 (E) dt 10.4.97, the project authority would allow public views against the proposed project by keeping all project information including pollution levels (water and air) in concerned district DM's office or office of central SPCB in the state capital. District S.D.O will fix hearing dates from public for any complaints which can be lodged in S.D.O's office.

8. C.O.D

It is a measure of the components which can be oxidised in chemical reactions. Amount of Sod. permanganate or Sodium dichromate (oxidants) consumption in reaction determines the value of COD.

8.1 B.O.D

It is the amount of Oxygen necessary for bacteria to consume organic matter in water and is determined by means of O_2 depletation of a diluted aqueous sample containing microorganisms. Usually it is determined in 5 days duration at 20° C i.e. B.O.D₅.

9. AIR POLLUTION CAUSES

Air Pollution occurs due to dispersal of the pollutants into atmosphere. The pollutants emerge from chimneys of various furnaces, using fossil fuels, solid or liquid, automobile exhausts, various chemical processes. The pollution is also due to the dispersion of dust particles which come from grinding operations, chemical dusts emission, furnace fumes and fumes from solid wastes incinerators etc. The emitted gases are of varied nature viz smoke particles, CO₂, CO, SO₂. NOx, HF, NH₃ etc. The so called green house gases viz CO₂ etc are responsible for increase in atmospheric temperature which is responsible for global warming and melting of polar ice caps resulting in rise in sea water levels. Increased industrial activities and fast increase in automobiles through out the world are responsible for increase in green house gases in atmosphere. The emission standard is given in Table 3.

10. ANTIPOLLUTION MEASURES TO REMOVE AIR POLLUTANTS, VARY ACCORDING TO THE SOURCES OF POLLUTANTS. SOME OF THESE AIR POLLUTION ABATEMENT EQUIPMENT ARE AS FOLLOWS.

- (i) Gravity settling chambers
- (ii) Suction air filters
- (iii) Bag filters for dusts
- (iv) Electrostatic precipitator for dust laden furnace gases.
- (v) Dust cyclones
- (vi) Gas scrubbers for removal of fine dusts and soluble gases.
- (vii) Pulse jet bag filters for dedusting.
- (viii) Venturi scrubbers.
 - (ix) Air filter houses with reverse cleaning for removal of fine particulate matter.
 - (x) Dust and fume extractor.
- (xi) 4th hole dedusting system for electric arc furnaces.
- (xii) Burning of inflammable gases in a flare stack.
- (xiii) Use of high rise chimneys for dispersal of residual fly ash in atmosphere from coal based power plants/cement klin
- (xiv) Extension of chimneys with increase in static head of I.D fans where ever feasible.
- (xv) Better design of burners for reduction in smoke and NOX.

10.1 (i) Gravity Settling Chambers

For separation of dust particles having diameter lower than 43 µ, gravity settling chamber is

suitable which is used for flow of dust laden air/gases having low degree of turbulance. Rectangular long chambers are suitable for settling of heavier dust/soots. These gravity filters are rarely used now and are replaced by more efficient filters.

(ii) Suction Air Filters

These are used for separation of dust of size $1{\text -}10\mu$ from atmospheric air and are placed at suction of air blowers, boosters or compressors. Atmospheric dust conc. depends of locality, its industrial units, wind velocity etc. In rural areas dust conc. is the lowest 0.3–0.5 grain/1000 cft, in industrial area it is about 0.9–1.6 grain and in metro cities it is 0.6–1 grain. Life of air filters is short, usually 1–3 months.

There are 3 types of air filters, dry, viscous and continuous. Filtering media, is cotton, felt pad, glass wool, cellulose pulp wire mesh, corrugated fibre board, and cotton/syn. fibre wool etc. In viscous type filters are coated with mineral oil (having high viscosity and flash pt.) Viscous filters are having less thickness of filtering medium. Pr. drop across the air filter increases as more dusts separate out. Maximum allowable pressure drop varies from 0.2-0.5 inch water. Dust conc. in an air filter is normally allowed upto 0.6-4 lbs for a $20'' \times 20''$ filter. Efficiency of dust collection is usually 60-85%.

Automatic filters have continuous rotating moving perforated crimped or woven metalic screens. The washing arrangement is by water spray which is often of viscous type.

(iii) Bag Filters

These are having filtering media of woven cloth for fine dust laden air or gas mixtures which are allowed to flow through the bags when dust particles separate and form a layer, inside the wall of the bags which increases the collection efficiency. Once the dust layer is formed, continuous separation of dust takes place. Excess dusts from the layer fall at the bottom of bags and are taken out through seal lock. The filtered air/gas goes out of the bags. Automatic arrangement for shaking of bag filters at regular intervals is done when separated dust falls at the bottom and removed. This reduces the Pr. drop. A battery of woven bags are placed vertically with hopper and seal lock provided at the bottom for collection of dusts. Dust particles size to be separated, varies. The collection efficiency could be 80–90%. Woven cloth has openings larger than dust particle dia. These filters can have arrangement for automatic shaking for cleaning dust layer from inside the bags.



VEGETABLE OIL REFINING

1. THERE ARE VARIOUS TYPES OF VEGETABLE OILS VIZ

Coconut oil

Rape seed oil

Groundnut oil

Cotton seed oil

Sunflower oil

Soyabean oil

Rice bran oil

Corn oil

Castor oil

Lin-seed oil etc.

Out of the above oils, crude vegetable oils extracted from oil seeds except Rice bran oil which is made from bran of paddy while rice dehulling process is carried out – the bran is the outer brown coating on rice and husk forms the outside hull of rice. Rice bran oil is made from rice bran by n hexane solvent extraction process. The crude veg. oils from corresponding seeds are usually expelled by mechanical expellers followed by refining by degumming process, alkali neutralisation process, bleaching process and deodourisation process. When mech. expeller is not used, rice bran is pelletised and then solvent extraction is done in a series of 4 solvent extractors which also removes oil from meals from oil seeds. Vegetable oils can also be extracted by suitable solvent extraction process after the cooked seeds are flaked in a flaking machine.

2. CRUDE OIL EXTRACTION FROM OIL SEEDS

(i) Oil seeds, as it is received in oil plants, contain naturally occurring seeds, pods, earth and often metal iron parts. Before storage, the foreign materials are removed by screening and aspiration and iron removed by electromagnet and sample is analysed for moisture content, oil content etc. The freshly harvested oil seeds contain as much as 20% moisture and grain must be dried to around 13% moisture for extended storage. High moisture reduces oil content, decrease in protein, increase in colour of extracted oil, and refining losses.

Oil seed grains, if left unattended and temperature of storage is not checked, grain temperature will rise spontaneously and damage the seed for which it is to be either processed immediately or heap is shifted to another location.

- (ii) Drying of oil seeds, containing 20–50% oil, is usually done in direct gas fired furnace and hot gases move upwards and make contact with falling seeds from vertical drying tower. Other heat source is, indirect steam heating of air in a heater or solar drying units. The drying temperature limit is 63°C; higher temperature will increase colour of meal and oil, denature the protein and will increase the phosphatide levels in crude oil and even grain fire may occur. Storage should be of concrete structure.
- (iii) Oil expelling by mechanical expellers: The oil in seeds are lightly bound with the cell and mechanical pressure is applied to remove the oil by expellers which are located in the seeds preparation section building. The operation involve cooking, pressing of dried seeds, cake cooling, finishing and crude oil filtration.

Oil seed or seed flakes (whenever required) are put into vertical stacked agitated cooker when heat is applied. After cooker, hot meals enter screw presses or multiroller expellers. Modern batch process uses hydraulic presses at $300 - 500 \text{ kg/cm}^2$ press.

In open type haudraulic presses, seeds must be wrapped in pressure standing cloth and the closed type are provided with pots and cages. In screw presses the applied pressure is very high (upto 3000 bar) and process is efficient as oil upto 98% can be expelled. Usually oil removed varies from 60–98%. The oil cake passes through end plate and becomes hard and oil comes out through drainage bars. After the cake is broken and cooled it is sent to solvent recovery section, if installed for further recovery of oil. In case solvent recovery of oil from cake is not desired, the expellers are operated with the highest pressure. The crude oil, after expellers, contain fine meals which is removed in scheming tank followed by filtration in press leaf or plate and frame filter presses. Crushed vegetable oil is sent to storage or sent for refining. The quality of oil is higher than solvent extracted one because less oil soluble impurities (viz phosphatide etc) are removed. Removed fine meals are sent to pressure flaking operation for further recovery or sent for solvent extraction if desired. Oil seeds are often subjected to flaking operation by a flaking roller if needed for better oil extraction in expellers. Mechanical extraction is suitable when oil seeds contain over 20% oil.

3. RICE BRAN OIL

It is a desirable vegetable oil and which is harmless. It is produced from rice bran by n-hexane solvent extraction. Better solvent is isopropyl alcohol due to its low inflammability. By solvent extraction very low residual fat content can be achieved. (Apart from rice bran, whenever other seeds are used for solvent extractions, where oil content is less than 20%, Iso-propyl Alcohol which is a better solvent due to its low inflammability and having B.P. of 55–70°C which can be steam stripped-can be used.) Hexane can be removed from oil at temperature below 100°C in vacuum. The solubility of water in hexane is only 0.1%. The process of crude rice bran oil production by solvent is given in Fig. 2. The solvent dissolves only glycerides but not undesireable materials viz colouring matter, gums or phosphatides. Since rice bran contains 8–16% vegetable oil, it is usually processed by solvent extraction after drying of brans followed by pelletising.

Solvent extraction of seed flakes or rice bran consists of cylindrical vessels of size with high D/H ratio and fitted with a sweep agitator with scrapper to remove the extracted seed flakes or bran during solvent stripping with steam (direct and indirect steam heating) solvent inlet/outlet facilities for pumping and crude oil inlet. A 3–5 m³/hr capacity extractor with 5 such batch extractors in series

VEGETABLE OIL REFINING 277

is capable of producing 600 MT/day rice bran or other veg oils. Hexane required is 50 MT. Often 4 stage solvent extraction of pelletised rice bran or meals from oil expellers after filter pressing is used. Solvent extractor using 4 stage extractors where meal, rice bran pellets/seed flakes and solvent from previous extractor is used and fresh solvent enters into 1st extractor and successively move to last or 4th extractor. Flow sheet using one extractor is given in Fig. 1.

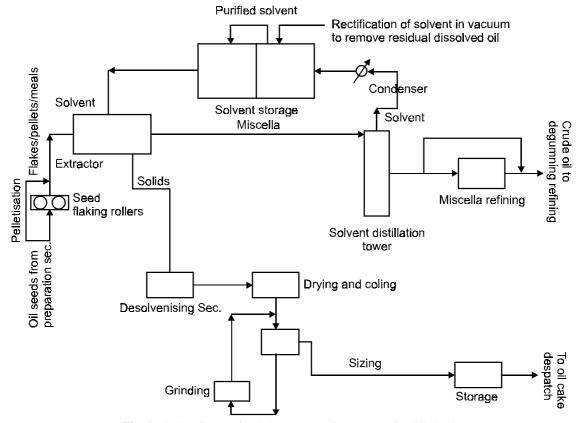


Fig. 1 Block Diagram for Solvent Extraction Process for Oil Seeds

Flow in extractor is counter current where pure solvent comes in contact with, meal/flakes and pellets which already have been largely extracted or vice versa, in both batch and counter current process. The solvent rich oil is then steam stripped in a steam stripper to remove solvent and recover vegetable oil. The solvent is then rectified in a distillation tower in vacuum to remove dissolved oil. The solid meal from extractor is further treated with hexane to remove residual oil in meal (cake), dried and cooled and then sizing operation with grinding is done. The fixed meal is then sent to storage. The crude rice bran oil is then either subjected to miscella refining or further subjected to refining process which gives a light yellow colour to rice bran oil and is a relatively stable edible oil. Rice bran oil hardens at 30–35°C and is often used in margarine. The properties of vegetable oils are given in Table 156/158 in vol. IIA and its empirical formulae for physical properties in table 155 in vol. II.A.

4. REFINING OF CRUDE VEGETABLE OILS

The crude vegetable oils contain phosphatides, carbohydrates, protein, fatty acids and toxic compounds (Pesticides etc.) Therefore, refining operation, are carried out to remove these materials as far as possible without affecting main constituents, vitamins and poly unsaturated fatty acids.

However, some vegetable oils viz. castor oil, olive oil, linseed oil or cold pressed sunflower oils are not refined in order to preserve the main properties of these oils. The refining operations are described briefly as below.

(i) Degumming operation to remove phosphatides from vegetable oils, containing high phosphorous viz corn and sunflower oils, by water degumming to remove water hydrateable phosphatides only. For NHP removal, special treatment is necessary. Phosphatides, gums and other colloidal compounds promote hydrolysis of an oil. In hydration, degumming oil is treated with water or steam, to form a sludge that is insoluble in oil. This is used to remove lecithin (1–3%) from soyabeen oil containing 2.5% $\rm H_2O$ by mixing with crude oil at 70–80°C with contact time 1–30 mins. The sludge is separated by contrifugation with addition of citric or phosphoric acid after mixing with crude oil which increase hydration. The process varies depending on crude oil. Preliminary crude treatment with bleaching agent or other adsorbent, in presence of citric or Phosphoric acid, can be helpful. Some oils can be degummed by heating upto 240–280°C.

Refining by distillation is possible for low Phosphatide content. Special degumming technique involves the addition of citric acid, followed by hydration at 70°C for several hours before centrifugation. The flow sheet is given in Fig. 2.

(ii) Neutralisation Process

Vegetable oils contain 1–3% FFA. It is removed by treatment with caustic lye or distillation, when soap solution is used. Other undesirable constituents viz oxidation products of fatty acids, residual phosphatides, gums, phenol and toxins are also washed out.

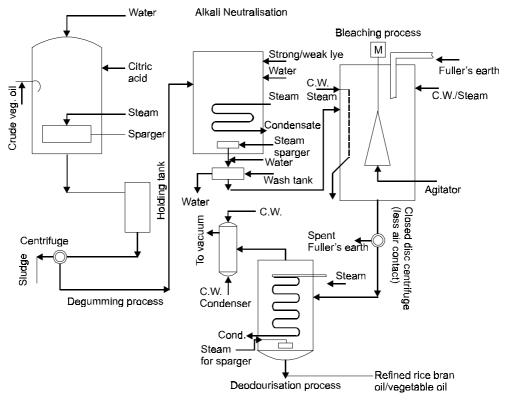


Fig. 2 Vegetable oil refining process including rice bran oil

VEGETABLE OIL REFINING 279

(iia) Alkali Neutralisation

Here conc. lye of (4–7 N) with crude oil is used in a reactor fitted with steam heating coil and live steam heating upto 40–80°C with strong lye which settles at the bottom. For weak lye, it is sprayed to crude oil at 90°C to neutralise FFA. After neutralisation and discharge from reactor, crude oil is washed with dil. lye (0.5N) and then with water to reduce residual soap to 500 ppm. conc. Incomplete removal of soap impairs colour of oil and efficiency of following refining steps. Soyabeen oil is subjected to post treatment with Na₂CO₃ and silicate to remove residual traces of oxidised glycerides and phosphatides. Soap stock can be used in boiler fuel or it can be converted to acid oil, used as animal feed or other use. The quantity of acid oil (mix of fatty acid and neutral oil) is variable.

(iii) The method to remove FFA is by distillation or neutralisation in vacuum after degumming operation. The process is suitable for rape seed, soyabeen and sunflower oils with the technology available for reducing phosphatide content. Distillation temperature required is 240–270°C when FFA content become less than 0.1%.

Other process of esterification with a catalyst is also available.

A refining factor of 2 means that for each mass unit of free fatty acid (FFA) in crude oil, 2 mass units of acid free oil is produced. Process flow sheet for alkali neutralisation is given in Fig. 2.

(iii) Bleaching Operation

Degumming and alkali neutralisation do not generally give significant decolourisation. The process involves the use of Fuller's earth (bleaching earth) and/or activated carbon (charcoal) for dicolourisation of crude oil. The process of neutralisation and bleaching is usually carried out together in a vessel fitted with agitator and vessels connected to vacuum. The crude oil is mixed with Fuller's earth, stirred and filtered off. The bleaching should be done below 100°C through steam coil in bleacher. Oil retention in bleach is 50% of bleacher or 100%(wt) of activated charcoal when used in combination with F.R. (Fullers earth).

The operation is carried out under vacuum as bleach catalyzes the oxidation of oil. Process is carried out in air free atmosphere including filtration, after discharge from bleacher. Some times bleaching is carried out at 65° C and 100° C and preceded by addition of citric acid and Phosphoric acid to chealate trace materials and to precipitate hydrated phosphatides. Soap solution and wash water are introduced from bottom nozzle. Pigments to be removed are condenoids and chlorophyl; but the bleaching operation also reduces phosphatides, soaps, trace metals and oxidation products such is H_2O_2 and non volatile polar decomposition products.

Bleaching earth (mainly Al silicate) containing 5–10% moisture is first activated and dried. Quantity of activated F.R will be 0.5–1% and activated charcoal (0.1–0.4%) is used when there are difficulties in bleaching. The crude oil is dried in vacuum for 30 mins at 30 kpa and adsorbent earth is added and stirred for about 1–30 minutes in vacuum at temperature of 80–90°C. The slurry is pumped out to special filter presses or closed disc type centrifuge which have limited air access. Bleaching and centrifugation is done batchwise. The colour in crude oil is mostly removed. The process is given in flow sheet in Fig. 2.

(iv) Deodourisation Process

Here odours/flavours in crude oil are removed from bleached oil. The process uses steam distillation under vacuum, when volatile compounds (odour and flavouring agents) are removed from nonvolatile glycerides. The odour causing compounds in crude oil are primarily aldehydes and

ketones formed by auto oxidation during handling and storage and usually has threshold value of a few ppm. Other volatile compounds (FFA, sterols or phenols) are also partially removed. The flavouring compounds can also be formed by hydrolysis and thermal decomposition of crude oil. Distillation under vacuum is necessary due to low partial pressure of removeable compounds. Steam consumption rate is 5–10% wt. of crude oil for batch process and 1–5% wt. for continuous process. Distillation temp. is 190–270°C at press. 0.13 to 0.78 Kpa (1–6 mm Hg). Steam required is 10–20m³/kg of oil. The distillate removed is about 0.2% of oil and contains very little oil. Time required for batch process is 4 hrs. The end point is determined organometrically. Steam used must be free from oxygen and dry. To deactivate peroxide. Like trace metals, aq. citric acid soln. (2–5 mg c. acid/100 gm of oil) is often injected into the oil towards the end of decomposition. The sketch of batch deodouriser is given in Fig. 2.

5. HYDROGENATION OF VEGETABLE OILS

The double bonds in fatty acid chain can be mostly or partially saturated by adding Hydrogen in presence of nickel, platinum or palladium catalysts which increases the m.p and make the vegetable oil solid at room temp.

6. PROPERTIES

Naturally occuring vegetable oils are liquid or semi solids consisting of glycerides. Liquid oils are termed as liquids vegetable oils and solids as fats. Such oils also contain minor constituents of free fatty acids, phospho liquids, sterols, hydrocarbons, pigments, waxes and vitamins. The veg. oils usually contain 97% glycerides i.e. triesters of glycerol with fatty acids, upto 3% diglycerides and upto 1% monoglycerides. They constitute 3,2 and 1 molecule of fatty acids respectively and triglycerides contain at least 2 different fatty acids groups. Their physical, chemical, and biological properties are determined by type of fatty acids group present and their distribution over triglycerides molecules. M.P of oils increases with the increase in long chain saturated fatty acids or decreasing proportion of unsaturated or short chain fatty acids.

Fatty acids are generally even numbered, straight chain aliphatic monocarboxylic acids with chain length ranging from C_4 – C_2 . The no. and position of double bonds in unsaturated fatty acids differ in configuration (i.e. cis or trans isomers)

The common fatty acids are butyric, lauric, palmitic, olive, stearic and linoleic, acid. Crude fatty acids contain significant quantity of free fatty acids, FFA and most vegetable oils contain palmitic, linoleic and olive oils.

Glycerides can be hydrolysed, as seen from refining processes, into fatty acids and glycerols.

Unsaturated fatty acids in oils and fats can be polymerised by heating at 200–300°C forming dimeric, oligomeric and Polymeric compounds.

Auto oxidation of veg oils develops rancidity, off flavour and reversal of flavours during production and storage. Oil cake and spent bleaching earth (Fullers earth) can cause sponteneous combustion.

High moisture content in oil seeds help uptake of oxygen resulting in degradation.

VEGETABLE OIL REFINING 281

Rice Bran Oil

Saturated fatty Acids

C₄ constituent = gm/100gm 0.58 fatty acids C_{16} constituent = 13–18 gm/100gm fatty acids C_{18} constituent = ~ 2 gm/100gm fatty acids C_{20} constituent = $\sim 0.5-1$ fatty acids C_{24} constituent = 0.5 fatty acids

Unsaturated fatty acids

 C_{18} : 1 = ~44 gm/100gm fatty acids C_{18} : 2 = 30–40 gm/100gm fatty acids

Density of R.B oil vary from 0.916 - 0.921 gm/cc

Sap value = 183-194 (mg KOH)

Iodine value = 92-109

N S M = 3.5 - 5.0 gm per 100 gm oil

MP = $\sim 10^{\circ}$ C

R. I $(n_D 40)$ = 1.466 - 1.469

R. B oil is most suitable edible oil as its saturated fatty acid content is the minimum or so.



FURFURAL

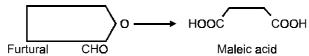
1. FURFURAL, $C_5H_4O_2$, MOLECULAR WT 96.08 IS AN INDUSTRIALLY IMPORTANT CHEMICAL AND A STARTING MATERIAL FOR FURANS.

1.1 Properties

It has excellent thermal stability in absence of oxygen upto 230°C and exposure for considerable hrs is required to produce detectable changes in its physical properties with the exception of colour. A fresh distilled furfural is a colourless liquid with a obnoxous aromatic smell similar to almonds. It darkens in air due to presence of oxygen.

Furfural is an excellent solvent with low viscosity over a wide temperature range. It mixes with a no. of organic solvents but is slightly miscible with saturated hydrocarbons which makes it a selective solvent for a no. of industrial uses viz. in petroleum refinery. Chemical properties of furfural is similar to aromatic aldehyde (Benzaldehyde) with other reactions due to dienic character of furan ring. The vapour pressure of furfural is given below.

Furfural is reduced to furfuryl alcohol and can be oxidised to furoic acid and decarbonated to furan, catalytic vapour phase oxidation of furfural yields malteic acid.



Flammability of furfural is similar to that of hexane or no. 1 fuel oil. It should not be mixed with strong alkali or acid and stored near strong oxidising agents. Usually a few pentosan containing materials (Xylan) are used to manufacture furfural.

1.2 Manufacturing Process

Raw materials – Rice husks, hulls of cotton seed husks, oats hulls and cereal grains. Other raw materials are, wheat chaff, bagasee, corn cobs and deciduous and coniferous tree woods, sulfite waste liquor and cellulose waste liquor.

Meterial	% pentosan content	Avg. Furfural Content,%
Cotton seed husks	23–28	18.6
Bagasse	25–27	17.4
Corn cobs	30–32	23.4

FURFURAL 283

Material	% Pentosan content	Avg. furfural Content, %
Oat husks	40	22.3
Corn stalks	24	_
Birch wood (after tannin extraction)	25	_
Corn husks	30–33	_
Wheat chaffs	18	_

Pentosan is the main constituent in Xylan–a polysaccharide with β –1, 4– linked D–xylopyransone units together with small amount of arabiran, a highly branched polysaccharide of 1,3 and 1,5 linked α –D cerbinofurarone units. Xylan in cereal strawps and grains constitute 23–30% and about 15–25% in deciduous tree wood and 5–15% in coniferous wood based on dry matter.

Process – The raw material, such as bagasse, is charged in a batch or continuous digestor with addition of a strong mineral acid and H.P. steam is passed to raise temp of digestor. After operation, temp. and press. of digestor is attained and the spent reaction material is withdrawn from digestor and furfural water vapour from the top of the digestor is condensed in a condenser with cooling water.

The condensed digestor vapour, containing furfural-water mixture is stripped with H.P. steam stripper and the vapour from top of the stripper is condensed in a cooler and put in a decanter where furfural containing 6% water, settles at bottom as being heavier than water and water forms the top layer in decanter.

Liquid furfural is pumped to dehydrator (Rectification Column) to obtain pure furfural (98% min.) which is tapped out from the bottom of dehydrator while top vapour of moisture with 8% furfural, is condensed in a condenser and drained to decanter for recycle. Water from the top of the decanter is periodically drained.

The cellulosic material in digestor undergoes partial degradation during digestion and remains with lignin and ash in the residue, this is burnt in steam plant as a fuel support for the energy required for furfural plant.

Reaction in digester:

$$(C_5H_8O_4)_n \xrightarrow[\text{acid} + H_2O]{} OH \xrightarrow{-3 \text{ H}_2O} CHO$$

$$CHO$$

$$CHO$$

$$OH$$

$$CH_2OH$$

Another form of reaction:

1.3 Handling, storage and Transportation of furfural in steel tanks, All steel tank trucks and steel drums are used. Proper packing in valves should be used to make them leak proof because furfural is an excellent solvent. The storage tanks/drums should be oxygen free. Colour change of furfural is associated with acidity increase and polymer formation occurs when furfural is stored for long time in presence of air

1.4 Uses

- (i) Extractive distillation of C_4 and C_5 hydrocarbons for the production of synthetic rubber. The use has come down due to butadiene availability from ethylene.
- (ii) Furfural is selective solvent for separating saturated from unsaturated compounds in Petro lubricating oils, gas oil and diesel oil.
 - (iii) It is a solvent for furfural alcohol resin for fibre glass reinforced plastic articles.
 - (iv) As a flame retardant in plastic articles.
 - (v) Extractive recovery of butadiene from cracked refinery gas.
 - (vi) As insecticide, herbicide, fungicide and enbalming fluid.



POLYETHYLENE TEREPHTHALATE RESIN (BOTTLE GRADE)

MANUFACTURING PROCESS

1. It is manufactured by reacting Monoethylene Glycol (MEG) with pure terephthalic acid (PTA) in presence of additives, comonomer–Isophthalic acid (IPA) and Diethylene Glycol (DEG) when bottle grade PET (Food grade) is desired to reduced MP of PET and increase the crystallisation point. A catalyst, Antimony based, is also required to enhance reaction rate.

The German process (Zimmer) consists of initially making the oligomer formed by solid state poly condensation and finally is subjected to solid state polymerisation.

PTA + 2 MEG
$$\rightarrow$$
 Oligomer + 2H₂O ... (1)
n(Oligomer) \rightarrow (n-1) MEG + PET ... (2)

2. PROCESS DESCRIPTION

The Polycondensation process involve first formation of oligomer from a thick paste in a paste preparation vessel where MEG (liquid) and PTA (Powder) are mixed intimately. This thick paste is esterified in a series of two esterification reactors having internal heating coils using heat transfer media (Therminol 66 liquid) circulation. Therminol vapour is used in jackets of esterification reactors. Liquid therminol temperature is around 325°C. The MEG V.P. in the EST reactors – I and II is increased above atmospheric by heating of reactants so that reaction rate increases. Esterification is completed by transfering reactants and reaction products in 2nd esterification reactor, EST–II through a transfer pump. The reaction liberates water as per reaction (1).

The vapour from esterification reactors, EST-1 and EST-2 contain water and MEG is condensed and sent to a distillation column where the effluent water is distilled and taken out as distillate and sent to effluent treatment plant for reduction of BOD, COD and neutralisation. MEG accumulates as a bottom product of distillation tower as its B.P. is 197.4°C. The quantity of distillate water liberated gives the amount of conversion.

3. POLY CONDENSATION

The reaction product is then transferred to pre–polycondensation reactor–1 (PP–1) by gravity where vacuum is maintained by vacuum pumps and reaction temperature, at higher desired level, by heating coil using HTM fluid (Therminol 66). Poly condensation reaction starts in PP–1 and final Poly condensation reaction is completed in PP–2. The reaction product is transferred from PP–1 to

PP-2 by gravity. In PP-2, having similar HTM heating coil, the product temperature is further increased. The vacuum level is miantained here as in PP-1.

The product from PP-2 is transferred to a disc ring reactor (DRR) with the help of a Polymer transfer pump. vacuum level in DRR is more. The vacuum in PP-II and DRR is maintained by MEG vapour jets and vacuum pumps instead of steam.

The vapour from waste water distillation column vent and vacuum pumps discharges are sent to a scrubber where any residual organic material is scrubbed and waste liquor is sent to the effluent treatment plant.

In PP-II and DRR, the MEG liberation occurs as per reaction (2) and is enhanced by Polymer film formation due to agitation of contents in these vessels. The MEG vapour liberated is condensed in the scrapper condenser of each Polycondensation loops and recycled to paste EST-I and II reactors.

A gear pump transfers the viscous product of DRR via 3 nos product filters. The filtered PET Polymer is then fed to 3 nos cutters (under water strand granulator) where the polymer gets quenched with DM water and granulated into chips. The chips are then transferred by conveyors into intermediate product silo storage.

4. SOLID STATE POLYMERISATION

The amorphous PET resin thus obtained is upgraded (bottle grade) to get an IV (intrinsic viscosity) lift to final level by solid state polymerisation.

The amorphous PET chips from storage are then conveyed into a dosing vessel. From dosing vessel the chips flow by gravity via a rotary lock into the precrystallizers where the chips are fluidised by hot pure Nitrogen gas thus increasing the chips temperature. The residence time in precrystallizer is such so as to initiate crystallization of chips. Temperature of N_2 and flow of chips is controlled, otherwise the chips will stick to the precrystallizer inlet. The circulating N_2 gas is heated up in a finned H.E. with hot liquid HTM flowing through the finned tubes. The heat of crystallization is highly exothermic.

The precrystallizer product chips flow by gravity into the rotary crystallizer which is having 2 nos paddles rotating in opposite direction with liq. HTM, flowing through the paddles from inside. The crystallizer bottom having slope towards outlet and crystallizer jacket heating by liq. HTM. Further crystallization of chips occurs in rotary crystallizer due to increased heating of the jacket and paddles heated by liq. HTM. A stream of hot nitrogen gas is passed through the crystallizer to remove chip dust, produced by rotating paddles.

The crystallised chips are then conveyed by hot nitrogen gas into the solid state reactor (SSP) when IV of the chips are raised to the required value for bottle grade PET. The rise of IV (Intrinsic viscosity) depends on

- (i) IV of base chips and its size
- (ii) Carboxylic end groups
- (iii) Catalyst concentration used in Poly condensation
- (iv) Residence time in SSP reactor and
- (v) Dew point of circulating hot gaseous nitrogen gas.

The hot N_2 gas enters into the conical bottom of SSP reactor while the chips are fed from a point above this section which keeps the chips agitated and lifts the IV of the chips while hot N_2

gas becomes impure. The impure N_2 gas is treated in Nitrogen processing unit where oxidation by compressed air is carried out in O_2 reactor in presence of Platinum catalyst. All hydrocarbons present in impure nitrogen are burnt in presence oxygen and temp. of reactor is maintained high. The pure N_2 thus obtained is taken out of oxygen reactor and is dried in a molecular sieve drier for moisture removal. O_2 content in N_2 gas outlet of the reactor is monitored by an oxygen analyser (cartherometer). The chips from SSP reactor with increased IV, are fed into deduster cooler by gravity through a rotary lock and chips are cooled and dedusted by compressed air. The product PET chips are then stored in storage silo where it is bagged in 25 kg bags or jumbo bags.

5. SPECIFICATION OF FINAL IV LIFTED PET CHIPS IS AS FOLLOWS

Intrinsic Viscosity (IV) at 25°C, P+DCB, dl/gm - 0.72 to 0.86 D E G Content, wt% - 1.0 - 1.5 Carboxyl end group, μ g/kg - 35 (max) I P A content, wt% - 1.5 - 2.5 Chips wt, gm/100 gm chips - 1.7 Acid Aldehyde, ppm (wt) - Max 1 Antimony content, ppm (wt) - 170 - 250

6. RECYCLING OF PET BOTTLES

Now-a-days,. IV lifted PET bottles can be recycled as per developed process of manufacture by which clean PET bottles are cut into chips and using extrusion moulding process, new bottles can be made. For less clean PET bottle, PET is subjected to degradation by glycolysis and other steps for recovery.



PROCESS EVALUATION OF A CHEMICAL PLANT

- 1. Whenever a detail process engineering package has been supplied by a licensing organisation or plant designer concern, it is imperative to subject the design and process engineering documents to close scrutiny for any shortfall or inconsistencies in the package offered.
 - The following preliminiary checks are to be made.
- (i) Whether the package given is in line with the requirement of the project for a new plant facilities or for expansion of existing plant facilities or for debottlenecking additional facilities.
- (ii) The process informations or data supplied by the designer are to be tallied for the basic process engg. documents viz process flow diagram with material balance, piping and engg. flow diagrams, equipment data sheets and major equipment drawings, instrument schedule etc. The process designer is reqd. to supply their piping and material specifications to project authority or operating co.
- (iii) To check the basic data, supplied by project authority on ambient conditions, wet bulb temp., safe soil bearing load, wind, velocity with maxm. wind speed, water table and seismic data and ISI seismic standard to be used, and electrical supply data etc. have been used by the designer.
 - (iv) Specification of equipment are to be checked for suitability.
 - (v) To prepare project cost estimate with cost data supplied or determined from other sources.
 - (vi) To determine project economics and financing mode and to determine viability.
- 2. Secondly, plant capacity rating is to be examined with the limiting equipment size/capacity with similar plants existing elsewhere with same or improved process with additions. Process material balance is to be checked for missing or inconsistent flows. The fuel, power, steam and process raw, material requirements are to be compared with available data for similar plants about adequacy and proper consumption norms. A detailed study is also to be made to narrow down the gap between process Licensor's standard package supplied with the specific requirement of the project or operating co.

3. HEAT AND MATERIAL BALANCE CHECKS

The data furnished by licensor for these items are to be thoroughly checked for any deviation/

missing items for any deviation/missing items in these vital process requirements. The licensor is to be asked to give energy balance for different sections of plant and atmospheric emissions.

The operating company is to undertake EIA (environment impact assessment) study around plant by an authorised environment study agency as per requirement of local regulation for medium and big process plant, taking into account the possible impact of effluents (air and water) releases as per data supplied by process licensor.

4. UTILITY BALANCE

- (i) A study is to be made for peak and normal power requirement including emergency power provision as per electrical balance given by the licensor. Even full or part power generation inside the plant is envisaged, a comparative study on cost aspects is to be made for outside power visavis own generation. The emergency power installation should have appropriate fail safe auto start-up system. Receiving substation for outside power and control system should have high reliability. The licensor shall supply the electrical distribution arrangements to different plants, utilities, auxiliary buildings and administration buildings. Substation with MCCs are to be clearly rated. Emergency power supply need to be provided for plant lighting and critical equipment for safety during power failures. Due agreement with local electricity board or company is to be made once total power requirement is given by the licensor and when auxiliary power requirements have been finalised.
- (ii) Steam balance for the project or expansion as given by the licensor, is to be checked so as to ascertain the capacity of steam plant required, using a 25% excess capacity to cover for extra process consumption and leakages. The condensate is normally reused after cation polishing, followed by mixed bed treatment in ionexchange plant of the factory. Good quality steam traps for steam piping should be laid at 50 m distance with gradient of 1 in 200.
- (iii) Cooling water balance: Normally induced draft cooling tower is used and is sized adequately for about 15–20% over capacity. The cold water temperature will depend on dew point and cooling range. Dew point and relative humidity are also to be calculated theoritically when actual data are not available from metrological department's long span data and psychrometric chart. Parabolic natural draft cooling tower is often used when circulating volume is higher and cooling range is low and wind velocity is less. Cooling approach is to be judicially selected. Wind velocity is to be considered for mechanical draft cooling tower as waste humid heat for cooling tower is to be adequately dispersed into atmosphere. Provision for emergency cooling water pump is to be made with emergency power supply. The cooling water circuits, both incoming to outgoing from cooling tower, is to be checked for pressure drops so that the sum of the pressure drops is 0 as per Casey formula. Dew point temp. can be found from steam table knowing the partial pressure of water vapour. Heat load in a cooling tower is expressed in kcal/hr or MW.

Cooling approach = Cold water temp - W.B. temp.

Cooling range = Hot water temp - Cold water temp.

W.B. depression = D.B temp - W.B. temp.

Relative humidity = $\frac{\text{Partial pressure of water vapour at any temp.}}{\text{vapour pr. of water at existing temp.}} = \frac{\text{p w}}{\text{p}^{\circ}\text{w}}$

Renault's equation : cs' - c = A.P (T - T')

for determination of wet bulb temp.

Where, c = V. P. at temp (to be, determined) cs' = Satd. V.P. at temperature T', mm Hg. T = D.B. Temperature T' = W.B. Temperature A = Constant P = Total atm. press. mm Hg $Absolute \ humidity \ (molal) = \frac{pw}{p-pw}$ $percentage \ molal \ humidity = \frac{pw}{p^\circ w} \cdot \left(\frac{p-p^\circ w}{p-pw}\right) \times 100$ where, $pw = partial \ press. \ of \ water \ vap. \ at \ any \ temperature <math display="block">p^\circ w = vap. \ press. \ of \ water \ at \ existing \ temperature$ $p = Total \ atm. \ pressure.$

Waste Water Generation and Treatment

The licensor should indicate the qualities, temperature and pressures of waste water generated per hour per day from each section of the process and utility plants. The analysis of waste water from each section is important. The licensor is required to inform the statutory requirements of effluents to be discharged into natural streams, rivers or lakes after treatments for which the licensor is to give guarantees. It is advisable to have two impounding ponds of sufficient capacity for storage of effluents should the analysis of outlet stream/streams from effluent treatment plant goes beyond the stipulated limits or break down of treatment plant. The acidic and alkaline effluents from D.M plant need to be neutralised before discharge to effluent sewers. Inside plant sections separate effluent sewers and rain water sewers are required to be put. Boiler blowdown should be collected in pipe lines and discharged to effluent sewers as per statutory requirement and also for hazardous effluents from plants and pump leakages. Cooling tower blowdown also needs treatment for chromium removal (hexavalent to trivalent).

Often effluent treatment plant is kept outside the perview of Licensor's scope of work and the same is designed by contracting firm as per specification of effluent given by licensor which is cheaper and the firm gives the guarantee for treated effluents.

(iv) Air Pollution

The licensor is to be given the statutory limits as per air pollution act for emission through chimneys/stacks based on which the licensor designs the plant for proper atmospheric emission monitoring system which is required for large plants along with wind velocity indicator and direction of wind indicator. EIA report gives the velocity and direction of the wind and also indicates any inversion level. Large coal based steam/power plants need electrostatic precipitator.

(v) Instrument air and auxiliary air services

Dried instrument air at 6-7 kg/cm of pressure and dew pt -40°C is normally required in a process plant. The Licensor is to give proper scheme for I.A. system consisting of Air compressure (Reciprocating/centrifugal), silica gel driers (auto change over) with 1+1 heaters (steam and power) and a central dry air receiver to cater for atleast 20 mins after power failure. Individual plant sections

also need to be provided with I.A. receivers of atleast 20 mins capacity for safe shutdown. Emergency power is required to be provided for atleast one air compressor and heater for I.A system. Air capacity should be made atleast 20% more than normal requirement due to leakages.

A small auxiliary air compressor is required to be put for service air requirement in plants and mech/elec/instrument work shops.

5. DESIGN CHECK POINTS

(a) Material Balance

To indicate each item of flow with quantity, temperature and pressure at different points of flow sheet along with utility streams. Percentage conversion is to be ascertained from flow conditions in the reactor or at converter inlet and outlet. Critical items are often shown in ppm and its importance in products, intermediates and raw materials are to be evaluated.

(b) Utility Balance

To check for compatibility with process flow diagram, steam production and fuel input, air flow etc. are to be ascertained to find out energy consumption, and excess air in steam generation and power plants. Instrument air, service air, nitrogen (for purging), C.W, C.W for pump glands are to be specified by licensor.

(c) Metrological data with 95% extreme temperuatre for 50 years average data, 100 years flood data, seismic data as per IS code 1893 and earthquake factor/code are needed. Water table of the site and source of factory water with analysis. Soil bearing load data are required and if not available, test bore is to be made to ascertain the soil bearing load and water table.

The data on the wind velocity and direction of wind for last ten years, with maximum wind velocity have also to be ascertained as these data are to be furnished to licensor prior to design of the plant. Analysis of fuel and its source and pressure/temperature etc., as well as raw material source with analysis are also to be furnished to process licensor.

(d) Auxiliary Services

Although these might not have been considered in agreement, it is important to have maintenance (mechanical, elecctric and instrumentation) requirements spelt out by licensor, along with analytical requirements and manuals, storages for raw materials and products, fire services and safety requirements for personal protection and gate office for punching and security.

Secondary systems – Start up requirements of spare equipment, refrigeration system in process, hydraulic systems of rotating equipment as per vendors etc., are to be clearly spelt by licensor or vendor drawings supplied to operating company.

(e) Plant Operating Safety

The licensor is required to provide flare system with tall stack, trip systems provided in process control description reports, emergency stoppage of Hazardous storage systems in case of mechanical failure of storage vessels/outlet line.

Hazards of operation study in a process plant is helpful for better safety in operation.

Hazop-I study is made before process design; Hazop-II analysis is done when process design is in advance stage and that for Hazop-III when the plant goes into commissioning.

(f) Offsites

Requirements of loading and unloading of production and raw materials, plant roads, railway siding (if required) are to be taken inoaccount. The factory act requirements of rest rooms and lavatory, lockers for factory staff, plant storages, process central control rooms, technical and admn. building, modern communication systems provision are required to be considered with some input available from licensor like product bagging. and storage, railway siding etc. The hand railing and toe foot board and equipment guarding requirements as per factory act are also to be considered.

(g) Land for Factory and Township

Land requirement for factory is given by licensor in the plot plan which is to be checked. The land includes areas, not shown for off sites, utility and auxiliary services. In addition, safe distances for Hazardous chemicals storage layout as per statutory requirement, liquid effluent impounding areas, Hazardous chemical wastes dumping area as per statutory requirement, are to be included. It is better to provide a jeepable road along boundary wall for routine check for big factories and provision for expansion area for product, and intermediate and steam plants. Procedure for land acquired from govt is lengthy and efforts are to be made early once the approximetely size of land is ascertained. Land acquision is through district collector or magistrate.

(h) Process Check

- (i) Basic conversion yield. The licensor need to provide data about catalysts type, composition, operating temperature/pressure, yield, reduction procedure, inert gas requirement for used catalyst unloading, life of catalyst recommended, supplier etc. If these are not furnished, the licensor is to be requested to provide answers to these and other questions. In addition, whether yield is assumed if not full scale testing is done; how much is contingency factor. If scale up has been made in reactor design and other equipment by licensor, the extent of which should be asked.
- (ii) Thermodynamics. The licensor should give separately, when asked for by operating company, thermodynamics of the process taking its account of the heat of reaction, heat of combustion for each reaction and overall reaction. The sectionwise heat balance in the overall heat balance of the plant need to be asked from the licensor.
- (iii) Material balance calculation. The licensor often, if agreed to, in agreement, gives the total material balance calculation which is of course confidential. If the licensor do not agree, then licensor is to be asked to provide calculation for yield rate with raw material input shown in material balance. Process design data sheets for the entire plant should be asked from the licensor during finalisation of the agreement with the licensor. The equipment design calculation data sheets could be asked for from the licensor for extra payment if agreed to.
- (iv) Fractionation and absorption columns suitability. It is advisable to recheck the designs of these columns, using a computer and material balance and other data supplied.
- (v) Pressure drop calculations. Check the press drop calculations across packed columns and fractionating towers with available equations or Norton generalised pressure drop calculations.
- (vi) Heat exchanger. The film co-efficient (both sides) used as per process equipment data sheets are to be checked.
- (vii) Vessel diameter/nozzele sizes. Check vessel diameter as per available data for other plants using 6/10th rute and nozzle diameter as per similar data, available from other plants.
- (viii) Check for boiler design based on fuel gas flow and temperature, steam conditions (pressure, temperature), feed water flow and temperature and blow down etc.

(ix) Instrument Air. The running I.A. compressor (120% capacity) should be steam driven and spare one should be an auto-start electrical driven compressor with emergency power.

Instrument Air is connected to compressed air receiver from which instrument air is sent for dehumidification in a duplex silica gel drier for regeneration, separate electrical driven blower (with spare) and electrical heater (with spare stream heater) need to be provided. Emergency power connection is required for blower and electrical heater. The capacity of compressed air receiver and I.A. receiver from drier should be atleast for 20 minutes each respectively.

- (x) Raw material and fuel gas system. If N.G. or L.P.G. is used as raw material and fuel gas supply proper knockout drum, with auto drain system, is to be provided. Heating system for knockout vessel or outlet line (drain) is also needed. To be provided for N.G. incoming system.
- (xi) Flare stacks. Adequate bottom drain vessel, sliding support and flare ignition system with purging, are to be provided. All S.V. outlets, handling inflamable gases are to be connected to flare stack header.

For plants, handling ammonia, separate high vent stack is needed. The liquid ammonia knockout drum should be steam jacketed at bottom to vaporise liquid ammonia.

- (xii) Fire water system. Should be as per standard statutory codes and a constant running jockey pump for developing pressure of 8 kg/sqcm in fire water header. The stand-by jockey pump is to be connected to emergency power. A constant bleed from jockey pump discharge is to be provided to prevent cavitation inside the pump. The diesel driven fire pump should have battery back up for emergency start up when the discharge pressure falls below the preset limit. No. of fire pumps and capacity will depend on fire system design.
- (xiii) Lifting cranes. All heavy rotating machinery should have provision for E.O.T. cranes of capacity for maximum weight of parts of the rotating machines.
 - (xiv) Waste disposal
 - (a) For oil in compressors condensate, API oil separate is required
 - (b) Cooling water blow down- separate treatment for chromium removal is required.
 - (c) Waste water from plants is to be pumped to waste treatment plant as required.
 - (d) Incinerator for paper and other combustible material is required.
- (e) Disposal of treated effluent through weir for draining to natural streams with monitoring arrangement for flow and effluent constutents (major) are also needed for satisfaction of state pollution control board.

6. INSTRUMENTATION AND CENTRAL CONTROL ROOM

Instrument control room is the heart of a process plant. Proper selection of instruments of reputed maker is a fundamental task for safe and trouble free run of a process plant. The following aspects need to be checked in process instrumentation.

(a) Flow measurments

Primary measuring elements orifice meters, online turbine flowmeters, oval flowmeter and pitot tubes (for large flow measurements like C.W. flow) and rotameters etc. Proper distance requirement for differential pressure across the orifice located in straight pipeline section is to be ensured. The flow is generally transmitted through pneumatic flow transmeters or pneumatic-electrical transducer

to central control room. Site indication of flow is often required for process control. The flow controllers in control room through actuators are to send electrical pneumatic signal to control valve to position for process requirements. The flow controllers can be set at manual or at auto position after setting the set point of the controller. Alarm annunciator is actuated when flow is lower or higher than the set point.

(b) Pressure Measurements

Primary pressure measurement element is spiral or helical Bourdon tube of required material to suit process fluid. For pressure, lower than 0.5 kg/cm² bellow, diaphragms are used. The pressure is transmitted through pneumatic transmitters or pneumatic-electrical transducer to the pressure controller in control room. The pressure controller sends controller out put pneumatic signal to control valve as per process requirement. The controllers can be operated manually or can be kept in auto operation at set point beyond which an alarm circuit will be actuated in alarm annunciator panel. Separate pressure indicator is put on the vessel/pipeline for on-site observation. The range of dial type pressure gauges should be twice the operating pressure, differential measurement of pressure shall be done with bellow or diaphragm type instruments.

(c) Level Measurement

Primary measurement is by float level transmitter, capacitance probe etc. For freezing solution, the level transmitter is normally stem jackated. The material of construction should be carefully selected to prevent corrosion.

(d) Temperature Measurement

Primary measurement is by resistance thermometer, thermocouples of suitable metals or combination for the temperature range to be measured. For high temperature, pyrometers and segar cones are used.

Molten metal bath temperatures are taken by H.T. termocouple which is pushed through the bath and finally gets melted. Liquid filled thermometers are used for low temperature indications. Ranges of different thermocouples etc., are as follows:

```
Resistance thermometer = upto 350^{\circ}C
Iron constant at thermocouple = 350 - 450^{\circ}C.
Chrome Alumel thermocouple = 450 - 850^{\circ}C.
```

Locally mounted thermometers upto 8 m in distance from impulse point shall be dial types bimetallic.

Electro/pneumatic Transducer type transmitter and final control valve, pneumatic type are used for temperature control.

(e) Controllers

The modes of controllers shall be carefully selected depending on process requirements. Generally temperature controllers should be 3 modes types (percentage, proportional and resets and rate) with auto reset. The flow controllers, level controllers and ratio controllers could be 2 mode controllers (percentage proportional and reset) with auto reset. The pressure controller can be either 2 mode or 3 mode controllers depending on criticality of operation. Controllers should have automanual change over. The control points of controllers may be 0.75–0.80 of full scale range (*i.e.*, 75–80%). Reset mode is required for precesion control with adjustable sensitivity.

(f) Control Valves

There are various types of control valves *i.e.*, self acting, remote operated automatic control valves, direct or reverse acting, with pneumatic diaphragm control valve, solenoid operated control valve or electric motor operated control valve. The valve port type is double seated with suitable design for lower pressure on valve glands. Hand wheel in control valve is required under the following conditions. (*i*) where there is no bypass or block valve (*ii*) In 3-way valves and valves under special services. However, no handwheel is provided in emergency control valve. Control valve of size above $\frac{1}{2}$ " shall be of single seated type. Valve positioners are provided when the valve size is $2\frac{1}{2}$ " and above. Valve positioner in control valve is required for the following conditions:

- (i) Butterfly valves of size 4" and above. These valves have low pressure drop.
- (ii) Temperature control valve above 200°C operating temperature.
- (iii) When distance from controller to control valve exceeds 50 metres.
- (iv) Control valve with extra deep gland packing.
- (v) Double seated control valve of size 4" and above.
- (vi) Single seated valve of size 2" and above.
- (vii) For services where close control is required or hunting is to be avoided.
- (viii) Where control valve requires valve positioners, they should be of force balance type.
- (ix) Special purpose relay or volume booster may be incorporated into the control loop to overcome lagtime or to accomplish special control functions.

(g) Flow Through Orifice Meters

There are various empirical equations for orifice flows which incoporate a correction factor. Correction factors for steam and gas orifices are given below:

$$K_S = \sqrt{\frac{\rho_{SM}}{\rho_{SD}}}$$
 where,
$$K_S = \text{Corrector factor}$$

$$\rho_{SM} = \text{Steam density at operating condition.}$$

$$\rho_{SD} = \text{Steam density at design condition.}$$

$$K_G = \sqrt{\frac{\rho_M}{\rho_D}} \times \sqrt{\frac{\Gamma_D}{\Gamma_M}} \times \sqrt{\frac{\rho_D}{\rho_M}}$$
 where,
$$K_G = \text{Gas correction factor}$$

$$\rho_D, \, \rho_M = \text{Pressures at design and operating conditions.}$$

$$T_D, \, T_M = \text{Temperature at design and optg. conditions.}$$

$$\rho_D, \, \rho_M = \text{Gas desnsities, design and operation conditions.}$$

(h) Recorders

Generally 12 point recorders are to be used in control room or field (if necessary)

(i) Instrument air receivers

There should be atleast 20 minutes storage of instrument air at 8 Kg/sqcm and dew point of -40°C. The instrument air receiver should be divided into 2 or 3 storage vessels for various sections for safe shutdown due to power failure. Pneumatic instruments generally operate upto 2.5 Kg/cm² air pressure at the instruments. Filters for instrument air and I.A. receiver are to be periodically drained.

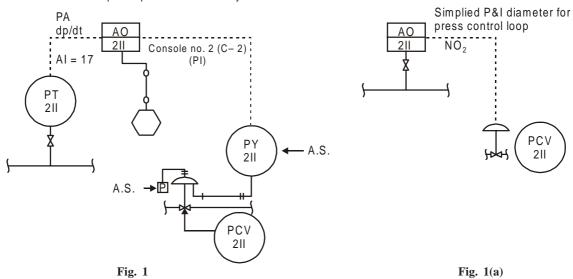
(j) Online instrument analysers

(i) Condensate coolers in gas sampling point with drains are to be provided before gas flow to electrodes for analysers. Air conditioners are generally required for sensitive analysis.

7. PLANT INSTRUMENTATION

(i) Process plants of early 80's design were usually provided with pneumatic and electrical instruments (both field and control room) without any shared distributed control system (DCS) with basic logic diagram for specific control system using pneumatic – electronic transducers for controllers and pressure/flow etc., were transmitted to controller electronically by electronic transmitters. The working of DCS using basic logic diagrams and computers is given below:

Detail loop of a pressure control system



The left side diagram of Fig. 1 would be as it appear in detail P and I diagram and that in the right side diagram (Fig. 1a) would appear in simplied P and I diagram.

The pressure indicating control loop is controlled by a shared distributed control system (DCS). The setting of this conroller is received from a supervisory computer over a shared data highway that provides software link between the computer and DCS system. The control loop tag no. 211 indicates that it is the 11th instrument on P and I flow sheet no. 2.

On the measurement side of the loop there is an electronic (4–20 mA DC output) pressure transmeter which is connected to a process pipe line by a $\frac{1}{2}$ " shut of valve (13 mm) and has a pressure range of 0–3000 PSIG. The output from this transmeter is received and identified at the multiplexer of DCS system as an analog input no. 17 (AI–17). The controller PIC–211 is located on

console no. 2(C-2) of the DCS system and is provided with proportional and integral (PI) algorithm. The DCS system also provides a high pressure alarm function PA and a high rate of pressure rise will provide an alarm on this measurement.

The analog signal, leaving the multiplexer in the output side, is identified as AO-211. The signal is 4-20 mA DC signal which is received by a current to air converter (PY - 211) mounted on the control valve. The pneumatic output signal from I/P converter goes to the diagram motor of the control valve. Air supply is provided for both valve positioner (P) and I/P converter.

- (ii) Therefore, (a) process function diagram which gives a site specific logic diagram (b) a P and I diagram and (c) a hardware diagram giving detail wiring diagram, will constitute the basic drawings for a process plant. Such set of drawings should be provided by the plant designer.
- (iii) All the above drawings for instrumentation shall be checked thoroughly for any inconsistencies and process requirements. If Hazop analysis I and II are available, the recommendations should have been incorporated in these drawings. Special requirements of emergencies and instruments to tackle these emergencies should be looked into. Hazop III requirements during commissioning are to be noted for eventual implementation.
 - (iv) Thermocouple and Pressure elements materials should be checked for compatiability.
 - (v) Adequacy of field instruments should be checked.
- (vi) Data logging computers are provided in DCS systems; printers and voice communication with field staff should also be made available.



DETAIL PROJECT COST ESTIMATION

Once it is decided by the top management to set up a new project on the basis of a technoeconomic feasibility report, the estimation of a detail project cost is the next step. The cost estimation for a new project involves consideration of various factors in detail so as to arrive at the total cost of the project. The major heads are:

- 1. Preliminary expenses for TEFR, survey, metrological data etc.
- 2. Land and site development.
- 3. Civil works cost of factory, plant buildings and auxiliary buildings.
- 4. Plant and machinery cost including handling and duties.
- 5. Miscelleneous fixed cost.
- 6. Cost of auxiliary utility services.
- 7. Cost of Effluent treatment plant and measures.
- 8. Design Engineering and procurement charges.
- 9. Technical know how, process licence, drawing checking fees and royalty (if any).
- 10. Project management charges including statutory fees.
- 11. Erection charges.
- 12. Incidental charges.
- 13. Erection supervision charges.
- 14. Commissioning charges including pre commissioning.
- 15. Interest charges during construction and commissioning.
- 16. Margin money on working capital.
- 17. Township, welfare and medical expenses.
- 18. Escalation or contingencies.

Other Informations

19. Typical percentage costs for a new chemical plant and depreciation rates.

1. PRELIMINARY EXPENSES

Here TEFR required survey cost, metrological data acquisition cost etc., are to be included. Metrology data are important as it is to be included along with other data on site for sending to process designer as basic data on site.

2. LAND AND SITE DEVELOPMENT

The quantum of land required for the manufacturing plant/factory for a particular product selected, is to be ascertained from the process technology supplier or process licensor. For this, process licensor will ask for basic design data viz ambient temperature (Dry and wet, bulb temperature), data on the velocity and direction of wind and water table.

Past earthquake data/seismic group of the area as per relevant IS code – 1893, land contour map etc. For smaller projects, earthquake data, land contour map (geotechnical map) are usually not required. The other data required are:

- (i) Soil load bearing capacity, type of soils, flood water levels (minimum and maximum) of nearby river. If soil load bearing data is not available, test and determine it.
 - (ii) Elevation of site and survey data of the site.
- (*iii*) Availability of basic infrastructure facilities, viz. P.W.D. road nearest to site, its width and the condition of road, H.T. power supply nearest point, either substation or H.T. transmission line, fax, telephone/e-mail facilities.
- (iv) Nearest drainage canal for surface water and factory, treated effluent discharge, availability of any river or irrigation canal nearby.
 - (v) Availability of skilled and semi skilled labour.
 - (vi) Nearest town and public transport availability for going to site.
 - (vii) Type of land available in the area, agriculture, homestead and barren.
 - (viii) State/central Government policy on location of industry.
 - (ix) Distance from nearest rail head and marketing zone location.
 - (x) Pollution norms both air quality and water limits for the type of industry planned.
- (xi) Bulk power supply rates and cost of laying H.T. transmission line to factory substation, H.T. voltage availability.
- (xii) Municipal water supply availability and analysis of water. River water analysis and distance of river water from proposed site. Tubewell water analysis in the area.

The land and land development cost shall include the following

- (a) Current market rate of land
- (b) Legal fees for 13 year search of proposed land area holdings and conveyance charges.
- (c) Cost of macadam metalled roads (min 5m wide) to site from P.W.D. road.
- (d) Survey and site levelling cost.
- (e) Cost of factory 5–7 m wide internal semi pucca roads with approach roads, culverts and pucca surface drain.
 - (f) Barbed wire fencing/boundary wall construction. cost.
 - (g) Main gate with security post and barrier cost.

- (h) Cost of temporary office shed, godowns and hard core open space for storage of equipment and plant stores.
 - (i) Initial tubewell boring cost for site construction and temporary overhead tank.
 - (j) Cost of initial temporary surface water drains from site to outside discharge point.

3. CIVIL WORKS COST FOR FACTORY AND AUXILIARY BUILDINGS

Total civil works cost to be determined for the following heads.

- (i) Main plant factory civil works and cost of structurals.
- (ii) Auxiliary plant buildings for utilities plants. Safety office, plant laboratory and central lab, Fire service, rest room, river water pump house or Tubewell battery cost, cooling tower cost and over head tank.
 - (iii) Administrative building, plant offices and canteen.
 - (iv) Factory effluent treatment works and Air quality monitoring station.
- (v) Cost of finished product storage, raw material storage, warehouse for plant stores are to be included.

Once the plant process design is completed and plant designer have furnished the preliminary plant layout drawings and civil scope drawing, civil works cost against the above heads are to be determined as per local area civil construction rates. The cost of AC, electrification for roads and buildings, Air conditioning of control rooms are also to be ascertained. Doors and window are reqd. to be of steel construction with glass panes and minimum height as per factory Act. Toilets costs also have to be included. FI's have specified civil construction rates, there rates also to be checked. Escalation cost @ 10% to be considered.

4. PLANT MACHINERY COST

(i) Main and Auxiliary Plants

Once the plant designer or Technology supplier had finalised process design and factory layout and duly approved by plant authority, the basic data sheets for static equipment and moving machinery are available, project authority is to invite quotation from reliable and reputed equipment suppliers. Based on their quotation rates, cost of plant and machinery are worked out. For urgent evaluation, when quotation is not available, cost is usually evaluated by 6/10th rule which is applicable when cost for other sizes of the same equipment is available.

For selection of a particular process, offered by the plant designer, after basic design data of site is sent to them, the following factors are to be considered.

- (a) Consumption norms for raw materials, utilities, raw materials and, product/by-product specifications. This is to be compared with data available from other plant designers for better consumption norms and product quality (usually a M.O.U. is executed with the plant designer earlier which detail out the scope of work, etc. of both plant designer and plant authority/consultant.) Instead a contract document could be signed.
- (b) Availability of raw materials indigenously of particular purity, specified by plant supplier or to be imported.
 - (c) Number of operating personnel required for each main plant under this scope.
- (d) Whether the process, to be supplied, is the latest one, requiring lesser equipment and operating personnel.

- (e) Technical know-how and supervision charges of the technology supplier. If royalty is involved this is to be within the limit of present tax laws.
 - (f) Nearest port distance and mode of import.
 - (g) How many plants of similar or of higher capacity, are working else where and their addresses.
 - (h) Plant designer to provide 10-15% excess capacity margin in equipment supplied.

Only sophisticated/patented equipment are imported and other equipment are procured indigenously.

The process of evaluation of cost of plant and machinery is a time consuming affair. All cost of moving equipments specified, including commissioning and 1–2 year spares. Fi's do not insist for lowest quotation rate and cost heads are given as imported (items) and indigeneous rupee cost. If the imported items are listed in OGL group of current import export policy book, the payment can be made in Indian rupee and if not payment is to be made in F. C. The cost, insurance, frt, C.D., port handling and transport cost is to booked in appropriate heads of project estimate. For loan assistance of F.C., the imported item cost, CIF value to be separated out for F.C. loan. Consider the piping, insulation painting material costs for main and auxilation plants.

For auxiliary utility plants, the quotation is usually invited from indigenous plant suppliers with detail procurement specification of equipment.

5. MISC. FIXED COSTS

- (a) D. G. set of required capacity as per plant designer's requirement with extra 25%. Cost of commissioning by supplier to be included.
 - (b) Yard piping cost for process materials and utilities
 - (c) Laboratory testing items for main and plant lab.
- (d) Electrical cable and from main substation to plant substation. The transformer and relays panels, bus section; all MCCs to have single/3 phase thermal over load relay of reputed manufacturer.
- (e) Cost of outside H.T. transmission line from nearby transmission line to proposed site substation etc. H.T./400 volts AC three phase, 50 cycles Hz transformer. All the cost should include construction with spares for 1–2 years spares. D.G. set cables cost to be included.
 - (f) Insturmentation cost for main plant including instruments cables etc., and spares.
 - (g) Cost of all lab. testing items and commissioning cost by supplier for critical items.
- (h) Fire protection item (fire extinguishers under ground fire hydrant lines, nozzles, fire houses item, fire alarm siren, fire pumps, (one operating + one spare booster pump).
 - (i) Transformer oil filter.
- (j) Railway siding (if any) cost, cost of special wagon if ODC consignment are there and a shunting engine usual norm for P and M cost is to take 5% escalation for firm quoted items and 10% escalation for non firm estimated cost.

6. COST OF AUXILIARY UTILITY SERVICES

Auxiliary utility plants viz. steam generation, D.M. water plant, process water treatment plant, Tubewells and pipeline cost to process water plant, sanitary water distribution line, cooling towers are required to be calculated judiciously in order to give suitable excess capacity margin, usually 20–25%.

(i) Steam generation plant: D.M. plant and P.W.T plant based on available fuel (N.G., fuel oil or any other available by-product fuel gas); various turn key suppliers quote for these items based on client's capacity, steam conditions, super-heat and quality requirments.

Once the process designer had firmed up utility consumption norms and accepted, quotations are to be invited from reputed S.G. plant supplies. D.M. water quality required is given by S. G. plant manufacturer based on which, quotation for D.M. plant is to be invited. The capacity required for S. G. plant should be about 20–25% excess, and co-generation of power also is to be considered by extracting heat from flue gases from SGP with auxiliary firing in big projects. The D.M. water capacity will include SGP requirement plus quantity for other main plants (if any). DM plant is a critical plant and all technical details are to be asked for. The plant should have adequate instrumentation for manual/auto operation for change over, silica analyser, pH meter, flow meter etc. Also gravity filters, deoxidiser for process water intake, condensate polishing unit (cation exchanger) etc should be available. The storage capacity of D.M. water tank should be for minimum 20 hrs or so. The selection of ion exchanger resins depends on the quality of process water which should be free from organic impurity. D.M water plant quotation is asked for after quotation for process water treatment plant is received and before issuing P.W.T. plant quotation the specification of process water available at site (either tube well, river/canal water or municipal water) to be finalised and included in quotation, giving the capacity and raw water feed quality to P.W.T plant.

(ii) Cooling tower and pump house – The cooling tower capacity, C.W. Hot/cold well temperatures, D.B. and wet bulb temperature are usually fixed by process plant suppliers based on the basic site design data given to them as per design process requirements. These towers are usually induced draft cooling towers with 2 speed fans at the top and top deck distribution lines, with plastic nozzles for hot water falling into the tower having glass reinforced wooded grid supports and asbestors louvre. The construction of tower is either of treated wood or concrete. The tower is divided into cells depending on cooling water flow required the cold well outlet is usually provided with screens (1+1) to remove any foreign material going to cold well pump suction; with provision for purge water valve pit for each cell.

C.W. Pump house – The capacity and discharge pressure with floded suction of C.W. pump plus spares to be decided carefully so as to provide return hot cooling water to flow upto the top of cooling tower. Emergency cooling water pump of adequate capacity with D.G. set power is required to be provided.

The layout of cooling water header and branch headers to different sections of a plant is to be suitably planned and header branch lines sizes are determined to cause minimum pressure drop in the C.W. circuit.

As per Casey rule, the summation of pressure drops in the outgoing and return circuits should be zero or nearer which requires vigorous pressure drop calculation for flows in each line. Excess margin of 15–20% should be considered in flow calculation.

7. COST OF EFFLUENT TREATMENT PLANTS

Environment protection requires effluent treatment for water and air pollution which is mandatory for all types of industries. The state pollution board should be initially asked to give the state requirements. The state requirements often is the same as per MINAS/IS or even stringent for final discharge point concentration of pollutants. It is also depend on the type of industry. The water discharge quality after treatment should be as per water prevention and control of pollution Act 1974 (central)/state act.

The process designers usually give the discharge quantities of pollutants from each plant (main or auxiliary). As per present day, PCB requirement is given for even condensate blow down from steam boilers, open condensate drains are to be separated by separate lines and collected in headers and sent to effluent treatment plant. The treated effluent discharge, coming from various industries is specified in environment protection Act-86. Air quality discharge limit of pollutants is given in the central Air (prevention and control of pollution Act-1981 which is given below.

Table 1
Ambient air quality

Area	Category	SPM	SO ₂	СО	NOX
			unit =	$\mu g/m^3$	
Α	Industrial and mixed use	500	120	5000	120
В	Residential and rural	200	80	2000	50
С	Sensitive	100	30	1000	30

N.B. New item: RSPM – Respiratory suspended particulate matter. MINAS or minimum national standards for limits of water and air pollution, is as per above act as well as EPA act rules 1986. EPA rules 1986 defines the sound decibel limit in work places as follows.

- (i) Continuous sound level = 65 db
- (ii) Sound level for short duration = 90 db

Sound level measurement at 2m distance from source. Also in steam generation plant use of ESP is mandatory for a certain capacity.

While asking a manufacturer or supplier to quote for plant facilities, it is always better to give the above pollution standard (Air and Water) along with expected water and air pollution concentrations as per plant suppliers. The effuluent plant supplier is to meet the EPA standard or MINAS standard or state PCB standard.

The total cost of liquid effluent treatment plant will include:

(i) Cost of C.T. purge water treatment facility to reduce Cr^{+6} to Cr^{+3} if chromate–phosphate treatment usually 10 : 20 ppm is contemplated for anticorrosion measure.

Note: When Phosphorate based anti-corrosion treatment is considered only delay chamber for purge water storage is to be provided.

- (ii) Cost of neutralisation tank (rubber lined or epoxy coated) for D.M. plant regeneration waste water (H_2SO_4 and NaOH).
- (iii) Cost of bulk effluent treatment plant for specified plant effluent coming to ETP either via a pump or separate utilities effluent drainage line from main plants.
 - (iv) Cost of delay ponds (1 + 1) for treated effluents for 1 to 2 months storage capacity.
- (ν) Flow measuring weir and cage for fishtest for liquid effluent discharge to canal, river, nullah should be included in cost along with all specific instruments, analyser etc.
 - (vi) Cost of electric installation of the E.T. plant building electrification, etc. to be taken.
- (vii) Cost of special concrete dumping pit if harmful effluent like arsenic etc. are to be handled as per Hazardous materials handling Act-89.
 - (viii) ASTM oil separation (with coke) cost for each plant and SGP plant.

- (ix) Cost of oil centrifuge for emulsified turbine oil.
- (x) Cost of central lab instruments for special analysis of water and air pollution.

7.1 Cost for Pollution Abatement Schmes

The air quality in the plant should be as per table -1. The plant designer should be asked to keep the stack emission minimum so that the above norms can be kept in the ambient air. The designer is to provide filters for dust emission, SO_2/NOX scrubbers in the main plant it self. CO emission from stack beyond the limit as per table -1 is not allowed. It causes headache at higher conc. in air. Unlike water pollution abatement schemes, air pollution control equipment are installed in the plant which generates the pollution.

7.2 Air Pollution Cost of Equipment Including Monitoring Instruments

- (a) Cost of one ambient air quality monitoring station.
- (b) Cost of scrubbing, if any, for air pollution control.
- (c) ESP for steam generation plant (if applicable).
- (d) Cost of wind velocity and wind direction indicator.

As per SMPV Act/rules cost of emergency shut off valves (remote controlled) are to be installed for Hazardous storage like liquid NH_3 spheres. Also the cost of commissiong spares and 1-2 yrs spares are to be included in all effluent treatment plants.

8. DEP CHARGES

Based on quotation from plant designers/ consultant, design and engineering charges are to be included. For procurement of equipment and machinery, it is either done through consultant/firm or by the client itself, in the latter case stage wise inspection or final inspection by competent/agency is required to ensure that the equipment conforms to specification issued by consultant/client/ designer before shipment. For foreign supply usually Lloyds registrar does it at a fee which is to be included in procurement cost along with indigenous items inspection cost. Usually DEP charges range form 15–20% of project cost.

9. FEES FOR KNOW-HOW, DRAWING CHECKING, PROCESS LICENSE AND ROYALTY CHARGES

These costs are usually mentioned in aggrement with technology provider for complete patented process of manufacture, royalty is to be paid which should be within the limit specified in Indian tax laws. Know-how charges is for complete design package and License fee is for use of any patented process.

10. PROJECT MANAGEMENT CHARGES INCLUDING STATUTORY FEES

These charges include all site expenses for salaries of employees, establishment cost, stationary and postage, Telephone and fax, Company vehicle/hired vehicle maintance and fuel cost, wellfare and medical expenses, bank charges, electricity and water charges, local taxes, tour expenses, Guest house (if any) expenses. Gardening and cleaning expenses, office furniture and equipment expenses etc. All statutory costs for CCE licence, fire licence, electrical licence, etc., are to be considered. These costs are to be taken upto the end of commissioning period and before start of commercial production.

11. ERECTION CHARGES

Costs based on quoted prices of erection contracts for equipment, piping and vessels for mechanical items, electrical and instrumentation items. Turn key supply cum erection contract values for certain items are also to be included. NDT tests cost also to be included. Every erection contract has a standard clause for escalation based on consumer price index for industrial workers. For big/medium/small projects, certain provision for delays due to reasons attributable to project owner's lapses is better to be included in erection cost. Insurance cost of erection to be included.

Hiring of construction equipment charges, Training expenses, Salaries and benifits provided by Company to site staff/other offices and income tax on foreign supervision is to be included.

12. INCIDENTAL CHARGES

These charges include ocean freight, railway and road transportation charges, Insurance, Inland handling at port transhipment cost which is applicable to customs duty, excise duty, state/central sales tax. The typical rates are as follows:

Inland handling and transportation = 6% of FOB for cost of equipment and supplies

Ocean freight = 15% of FOB

Customs duty = depends on type of industry (usually 20%)

Port charges = 2% of CIF

Excise duty = 15–20% of FOB (usually)

Central sales tax = 4% against C form

Insurance = 2% of delivered cost of equipment and supplies.

13. ERECTION SUPERVISION CHARGES.

Supervision charges for vendors of equipment including foreign equipment, erection supervision charges of foreign personnel, Income tax liability of foreign personnel and charges for supervision by consultant engineers, travel expenses (to and from) for both vendors engineers and foreign supervision including air fare, car rental for road travel etc.

14. TOWNSHIP, WELFARE AND MEDICAL EXPENSES

For few senior personnel and minimum Technical essential staff it is advisable to have a small township for which cost of land, civil works, O.H. electric supply, roads and drainage, factory dispensary (where applicable), ambulance and other facilities costs are to be considered. Bus facility for staff also to be included. Commissioning expenses based on commissioning schedule as per bar chart/P E R T or C P M charts, cost of commissioning expenses is to be determined. The variable cost of raw materials and utilities, plant stores, packing materials, maintenance materials. Insurance and taxes and selling, administration expenses and contingency.

On the total of above cost, debit the cost of finished product produced during commissioning.

15. MARGIN MONEY ON WORKING CAPITAL

Margin money is paid by banks—workout the working capital required at 100%, 90% and 80% loads. 25% of annual total working capital requirement will be margin money. The sale price of products is to be correctly determind. The cost of packing material, chemicals and consumables, product inventory assumed, goods in process, cash balance in bank, accounts payable deposits and

advances are to be considered. In other form of FI's norms margin money is calculated based on (1-4) months requirements raw material and consumables, finished goods, 1/2 month receiveable, 1 month salary and other expenses, one month period and imported raw materials for 4 months.

16. INTEREST DURING CONSTRUCTION PERIOD ON BORROWED CAPITAL

Based on debt equity ratio, the financing charges during construction period is to be ascertained. Initially equity amount is spent as it is a low cost capital. After expenditure of equity amount, calculate subsequent years interest at prime interest rate prevailing as per term loan condition of FI's. Assume loan amount is received at middle of the year and calculate interest there on.

17. ESCALATION OR CONTINGENCIES

Consider 5-10% escalation cost or contingencies

OTHER INFORMATION

18. PERCENTAGE COST OF A NEW CHEMICAL PLANT

<i>Item</i> Civil works		Range of Cost 10 - 30 %
Equipment		50 - 60 %
Piping	•••	15 - 30 %
Electrical	•••	12 - 20 %
Instrumentation	•••	8-20%
Depreciation rates		
Civil works		4 % (25 yrs)
All others		10 % (10 yrs)



TYPES OF CONTRACT

- 1. There are several types of contracts. Broadly the contracts can be classified as given below.
- **1.1** Contractor will do consultancy, design, engineering and procurement. Erection by others; precommissioning and commissioning by owner with supervision by consultant.
- **1.2** Owner will supply basic design data viz soil bearing load, cooling water parameters, dry and wet bulb temperature, wind conditions etc., and contractor will do design, engineering, procurement, erection and commissioning. This is also called turn key contract.
- **1.3** Owner will do design, engineering and procurement and contractor will do erection and commissioning by owner.
- **1.4** Owner will do process design only and contractor will do detail engineering procurement and erection. Commissioning by owner.
- 2. In case of plants where foreign technology is involved and when a contractor/consultant is involved, a memorandum of understanding between owner and contractor/consultant is to be executed where in detail scope of work by both parties are specified along with fees. The consultant/contractor usually executes an agreement with foreign technology supplier, giving detail scope and supply of technology and prices of each activity including know-how fee, detail engg. checking of drawings by consultant etc.
- **3.** Mode of re-imbursement to a contractor/consultant is an important parameter for legal and business point of view of a contract. There are four different types of re-imbursements as follows.

3.1 Cost Plus Contract

The contractor is reimbursed for all costs applicable to the contract, plus a percentage of the cost for overheads and profit.

3.2 Cost Plus Fixed Fee Contract

This is similar to Cost plus contract except that the contractor can only earn a specified fee. All other payments are reimbursed for direct cost only. There are many variations of this type of contract.

3.3 Lump Sum Fixed Fee Price Contract

This contract allows only a fixed sum of money nothing more or less than the fixed fee. Here all contract contror's services are detailed out by the owner in the NIT; escalation clause may or may not be there. This contract has the scope for dispute.

3.4 Guaranted maximum Contract

This is similar to lump sum fixed fee contract except that the guaranted price may apply to material (and labour) only; escalation on either material or labour may be allowed. In such contract, contractor is allowed a bonus depending on amount of charges for earlier execution.

3.5 Unit Price/Item Rate Contract

Here all types of work involved are itemised and payment is as per item rate quoted.

4. EXCALATION CLAUSES IN A CONTRACT

There are various factors in a contract where escalation is to be paid to contractor due to rise of consumer price index for labour, delay in handing over the site and site facilities like power, water, shed (if applicable) etc., delay in handing over of equipment for erection, erection materials (under owner's scope), delayed payment etc.

4.1 Penalty Clauses in a Contract

Owner usually put conditions for imposing penalty as liquidated damages for delay in completion of a contractual time period. Often failure to provide Bank guarantee in time by the contractor is penalised. The liquidated damages in failure in performance to meet rated capacity and specific consumption norms as per contract invite penalty for not meeting the guaranted norms, as per rates specified in contract.

- **5.** A contract document can be executed with the selected contractor and broadly should include also the following:
- **5.1** Effective date of contract
- **5.2** Name and address of parties, legal definition and act authority.
- **5.3** Acknowledgement of engineers knowledge in undertaking the project and inview with the client.
- **5.4** Nature and extent and character of the project and time table.
- **5.5** Service to be rendered by consultant.
- **5.6** Service to be rendered by client.
- **5.7** Provision of termination of contractor's engineer's services before completion of work.
- **5.8** Competence of engineers in services rendered.
- **5.9** Method of payment of account, interim payment and final payment in full settlement.

6. PROVISION FOR PENALTIES FOR DELAYED PAYMENT

- **6.1** Provision for change of scope of project prepn. of alternate drawing, if desired, drawings, construction documents and details of expenses required.
- **6.2** Specification regarding what constitutes approved engineers work by the client.
- **6.3** In addition, the document should contain clauses 4 and 4.1.



PROJECT FINANCIAL MANAGEMENT

1. FINANCIAL EVALUATION OF A PROJECT

This is an important task to evaluate a project for any manufacturing enterprise or for modernisation or expansion plans or installing a costly machine.

1.1 I.R.R.

This method is called internal rate of return. In order to determine I.R.R. it is necessary to calculate annual income at production levels of 80% or so starting from O date when financial arrangement or approval is firmed up. This method takes into account the time value of money by discounting the future net cash flows calculated before depreciation but after taxes to arrive at the present value of net annual cash flows. The I.R.R. is one at which the discounted future cash in flows equal to cash outflows. If this is +ve, the project will not only pay out the total project cost but will also give an annual return at the I.R.R. One important point of consideration is that projects with larger cash in flows in latter years may be rejected in favour of one generating higher cash in flows in earlier years. In the long term outlook, time adjusted I.R.R. to recover the investment in the shortest possible time is the best insurance for the investors point of view; subsequently profits are additional gains.

There are various DCF factor tables. The normally used DCF table is based on half yearly compounding of interest rate with the assumption that cash flows of each year is received/paid out at midpoint of the year and compounded in half yearly interest periods. For smaller projects annual compounding of DCF factors can be considered.

Procedure

- (i) Prepare expenditure statement for 10–12 yrs at 80% production level and considering increase in short term (upto 1 year) borrowing so as to arrive at the net income (cash in flows). Consider equity receipts but do not consider depreciation and interest.
- (ii) Incorporate the year-wise project cost expenditures made from DPR in the I.R.R calculation table, till the told project cost less foreign currency expenditure (if any) is fully neutralised for the duration of the project implementation period starting from first year.
 - (iii) Put the net annual cash inflows yearwise thereafter in I.R.R calculation table.
 - (iv) Discount each years cash flows at appropriate DCF rate which is usually the Co.'s cost

Total

of capital rate at two adjacent DCF factors. Calculate the discounted cash inflows for each discount factor for 10–12 years.

- (v) Add the two discounted values separately.
- (vi) Substract the total 2nd discounted value from the total of 1st discounted value. The difference of discounted value will give the cash inflows for 1% difference in discount factors.
- (vii) Divide the total of discounted value (+ve) of 1st discounted value by the difference in discounted values as per (v) above. The factor thus obtained is less than 1.
 - (viii) The required I.R.R. is the 1st discount factor plus the quotent factor of (vi) above.
- (ix) If the minimum rate of return or total capital employed is near or equal to the I.R.R., the investment should be made.

The ROC/ROR should not be less than the I.R.R.

(x) The detailed cost heads for net cash inflow is given in table-III.

2. COST-BENEFIT ANALYSIS

Another time adjusted capital budgeting technique is the benefit cost ratio (B/C ratio) or profitability index. Often B/C is generally called cost benefit analysis. This approach measures the present value of returns per rupee/ doller invested. This can be said to be the ratio which is obtained by dividing the present values of future cash inflows by the present value of cash outflows.

Table 1

Project Cost			
Years	Cash outflows	Discount factor	Discounted cash outflows
1			
2			
3			
12			
			Total
Ranafit (after			
Delient (arter	commissioning)		
Denent (arter		Table II	
Years		Table II Discount factor	Discounted cash inflows
•	Net cash inflows before depreciation	Discount	
Years	Net cash inflows before depreciation	Discount	
Years 1.	Net cash inflows before depreciation	Discount	
Years 1. 2.	Net cash inflows before depreciation	Discount	

Benefit-Cost Ratio =
$$\frac{\text{Total present value of cash inflows}}{\text{Total present value of cash outflows}}$$

This ratio should be over 1.10 (min.). Discount factor table for annual compounding for one doller (or Re) at the end of n years is usually considered.

3. PAY BACK PERIOD (P B P)

This is a traditional method of appraising an investment option and answers the question as to how many years till the project takes to pay back the original cost of investment. The method provides the no. of years over which the investment will be recovered or paid back from cash inflows. If the pay back period is quite lengthy or equal to or little less than the prime period of the project, it is clearly unacceptable.

Pay back period =
$$\frac{\text{Total investment}}{\text{Net annual cash flows}}$$

Here profit should be taken before charging depreciation but after deducting taxes. As investment will include long term loans; interest there-on shall be allowed to arrive at the net profit (i.e., net annual profit after interest and taxes). Since time adjusted money factor is not considered in this method it is a crude method. The situation can be greatly improved by applying the discount factor in the denominator. Shortest the P.B. period, better is the project economics. Subsequent period of economic life of the project of the period goes to the advantage of enterpreneurs. The technique may be applied to check whether the PBP is less than the predetermined PBP set by the management for acceptance or rejection of any project. It is, therefore necessary to determine the present value of cash flows for economic life of project and the shortest PBP out of the economic period. This approach takes care of major shortcoming of traditional method and easy to understand for practical application.

4. RATE OF RETURN VS COST OF CAPITAL AND OTHER ANALYSIS

IRR has to be comparable to required rate of return (RRR). Acceptability of a project depends whether or not IRR exceeds RRR. RRR has a direct bearing on the cost of capital. Capital is composed of different elements viz equity capital, preferance share capital and long term loan capital, meaning thereby components based on different sources. Obviously, each component of capital has its cost different from each other. The component which takes the maximum risk is naturally the costliest source of capital. Averaging the cost for all components on weighted basis may be said to be the rate of the cost of capital. Such capital is popularly known as capital employed.

Cost of capital is a major factor used in financial analysis. For a company to survive the return on capital invested must not be less than cost of capital. For growth the return must be at least 1% more than the cost of capital. Profit as per percentage return on capital should not be compared with the DCF yields and instead, a comparison of DCF yields with the rational cost of capital will give better result.

Required rate of return. This can be said to be the cost of capital employed. Capital employed is a mix. of owner's fund debt capital. Since debt capital is less risky from the point of view of lenders, the contributors in equity bear the risk of investing money. The ROR for such investors depends on various factors like average industry return, expectation in value of stock, wait period in divident pay out etc., RRR, is therefore, the weighted average of cost of debt capital and expected return desired by owners on their investment which is higher than the going rate of interest on debt capital.

Profitability index PI

This is usually important for plants after commercial production starts. Discount @ I.R.R. for cash inflows and outflows for 10–20 years @ cost of capital.

P.I. =
$$\frac{\text{Present value of cash inflows}}{\text{Present value of cash outflows}} \times 100$$

It is also defined as the rate of compound interest at which Co's outstanding investment is repaid by profit from the plant or project.

5. BREAK EVEN POINT (BEP)

It is the percentage capacity utilisation point at which all fixed cost and variable costs of operation are recovered.

A. Variable Cost (V)

- (i) Raw materials
- (ii) Labour cost
- (iii) Utilities
- (iv) Packing material
- (v) Interest on working capital
- (vi) Contingency

Sub total

B. Fixed Cost (F)

- 1. Supervisers and Manager's Salaries, and wages.
- 2. Over heads
- 3. Consumable stores
- 4. Insurance and local taxes
- 5. Depreciation
- 6. Selling and administrative expenses
- 7. Contingency
- 8. Interest on long term debt
- 9. Spares and maintenance material

Sub total:

C. Annual Sales Realisation (S) from Products Sold

Therefore,

(i) Break even point
$$=$$
 $\frac{F}{S - V}$ (Excluding L.T. loan)

(ii) Cash Break even point =
$$\frac{F - Int. charge}{S - V}$$

Additional Under Break Even Point

While estimating Cost-Volume-Profit analysis, certain assumptions are made:

- (1) Cost behaviour: It is assumed that costs of the firm are divisible into fixed costs and variable costs. While fixed costs remain unchanged, variable cost vary directly with the level of production.
 - (2) Unit selling price remains constant.
 - (3) There is no change in capital structure.

As BEP is the no profit no loss situation, the aim should be to go for projects whose BEP is at low capacity utilisation so that the margin of safety is large.

(4) BEP Calculation is usually made at 80% production level. Depreciation is often not considered.

6. CUT OFF POINT OF COST OF CAPITAL OR MARGINAL COST OF CAPITAL

Cut off point of cost of capital is the weighted averge of after tax rate of interest at which a firm is able to borrow and the rate of earning on its equity capital which will give stable prices of the firm's shares in the market. A company tries to use 1st the cheaper form of capital when the cost of capital from debt instruments is higher. The cut-off point of available capital is reached when no more equity can be raised. This point of cost of capital is called cut off point of cost of capital or marginal cost of capital.

Example: A Co's capital structure is as follows:

8% debentures = Rs. 20 lacks
Equity, Capital (Rs. 200 per share) = Rs. 60 lacks

$$\frac{Rs. 80 \text{ lacks}}{Rs. 80 \text{ lacks}}$$

The market price of each share is Rs. 300 and E P S 20 (after tax). Cost of capital assuming 34% income tax rate.

Say, 4% income tax rate on Rs. 20 lacks = Rs. 80,000 and 30% on Rs. 60 lacks = Rs. 18 lacks tax on Rs. 80 lacks : Rs. 18, 80,000 Cost of capital =
$$\frac{18,80,000}{80,00,000} \times 100$$
 = 23.5%

The conclusion is that, if the company keeps the present debt/equity ratio, it should not invest in any projects whose rate of return is less than 23.5%.

7. THERE ARE TWO APPROACHES TO ASCERTAIN THE RETURN ON CAPITAL

(a) Return on capital employed (ROCE)

$$ROCE = \frac{\text{Net profit after tax + Interest on long term loan}}{\text{Capital employed}} \times 100$$

This approach shows the benefit provided by the project on long term liabilities plus owners equity. If ROCE is greater than RRR, there is acceptability of the project.

(b) Rate of return on equity (ROE)

$$ROE = \frac{Net \, profit \, after \, interest, \, tax + \, pref. \, dividend}{Owner's \, fund \, (equity \, holding)} \times 100$$

In a sense, equity share holders are the real owners and they take all risks and participation in management, though they have insignifant role.

The ultimate profitability is judged by the above two criteria.

(c) Rate of return (ROR) =
$$\frac{\text{Profit before depreciation, interest and taxes}}{\text{capital employed}}$$

(For average rate of return, work out cash flows for 10-12 years period)

Table III

Sequence for Determining Cash Flow in IRR/NPV

- 1. Determine annual sales realisation.
- 2. Deduct variable cost to arrive at contribution.
- 3. Deduct all factory expenses for conversion cost excluding depreciation.
- 4. Deduct selling and administrative expenses.
- 5. Consider increase in S. T. loan during construction.
- 6. Consider equity as gross receipts if applicable.
- 7. Consider contingency provision.
- 8. Financing charges are not to be considered.
- 9. The resultant value will give the gross cash flows.

9. OTHER FINANCIAL TERMS

9.1 Compound Interest

It is the interest on any previous year plus interest on the principal. Formula:

C. I. Amount, $A = P_o (1 + r)^n$ Where $P_o = \text{Principal}, r = \text{Compound interest rate yearly}.$ A = Amount, n = no. of years.

N.B. = For half yearly compounding interest rate = r/2, Quarterly = r/4.

9.2 Simple Interest

It is the interest paid only on the principal borrowed or lent.

S. I. Amount, $A = P_o.r.n$ Where $P_o = \text{Principal}, \ r = \text{Simple interest rate},$ n = no. of years. A = Amount.

9.3 Annual Balance Sheet and P and L Accounts of a Company

(i) Gross block = Total fixed assets

(ii) Net block = Total fixed assets less depreciation.

(iii) Net worth = Paid up Equity + Pref. Share Capital + Reserves and surplus - Dr. balance of P and L A/C and Deferred Revenue Expenditure

or Net Block + Working Capital – Long term liability.

- (iv) Capital employed means net fixed assets plus net working capital (net current assets excluding provision for gratuity less net current liability).
 - (v) Capital structure as per debt/equity ratio. A high debt company has more debt.
 - (vi) Reserves and surplus value.

10. TERM LOAN

It is usually given by FIs. The loan is for over 1 year period. On variable interest rates depending on type of company. Big corporates usually get term loan on prime interest rate for new project, modernisation and expansion.

10.1 Fund Provision

Long term loan to a borrower company for a new project:

There are 4 mazor funding techniques in a S. S. I., medium and large industries followed by FIs.

10.2 Debt/equity Ratio (D/E)

```
S. S. I. = 3:1 or 2:1 (P and M Limit for S. S. I. = Rs. 3 crores)
```

Medium and large industries = 1.75 : 1 or 2 : 1.

In a Government undertaking, the debt equity ratio is 1:1. Higher debt equity ratio means lower term loan which reduces promoter's contribution. Debt equity ratio is also governed by debt service coverage ratio (DSCR). But higher debt (loan) also increases the D.S.C.R. D.S.C.R. should be 1.5 to 1.75. FI's often change these ratios.

It is from the cash flow statement that the DSCR can be determined as per scheduled repayment of loan and interest instalments. Central subsidy, depending on category of area, varies for Rs. 10–25 lacks. G.O.I. varies the central subsidy from time to time.

10.3 Promoters contribution

In a public limited Co. promoters contribution is determined based on location of the project in category A (most backward), B (medium backward) or C (least backward) areas and value of the project cost estimate by FIs. For projects above Rs. 25 crores promoters contribution is as follows.

"A" area = 12.5%

"B" area = 17.5%

"C" area = 20%

Nonbackward = 22.5%

N.B. for projects upto Rs. 25 crores, promoters contribution for A category area is 17.5% and rest of the above norms are same. These stipulations are not fixed always.

10.4 Unsecured Loan

FI's insist that unsecured loans and its interest should not be paid by promoters during the currency of term loan of FI's and as such any unsecured loan is considered subordinate to the loans of FI's. It is better to consider unsecured loan in project financing calculation estimate. Access to maximum unsecured loan reduces the equity component as it gives more return on equity or divident which enhances Co's performance. FI's usually restrict unsecured loan to 20–25% of promoters contribution. Unsecured loans, usually, thus remain blocked till commercial production starts or cash acruals begin.

10.5 Security Margin

It is an important factor while taking term loan from FIs. It is related to value of project cost and depends on promoter's contribution and D.E ratio. It is not a legal documents but FIs usually asks for this while sanctioning a term loan.

10.6 Other Forms of Short Term Loan for a Running Company

Short term loan is usually for 1 year or less.

10.6.1 Unsecured Loan (Contd.)

This loan is provided by banks and corporates only. The loan is generally for short period and repayment is due within a year. The loan is sanctioned under a line credit, revolving credit or on transaction basis, subject to credit worthiness of the borrower company. The debt is evidenced by a promisory note signed by borrower giving the time period, amount of payment and interest charges. The cash flow of borrower should be sufficient to service the debt.

10.6.2 Secured Loans

Based on security of land or fixed assets or both, or other forms of security, new Co's generally get secured loan from banks and FI's. The lender see that the company has sufficient cash flow to make scheduled repayment. The lender, in order to reduce risks, asks for security. The other forms of security collateral may be accounts receivable, inventory or other assets of the borrower. The loan aggrement is signed both by borrower and lenders giving details of security collateral time of repayment and interest charges and such aggrement is filed in Department of company affairs which record the transaction for the public to know that the lender has a security interest in the collateral specified in the aggrement. If loan is not realised, the lender can put up a case in debt recovery tribunal (or a recent recovery ordinance) who after proper hearing of both sides may allow sale by auction of the collateral to recover the balance loan with interest. For loan against accounts receivable, the lender considers only the larger accounts receivable in order to determine the size of loan. The borrower sends a schedule of accounts receivable assigned for the loan to bank. This is a continuous financing arrangement, as the firm generates more receivables, that is acceptable to the lender and more loan could be sanctioned by the bank and old receivables are replaced by new receivables.

10.6.3 Inventory Loan or Cash Credit

In floating lien system, finished product or raw materials, spares and inventores including receivables are kept as security and only a moderate amount of advance or cash credit is given to the borrower depending on the type of inventory which could be sold by borrower in case such neccessity arises. Usual documentation procedures have to be followed by borrower as demanded by lender banks.

10.6.4 Chattel (moveable property) mortgage, inventories are classified serially or in other means. This type of inventory can not be sold by borrower unless lender gives consent. In case of repaid turnover of inventories or inventory that is not identified, because of size or other reasons, these are not suitable for receiving finance from banks on mortgage deal.

10.6.5 Trust Receipt Loan

Here borrower keeps the proceeds of sale of inventory in a trust a/c for the lender who partly finances the loan to borrower. The lender checks regularly whether the sale proceeds of inventory is repaid to bank for repayment of loan given to borrower.

10.6.6 Ware House (field) Loan

The materials, stored in field ware house by borrower, is kept as a mortgage security for loan to the borrower against receipt, given by the field ware house company to the bank. A strict control of inventory in and out is maintained by the field warehouse company. The field ware house company may belong to the same company as that of borrower or its subsidiary company. The borrower is to provide insurance coverage of materials stored.

10.6.7 Terminal Warehouse Receipt Loan

Here the ware house receipt loan is given to the borrower when the borrower keeps the inventory in a public ware house company. As per loan condition, public ware house co. can release the collateral to the borrower only when authorised by the banker or lender. Insurance coverage of inventory has to be done by borrower.

10.6.8 Compensating Balance

Banks often require, apart from charging interest on loan to borrower, also ask borrower to maintain "demand deposit" balances at the bank in proportion to funds borrowed. Such balance is known as compensatory balances which usually varies from 15–20% of line credit. The compensatory balances enhance the liquidity position of the borrower.

10.6.9 Line Credit

This short term credit is offered to borrower on yearly basis subject to renewal after review of annual accounts of the company to determine the credit worthiness of borrower. The credit worthiness is determined from cash budget which gives the credit requirements. Banks require that the borrower company should clean up bank debt for at least 30 days in a year. This arrangement is not a legal commitment by the bank who can refuse loan should the credit worthiness of borrower detoriates. However, the bank generally honours their letter to borrower, indicating the amount of unsecured loan with interest rates and specify the minimum period when the borrower needs to be out of debt from the bank.

10.7 Revolving Credit

This credit, from a bank, is legal document in which banks commit to extend credit to a borrower company to a maximum amount of unsecured loan giving the interest charges and period of repayment of revolving credit. If borrower did not take maximum amount of credit, the borrower is to pay an additional commitment fee for the unutilised portion of loan.

10.8 Transaction Loan

This loan is given to borrower by the bank on the basis of a contract which the borrower has got. The company usually applies to the bank for transaction loan for executing the contract. Bank

offers such loan after checking the cash flow record of the company to pay the loan within the period of execution of the contract.

11. DEFINITIONS

11.1 Opportunity Cost

It is the perspective change in the cost structure of production, following an alternate machine or process route, revised raw material specification or change of operation sequence.

Alternate cost – It is a means of determining alternate cost if production is discontinued and resorted to use of purchased item or commodity of production.

11.2 Shell Company

A company which has ceased its original activity, has few assets but usually has a stock market presence as a listed broker. The company provides an easy way for a new company to acquire stock market quotation by a shell operation or deals with dubious flow of money and is usually located in island cities where mainland govt's has no control over the shell company.

11.3 Take Off Stage of a Country

The capital/output ratio and savings ratio each should be at least 10% of national income.

11.4 OTC Exchange

It serves as part of secondary market for stocks and bonds, not listed in a stock exchange. It has listed brokers and dealers who buy and sell stocks/securities at quoted price.

11.5 Co Shares

Earning per share (EPS) or price earning ratio, P E ratio

Net profit after interest, depreciation and taxes + pref. share dividend if any

Total no. of equity shares.

or $\frac{\text{share price}}{\text{E P S}}$

Price of share = EPS \times P.E. Ratio.

11.6 P E ratio should be 10 – 100 or more. P.E. ratio is

normal profit rate of a co.

Price earning to growth ratio = $\frac{P.E.}{Net Growth of Profit.}$

P. E ratio is higher where risk is low and vice versa.

A lower P.E. ratio indicates that net profit growth will exceed its P. E. A P.E. ratio more than 1 will indicate that the P.E. is higher than net profit growth. Net asset value (NAV) of a Mutual Fund – it is the total assets of a particular mutual fund scheme less all debts. It is expressed in unit currency per unit.

11.7 Market Value of a Company

It comprises paid up equity shares, preference shares, retained earning and appropriated surplus.

11.8 Real Interest Income

It is the interest rate prevailing less inflation rate.

11.9 Whole Sale Price Index

It is the whole sale markets' trading rates only and without transportation and marketing costs which is generally 40–50% of whole sale rate.

11.10 Goodwill of a Company

This is determined by three methods viz.

- (i) Average Profit Method
- (ii) Super profit method
- (iii) Capitalisation method

In method (ii) Actual profit of the year less normal profit of the year (expected rate) on the total capital is employed. The difference between the two profits, as above, is called super profit which is to be multiplied by no. of years of purchase of the Co. There will be no. goodwill if actual profit is less than normal profit.

In method (iii) goodwill is as per value of the business and is determined by the ratio of:

 $\frac{\text{Estimated annual profit}}{\text{Normal rate of return}} \times 100, \text{ The value of goodwill is the value of business less net assets}$ of the company. In goodwill determination, debentures are excluded. Fixed assets, less depreciation written off, + net working capital.



ISO – 9000 SERIES QUALITY ASSURANCE SYSTEM

- 1. ISO 9000 series quality assessment system was first introduced by EAC in Europe 1990s and EAC guidelines on the application of EN 45012 for quality assurance assessment entities in different countries accredited to few quality certifying authorities viz TuV, BvOi, RvC, DAR etc. ISO 9000 series standards are in six parts.
- **2.** There are three ISO (International Standard Organisation) standards for quality assessment developed in Europe as follows:

EN ISO 9000 : 1994 (3 parts) - Part 1 and 2 are for QMS and QAS guidelines for appln. for ISO 9001 and part 3 for soft ware.

EN ISO 8402 : — quality management and quality assurance, vocabulary and scope.

EN ISO 9001 : 1994 - Model for quality assurance in design, development,

production installation and servicing.

EN ISO 9002 : 1994 - Model for quality assurance is for selection and use and part 3 - production process installation and

services.

EN ISO 9003: 1994 – Model for quality assurance in final inspection and

testing.

EN ISO 9004: 1994 – Quality management and quality
(Part 1 and 2) system elements – Guidelines and equivalent.

EN ISO 10011 – Guidelines for lead assessors part 2

(Part 1, 2 and 3) and that part 1 and 3 give guidelines for quality systems.

NB. ISO 9000 series updated to 2000 from 1994

The corresponding equivalent Indian standard is IS14000 series viz IS14001, IS14002 and IS14003 (1994). The British standard institute equivalent to ISO9000 is BS5750 1994 (EN29000).

EN ISO 10012

- QA requirement for measuring equipment.

EN ISO 3534

- is for statistics (SQC)

- **3.** EAC Guidelines on the application of EN45012 (European standard) for bodies certifying suppliers quality system are applicable to entities doing assessment of a Co's quality control systems in different countries must be accredited to European Nodal authorities Viz TuV, BvQi, RvC, DAR etc., which gives its clearance. On the application of ISO –9001/9002 and ISO 9003 (as the case may be), and the quality assessment organisation issues the ISO compliance certificate.
- **4.** EAC guidelines in this regard has 29 clauses for compliance by a legal quality assessment organisation or a company accredited to TuV, BvQi, RvC, DAR etc. Each clause has EAC interpretation so that disputes are minimised between European certifying authority and the ISO certificate issuing legal entity in a country accredited to the European certifying authority.

The quality assessment of a company is usually done by a qualified trained lead assessor and its team of assessors as per EAC guidelines. This also specifies the duration of time (mandays) on quality assessment depending on number of employees in the certified entity for initial assessment, subsequent annual visits and re-assessment visits. There are 39 sectors recorded as per NACE Rev. 1 for quality assurance and issue of ISO certificate by certifying bodies accredited to above Nodal bodies. For preventing misuse of ISO certificate or collusion between certifying organisation or a company and its client there are clauses in guidelines such as impartiality, objectivity, reliability and expertise.

- **5.** There are 10 steps for quality assurance and control for registration:
 - (i) Planning an audit.
 - (ii) Preliminary audit.
 - (iii) Quality survey manual.
 - (iv) Preregistration audit check list.
 - (v) Initial meeting with organisation head for the necessary information.
 - (vi) Auditing operation.
 - (vii) Final closing meeting with the organisation.
 - (viii) Recording of discrepencies in auditing.
 - (ix) Audit reports.
 - (x) Corrective actions by the organisation and compliance. On going surveillance, is to continue
- **6.** Apart from quality assurance and control (TQC), there is a standard for quality management system (QMS). The concept of quality requirement means customer's requirement first and every time. Quality is to be measured, assessed and improve performance of business for which a business organisation is divided into 7 lines of departments as below:
 - (i) Marketing.
 - (ii) Selling.
 - (iii) Design and Development.
 - (iv) Production Process.
 - (v) Purchasing.

- (vi) Finance and administration.
- (vii) After sales service.

The objects of QMS are:

- (a) Improve customer satisfaction.
- (b) Elimination of error and waste.
- (c) Reduced operating cost.
- (d) Increased motivation and commitment from employees.
- (e) Increased profitability and competition.
- **7.** ISO 9000 or its equivalents, IS-14000 and BS 5750 certification are mandatory requirements for export of product to Europe or USA. In addition FDD (US) clearance for export of Food and Pharma products.
- **8.** Upto 1995, 150 countries out of the then 178 UN member nations, had adopted ISO–9000 series of quality controls. Upto end 1994–100 Indian company have obtained ISO quality certificates.
- **9.** Application clauses of ISO-9000 series

Applicable clauses	ISO-9001	ISO-9002	ISO-9003
(1)	(2)	(3)	(4)
Management and responsibility.	4.1	4.1	4.1
Quality system	4.2	4.2	4.2
Contract review	4.3	4.3	_
Design control	4.4	_	_
Document control	4.5	4.4	4.3
Purchaser supplied Product.	4.7	4.6	_
Purchasing	4.6	4.7	_
Product identification and traceability	4.8	4.7	4.4
Process control	4.9	4.8	_
Inspection and testing	4.11	4.10	4.6
Inspection and Test status	4.12	4.11	4.7
Control of nonconforming product.	4.13	4.12	4.8
Corrective action	4.14	4.13	_
Handling, Packing, Storage and delivery.	4.15	4.14	4.10
Internal quality audit	4.17	4.16	_
Training	4.18	4.17	4.11
Servicing	4.19	_	_
Statistical techniques	4.20	4.18	4.12

10. Procedure for adopting ISO–9000 certification by a company requires (*i*) visit to a ISO certified company and walk through the factory, discuss with management and quality assurance manager

and read through their quality survey manual (ii) Fill up application form and covering letter as to which ISO standard to be adopted as well as questionaire (iii) application fee and (iv) Explanatory notes. These items are to be sent to certifying organisation who is accredited to EN Nodal agency. The questionaire covers vendor assessment in process inspection patrol and final inspection, Training, Equipment, calibration, Policy Control Procedure, reviews, design, customer guarantees and failure records.

However, it is better to get a preliminary audit by a competent consultant before applying for ISO certification, who will give its recommendation citing shortcomings in various areas as per ISO requirements based on which top management can take appropriate actions if CEO has independent discretion. The areas of checks include initial audit, design of a system, establishment of specification and preregistration checks.

11. PRELIMINARY AUDIT (APPLICABLE TO ISO-9001 TO 9003)

- (i) Specification of raw materials and parts supplied by vendors.
- (ii) Visit to suppliers company to evaluate the response to a trial enquiry over telephone.
- (iii) Visit along with sales staff of prospective customers had either purchased goods from the company or had goods delivered to them. This will reveal about reactions of purchasers and supplier's system of recording of enquiries and mode of follow up action on sending the quotation.

This action will reveal how far in prelimary audit one has to cover to instal a quality management system in case of a production/service company. The findings of preliminary audit may give starting observations viz:

- (a) Sales people spending too much time to draw up specification
- (b) Lost orders through delayed enquiries.
- (c) Incomplete specification from sales to factory.
- (d) Rejects, deliberatily being delivered to customers.
- (e) High wastage in shop floor.
- (f) In-attention to production dept's functioning resulting in poor production rate.
- (g) Short supply in delivery.
- (h) Staff, blaming each other for problems or delaying.
- (i) Delay in procurement of raw materials and consumables etc.

Quality Audit manual by approved certification organisation or company. The following aspects are to be considered.

(i) Management Policy and Organisation, Points to be Proved

Whether clear written policy is in circulation throughout the company. Deptt for executing the policy – Any defined policy on quality with responsibilities – Are there any verification steps and responsibilities defined?

Any assigned authority,

Training programme existing.

(ii) Design and Revision Control

(applicable to ISO 9001/9002)

- Any control system for design and revision.
- Criteria for design, viz safety, reliability, maintenance, review and any other identified for deficiency and contractual or brief.
- Does the system control all documentation including production procedures and end users.
- Manufacturing and design interface is controlled or not.
- Any approved system for revision or changes.
- System of security, back up etc., or other changes and updating and traceability.
- Whether all finished products covered by full specification with user instructions.

(iii) Procurement (Applicable to ISO 9001/9002)

- Whether supplier agreement system exists.
- Standards for specification, identified for all incoming materials.
- Any agreement on quality with suppliers.
- Management procedure.
- Performance record of materials supplied.
- Suppliers capacity to adopt ISO 9000.
- Whether EDI (electronic data interface) exist with suppliers or other documentation systems.
- Traceability and identification possible.

(iv) Control Reviewing (Applicable to ISO 9001/9002)

- Whether formal contract entered with customer or only customer brief.
- Advertising process constitutes a contract or brief.
- Whether promises are being met or not.
- Equipment and its capacity is capable to meet control requirements.

(v) Quality System (Applicable to ISO 9001/9002/9003)

- Whether the quality system conforms with requirements of relevant standard.
- What are the written procedures, controls and audit.

(vi) Documentation Control (Applicable to ISO 9001/9002/9003)

- Whether quality control manual contains all aspects, including updated informations.
- Does the quality manual include all documents with procedural manuals and working instructions, duly controlled.
- Availability of all documents when needed.

12. PRODUCTION PROCESS

This varies according to production process in chemical, mechanical, electrical, food, packaging fields etc., based on the sector, a check list is to be prepared which will consider the following aspect:

- (a) Consider every item of appropriate standard on process, traceability and production.
- (b) Make sure that complete documentation about procedures, drawings, parts list/drawing suppliers, diagrams, instrument settings instructions, models/paterns and reference models etc., are available.

- (c) Ensure that all the appropriate instructions are kept on relevant places of manuals/units in plastic envelopes and put in each operation place.
 - (d) Specify what the supervisor or inspector will lookout on rounds of a production unit.
- (e) Check whether all necessary or critical controls and inspection sites/sections (where operators are posted) are manned and documented properly.
 - (f) Final assembly line check system for passed (O.K), in doubt or failed has been provided.

13. INSPECTION AND TESTING (APPLICABLE TO ISO 9001/9002/9003)

- Whether incoming raw materials, chemicals and others are being tested for which adequate facilities are available.
- Is the out-of-specification material controlled.
- Whether traceability of off-specifications is possible at storage for samples.
- Whether Q.C. inspectors has authority to release or prevent release of materials passed or failed.
- Whether there is system for procedural inspection or monitoring in accordance with quality plan and documented procedure.
- Is corrective action halts faulty items, allowing avoidance of off-specification items or towards removal of faults.
- Whether off-specification materials are identified, segregated and disposed off.
- Are the storage areas properly controlled.
- Is there any final inspection, dock inspection and Patrol inspection.
- Is the purchase order specification/aggrement specify final inspection.
- Whether inspectors have final say in rejecting off specification items as per inspection.
- What is done with segregated nonconforming materials—returning, rework, scrap of nonconforming items.
- Whether re-worked materials are inspected.

14. INSPECTION, MEASURING AND TEST EQUIPMENT (APPLICABLE TO ISO 9001/9002/9003)

- Check inventory of all testing instruments.
- Whether there is documented procedure for calibration.
- Are the reference standards traceable to external calibration which are in turn approved by an international laboratory.
- Whether maintenance system of instruments exist or is in planning stage.
- Is the equipment manual specifies maintenance schedule and duly labelled for frequency of check or calibration.
- Whether the off-specification plans of equipment are controlled.

15. HANDLING, DELIVERY AND STORAGE (APPLICABLE TO ISO 9001/9002/9003)

 Check for storage areas for storage of finished goods duly segregated for off-specification materials and duly controlled.

- Whether above items are marked as per status.
- Whether handling methods can damage the product.
- Whether the finished/semi finished/product items can be subjected to theft or malicious damage.
- Items, controlled by final inspection, can be either accepted or returned/objection placed by customer on any fault by inspectors.

16. AUDITS

- Whether any initial in house auditing or by consultant.
- Is the audit covered by a plan and procedure and corrective actions recommended by auditors or consultants.
- Whether top management reviews the audit results and implements recommendations.

17. TRAINING

- Whether regular training or seminar attendance in vogue.
- All such training courses/seminars are fully documented.
- Is the responsibility to fix training or seminar attendance is clearly defined.
- Are the supervisors properly trained.
- Whether training materials like books, videos, charts and lecturers can be searched out for which clear control system should exist.

18. HOUSE KEEPING

- What is the state of front garden or yard?
- How are the lobby/reception desk area look?
- Is the receptionist and telephone operator friendly and available?
- Is the plant and equipment maintained?
- Is the work place clean?
- Whether toilets are clean and system exists.
- Whether scraps are properly dealt with.
- Whether the walls, floors, roofs are clean.
- How does the canteen look? Clean and pleasant?
- **19.** Once the health of a company is determined, thus actual planning for audit starts, design of a system, establishment of specification followed by checks of parameters of preregistration checks and submission of quality survey manual to the company who applied for relevant ISO certificate. The steps involved are.
 - (a) Informed preliminary audit.
 - (b) Instal quality system.
 - (c) Final stage Formal audit.
 - (d) Final stage Inspection by certifying agency after rectification of short-comings.

(e) In case of refusal of registration by certifying agency, the company is free to reapply whenever the situation is corrected.

An ISO certified registard company cannot use certified Logo in products.

- **20.** Post registration requirements involve 2–4 visits by certifying agency auditors or assessors for which the company has to give free access to them inside the installation, supply documents and unhindered talk to the Co's employees on quality matters in order to ascertain any irregularity or changes from survey manual. The validity of an ISO certificate is usually two years or so.
- 21. The qualification and experience of an audit team (evaluation team) is given in ISO-1001, part 1 include training for ISO standards, assessment techniques, planning, organising, communicating and overall management. The numbers of an audit team may comprise inside and outside organisation (to be audited) members and to be chaired by must be an experienced person. The evaluation panel must meet ISO 10011– part 2 requirements and approved from nodal certifying agency as well as specifies graduation in science/engineering and a minimum. of four years of full time practical experience and at least two years in quality assurance, prior to become an ISO auditor. Addln. requirement of participation consists of 4 audits of 20 days duration each. The auditor must pass the testing of knowledge and skills by sitting in an exam, conducted by a national certification body, like Institute of Quality assurance (IQA) London U.K. or National quality assurance (NQA) U.K. The total cost involved including fees to certifying agency, is high (approx. Rs. 10 million or below).
- **22.** Total time period required including ISO 9000 certification for a big company by a certifying agency is as below:

(i)	Top management decision making		4	weeks
(ii)	Establish task force headed by a qualified auditor		4	"
(iii)	Training in ISO series		10	"
(iv)	Evaluate existing systems		15	"
(<i>v</i>)	Upgradation of system procedures		8	"
(vi)	Prepare documentation		7	"
(vii)	Appoint ISO certifying agency		4	"
(viii)	Execute improved systems		8	"
(ix)	Evaluation by internal audit team		12	"
(<i>x</i>)	Make up of short fall		6	"
(xi)	Certification audit		10	"
(xii)	Revisit by certifying authority			
	for compliance checking		2	"
		Total:	92 w	eeks*

^{*} For a medium sized organisation, it can be done at ½ of the total weeks.



CONVERSION FACTORS

WEIGHT

```
1 \text{ lb} = 16 \text{ oz} = 7000 \text{ grains} = 0.4536 \text{ kg} = 453.6 \text{ gm}
                       1 \text{ oz} = 28.35 \text{ gms} = 437.5 \text{ grains}
             1 oz (Troy) = 480 grains = 31.1035 gm
          1 fl oz (U.K.) = 28.413 ml; 1 drachm = 1/8 fl. oz
          1 \text{ fl oz (U.S.)} = 29.574 \text{ ml}
                       1 \text{ kg} = 35.27 \text{ oz} = 15432 \text{ grains} = 2.2046 \text{ lb}
               1 \text{ ton (Br)} = 1.016 \text{ metric ton} = 20 \text{ cwt} = 2240 \text{ lb}
            1 metric ton = 0.984 Br. ton = 10 quintal = 1000 kg.
1 \text{ c w t (hundred wt)} = 112 \text{ lb} = 50.8024 \text{ kg.}
       1 short ton (US) = 2000 \text{ lb} = 907.2 \text{ kg}.
                   1 \text{ lb/cft} = 16.018 \text{ kg/m}^3
            1 \text{ microgram} = 10^{-6} \text{ gm}
                   1 \text{ carat} = 200 \text{ mg}
                1 \text{ lb force} = 4.45 \text{ N}
              1 \text{ ton force} = 9.96 \text{ kN}
                   1 \text{ stone} = 6.35 \text{ kg}.
```

N.B. Troy system of weight is for precious metals/minerals.

PRESSURE - LOAD

```
1 lb per sq. inch (psi) = 27.71 inch water (62^{\circ}F) = .0703 \text{ kg/cm}^2

= 2.036 in Hg = 51.715 Torr.

1 kg/cm<sup>2</sup> = 14.22 psi = 0.9678 atm = 0.98 bar.

1 atm = 1.033 kg/cm<sup>2</sup> = 14.696 psi = 760 mm Hg = 29.92 in Hg.

1 N = 1 kgm/sec<sup>2</sup>; 1 kp = 9.81 N = 33.93 ft of water

1 bar = 0.9875 atm. = 10^5 pascal
```

CONVERSION FACTORS 329

 $1 1b/ft^2 = 4.88 kg/m^2$ $1 ton/sq.in (long ton) = 1.575 kg/mm^2$ $(short ton) = 1.406 kg/mm^2$ $1 kg/m^2 = 0.205 lb/ft^2$ $1 lb/sq.yd = 0.543 kg/m^2$ 1 inch Hg (32°F) = 0.491 psi.

1 inch Hg $(32^{\circ}F) = 0.491$ psi. 1 inch water $(62^{\circ}F) = 0.0361$ psi

Absolute vacuum = 760 Torr/mm Hg.

1 Kilo pascal (kpa) = 1000 pascal (Pa) $= 0.1013 \times 10^{-3}$ atm

1. Mega Pascal (Mpa) $= 10^6$ pascal = 10 bar = 9.87 atm = 145 PSI

1 PSI = 6.89 kpa; 1 pascal = 10^{-3} kpa. 1 Torr = 1 mm Hg = 133.32 Pascal

 $\frac{kpa}{101.3} = atm$

kp = Kilopond = kilogramme force

LENGTH

1 Angstorm = 1/1000 of a micron

1 inch = 2.54 cm = 25.4 mm (or 25 mm)

1 cm = 0.3937 in

1 foot = 12 inch = 0.3048 m

1 yd = 3 ft = 0.9144 m

1 fathom = 2 yds = 1.8288 m

1 m = 3.28 ft = 39.37 in

1 mile = 8 furlong = 1760 yd = 1.61 km.

1 km = 0.621 mile = 1093.6 yd.

1 knot = 6080 ft = 1.8532 km.

 $1 \text{ micron} = 10^{-6} \text{ mm}$

1 millimicron = 1 nm (Nanometer)

1 rod = 16.5 ft.

1 chain = 4 rods = 100 links = 66 ft.

1 mile = 80 chains

1 furlong = 201 m; 1 mil = 1/1000 of inch

VOLUME

$$1 \text{ m}^3 = 35.315 \text{ cft} = 264.2 \text{ U.S. gallons} = 220 \text{ gallons (U.K.)}$$

 $1 \text{ dm}^3 = 61.024 \text{ cu in}$

1 cubic in (Cu in) = 16.387 cm^3

 $1 \text{ cc} = 0.061 \text{ cu in} = 10^{-3} \text{ lit.}$

 $1 \text{ cft} = 0.02832 \text{ m}^3 = 28.32 \text{ lit} = 6.23 \text{ gallons (U.K.)}$

= 7. 481 Gallons (U.S.)

 $1 \text{ cu yd} = 0.7646 \text{ m}^3$

1 register ton, U.K. = $100 \text{ cft} = 2.832 \text{ m}^3$

1 ocean ton (U.K.) = $40 \text{ cft} = 1.328 \text{ m}^3$

1 gallon (U.K.) = 4.543 lit. = 8 pints

1 gallon (U.S.) = 3.7854 lit. = 231 cu in

1 bushel (U.K.) = 36.3677 lit.

1 bushel (U.S.) = 35.24 lit. = 2150.42 cu in

1 barrel (U.K.) = 163.65 lit.

1 barrel (U.S.) = 158.99 lit.

1 lit = 61.03 cu in

1 hectolitre = $100 \text{ lit.} = 0.1 \text{ m}^3$

1 Br. Gallon water weighs 10 lbs

1 cft water weighs 62.3 lbs at 4°c

1 pint = 568 ml

1 acre ft = 1230 m^3

AREA - PRESSURE

1 sq. in $= 6.4516 \text{ cm}^2$

1 sq. ft = 0.0929 m^2

 $1 \text{ sq. yd} = 0.836 \text{ m}^2$

1 acre = $4840 \text{ sq yd} = 43560 \text{ sq ft} = 4047 \text{ m}^2$

 $1 \text{ arc} = 100 \text{ m}^2$

1 sq. mile = $640 \text{ acre} = 2.59 \text{ km}^2 = 258.998 \text{ hectare}$

 $1 \text{ m}^2 = 10.764 \text{ sq. ft.}$

 $1 \text{ cm}^2 = 0.1550 \text{ sq. in}$

1 hectare = $10000 \text{ m}^2 = 2.47 \text{ acre}$

 $1 \text{ lb/cm}^2 = 0.07 \text{ kg/cm}^2$

1 sq cm = 0.155 sq inch

 $1 \text{ kg/cm}^2 = 14.22 \text{ PSI} = 0.98 \text{ bar}$

1 atm = $1.033 \text{ kg/cm}^2 = 14.7 \text{ PSI} = 760 \text{ mm Hg}.$

1 sq inch = 6.452 sq. cm

 $1 \text{ m}^2 = 1550 \text{ sq inch}$

1 decimal = 449.275 sq. ft.

CONVERSION FACTORS 331

TEMPERATURE

$$^{\circ}K = t_{c} + 273.15$$
 (abs. temp)
 $^{\circ}R = t_{f} + 459.7$ (abs. temp); $^{\circ}C = \frac{t_{f} - 32}{1.8}$; $^{\circ}F = 1.8t_{c} + 32$

N.B. For temp difference, there is no need to add or substract 32

SPEED-QUANTITY

1 ft/min = 0.00508 m/s = 0.508 cm/s 1 ft/s = 0.3048 m/s = 30.48 cm/s 1 mph = 1.61 km/h = 0.447 m/s 1 kmph = 0.621 mph = 54.6 ft/min 1 knot per hr = 1.8532 km per hr. 1 rpm = 1 u/min; 1 NM³/day = 38.102 SCFD 1 gal (U.S.)/min = 0.227 m³/hr. 1 gal (U.K.)/min = 0.273 m³/h 1 lb/min = 27.216 kg/h 1 cfm or cuft/min = 28.317 lit/min = 1.7 m³/hr. 1 lb/Hph = 0.6077 kg/kwh = 0.4473 kg/psh. 1 gm/cm³ = 0.036 lb/in³ 1 NM³ = 1.055166 SM³; 1 SM³ = 36.11 SCF

HEAT

WORK - MOMENT - POWER

1 ft lb = 0.1383 Kgm = 0.001285 BTU $= 0.5121 \times 10^{-6} \text{ Psh} = 0.3241 \text{ Kcal}$ $= 0.3766 \times 10^{-6} \text{ kwh} = 0.505 \times 10^{-6} \text{ Hph.}$ 1 w = 3.412 BTU/hr = 0.001 kj/s = 1 joules/s1 yd lb = 0.415 kg m1 in lb = 1.152 Kgcm1 ft 1b/s = 0.1383 Kgm/s = 2545 BTU/hr= 0.00184 Ps= 1.356 watt 1 HP = 550 ft 1b/s= 76.04 kgm/s= 0.178 kcal/s = 0.746 kw1 Newton (N) = 1 Kg. $m/sec^2 = 10^5$ gmcm/ $sec^2 = 10^5$ dyne 1 Kgm = 7.233 ft - 1b = 2.3438 Kcal = 0.009296 B T U1 H P = 0.746 KW= 1.014 Psh1 Boiler H. P. = 33475 B.T. U/hr 1 Hph = 1.014 Psh = 2680 Kj = 641 Kcal = 2545 B T U = 0.746 Kwh.1 kwh = 3412 B.T.U = 3600 kj = 860 kcal1 kw = 1.34 H.P. = 14.316 kcal/min = 1 kj/s = 3412 B.T.U/hr = 1.36 Ps1 J = 1 Nm = 1 WS = 0.102 kpm

REFRIGERATION

1 Tr (Europe) = 211 Kj/min = 3.5167 K w = 50.4 Kcal/min
1 Tr (ton of refrigeration) U.S. = 200 B T U/min = 3024 Kcal/h
1 Br. ton of refrigeration = 3340 Kcal/hr.
= 220 B T U/min
1 B T U/Hph = 0.338 Kcal/Kwh
1 lb/h tr = 9 kg/hr per 1000 Kcal/hr.
1 lb/min tr = 0.15 kg/h per 1000 Kcal/h

CONVERSION FACTORS 333

Refrigeration process entail bringing ambient temp to B.P. of ethylene (170 $^{\circ}$ K), low temperature range is from 170 $^{\circ}$ K to m.p. of nitrogen and cryogenics temp is below 120 $^{\circ}$ K.

VISCOSITY

1 poise =
$$0.1 \text{ Ns/m}^2 = 1.02 \cdot 10^{-2} \frac{\text{kps}}{\text{m}^2}$$

1 cp = $1.02 \cdot 10^{-4} \frac{\text{kps}}{\text{m}^2}$
1 st = $10^{-4} \text{ m}^2/\text{s} = 100 \text{ mm}^2/\text{s}$
1 cst = $10^{-6} \text{ m}^2/\text{s}$

For absolute viscosity in metric unit, divide cp by 1000, $\frac{(kg)}{m.s}$

POWERS AND FRACTIONS OF 10

Powers of 10		Symbol
10^{12} Tera		T
10 ⁹ Giga		G
10 ⁶ Mega		M
10^3 Kilo		K
10 ² Hecto		h
10 Deca	••••	da
10 ^{−1} Deci	••••	d
10 ^{−2} centi		c
10 ^{−3} milli		m
10 ^{−6} micron		μ
10 ⁻⁹ nano		n
10 ⁻¹² pico		p
10^{24}		Trillion (U.S. 10^{18} = Trillion)
10^{12}		Billion (U.S. $10^9 = Billion$)
10^{6}		million
10^{5}		hundred thousand

Important Values

$$1 \text{ cv} = 0.98632 \text{ H.P.}$$

 $\pi = 3.142$

Roman number

MM = 2000 $gc = 9.806 \text{ m/sec}^2$ M = 1000 1 Ps = 736 W D = 500 1 Gauss = 1 line of magnetic

C = 100 induction/cm²

SI units (New) and Relationship

The following chart contains a selection of SI-units (new units) as compared with those used formerly. The relationship of both units to each other is also shown.

Old Unit Name	Designat.	New Unit SI Name	Designat	Relationship
Angle, straight new degree degree arc measure	g	degree, minute, second, radiant	°,,,, rad gon	1° = $\pi/180$ Rad; 1' = 1°/60; 1" = 1'/60 1rad = 1m/m 1 g = 1 gon; 1 gon = $(\pi/200)$ rad 1 full angle = 2π rad
Mass kilogram	kg	kilogram gram, tonne	kg g,t,	1 kg = 1000 g 1 t = 1 Mg = 1000 kg
Density kilogram/cubic meter	kg/m ³	kilogram/cubic meter kilogram/ cubic decimeter kilogram/liter	kg/m ³ kg/dm ³ kg/l	instead of spec. grav. or density
Force pond kilopond	p kp	Newton	N	1 p = $9.81.10^{-3}$ N 1 kp = 9.81 N 1 N = 1 kgm/s ² ; 1 N = 0.10197 kp
Energy, work, heat quantity erg calone horse power hour kilopond meter	erg cal ps/h kpm	joule kilowatt hour Newton meter	J kW/h Nm	1 J = 1 Nm = 1 Ws = 0.102 kpm 1 kW/h = 3.6 MJ 1 kW/h = 1.36 PS/h 1 kpm = 9.81 J 1 kcal = 4.2 kJ 1 kJ = 0.239 kcal 1 PS/h = 0.736 kW/h 1 erg = 10 ⁻⁷ J
Power horse power kilowatt	PS kw	kilowatt watt joule/second	kw W J/s	1 PS = 736 W 1 kW = 1.36 PS 1 W = 1 J/s

Refer to the following DIN standards for further details on SI-Units:

DIN 1301. DIN 1306, DIN 1314, DIN 1315, DIN 1341, DIN 1342, DIN 1345, DIN 66034, DIN 66035, DIN 66036, DIN 66037.

Old Unit Name	Designat	New unit Name	Designat	Relationship
Pressure (gases, liquid) meter water column millimeter mercury column millimeter water colum	m WC mm Hg mm WC	Newton/sq meter = Pascal Decanewton square	N/m² Pa daN/cm²	1 m WS = 0.098 bar 1 mm Hg = 1.33 mbar 1 mm WS = 0.098 mbar 1 atm = 1.013 bar

CONVERSION FACTORS 335

physical atmosphere technical atmosphere torr	atm at torr	centimeter = bar	bar	1 at = 0.981 bar 1 torr = 1.33 mbar 1 mbar = 0.75 mm Hg = 0.75 torr 1 mbar = 10.197 mm WS 1 bar = 1.02 at 1 bar = 1.02 kp/cm ² 1 bar = 0.987 atm 1 N/m ² = 1 Pa = 10 ⁻⁵ bar
Stresses (mech.) kilopond/square centimeter kilopond/square millimeter	kp/cm ²	Newton/square meter = Pascal Newton/square millimeter	N/m² Pa N/mm²	1 kp/cm ² = 0.0981 N/mm ² 1 kp/mm ² = 9.81 N/mm ² 1 N/mm ² = 10.2 kp/cm ² 1 N/mm ² = 0.102 kp/mm ² 1 N/m ² = 1 Pa = 10 ⁻⁶ N/mm ²
Dynamic viscosity poise	Р	Newton second/square meter = Pascal second	Ns/m² Pas	$1 P = 0.1 Ns/m^2 = 0.1 Pas$
Kinematic viscosity Stokes	St	square meter/second square millimeter /sec	m ² /s mm ² /s	1 St = 10^{-4} m ² /s 1 St = 100 mm ² /s
Speed revolutions/minute	rev/min	reciprocal minute reciprocal second	min ⁻¹ s ⁻¹	Rev/min = 1/min = min ⁻¹
Temperature degree kelvin	°K	Kelvin degree centigrade	K °C	$1^{\circ}K = 1K = 1^{\circ}C$ (Temp. Diff.) $^{\circ}K = -273.15 ^{\circ}C$ $1 K = -272.15 ^{\circ}C$

Refer to the following DIN standards for further details on the SI units:

DIN 1301. DIN 1306. DIN 1314, DIN 1315, DIN 1341, DIN 1342, DIN 1345, DIN 66034, DIN 66035, DIN 66036, DIN 66037.

Active carbon 75

- Manufacture 75
- Activation processes 75

Α

- Properties 76
- Uses 77

Affinity laws for centrifugal pump 138 Alcohol 163

- Grades 163
- Proof of alcohol 163
- Products from 163
- Physical data for various alcohols (see T-11, vol. IIA)

Arsenic limit in water 125

- Range of removal 126

Aluminium prodn by electrolysis 210

Ammonia liq. production process 3

Analysis of sea salt and rock salt 48

Anodising 129

Anodic cleaning 129

Anode coating 129

A. P. John eqn. for dew point 257

Associated NG analysis 152

Atmospheric stability 260

Atmospheric temp above sea level 267

Bacteriological contamination in

В

raw water 124

Banned dyes 171

Beet sugar 229

- Process steps 229

Biogas plant (Domestic) 223

- Process 223
- CH₄ generation rate 224

Bitumen 76

Blasting explosives 110

Bleaching by Kraft process 41

Bleaching by sulphite process 43

Blue water gas or water gas 146

- Generator 146
- Composition and cal. value of B W G 147

Blast furnace gas 149

- Comp. and cal. value 149
- Cleaning 149

Benzene 162

- Products from 162

Betz co. eff. in wind power generation 134

B.O.D. definition 272

Boiler feed water pumps 237

- BFW pump, German regulation 237
- BFW pressure 237
- Power requirement of pump 237

INDEX	
- Std. values of BFW 238	- Output and efficiency 137
 Std. analysis of Boiler Water 239 	- Specific speed 139
С	- Losses in a pump 139
Carrier eqn. for dew point 257	 Hydraulic balancing 139
Carbon black 179	– Impeller types 142
- Grades and surface area 206	– Affinity laws 138
- CBFC specification 179	 Sketches for different suction heads 140
– Composition 180	 Sketches for different discharge
 ASTM grades name 180 	heads 141
 Raw materials for various 180 carbon blacks 	Co conversion processes (ammonia) 5
	- HT and LT 5
Cellulosic fibres (see Rayon) 50 Chlor–Alkali cells 45	- C O D definition 272
	Coating processes for 128
- Mercury cells 45	Cathode coating 128
Diaphragm cell 47Membrane cell 46	Anode coating 129
	 Resin electrodeposition 129
 Raw material (brine) soln. purification 48 	- Anodising 129
Equation for electrolysis 45	Coal gas 150
Chem. engg. operation in petroleum	 H. T. coal carbonisation 150
refinery 71	 Composition and cal. value 151
 Cracking and reforming process 71 	 Colour index of dyes 171
– Desulphurisation 73	- Colour wheel for complimentary
Chimney	colours 222
– Draught graph 67	 Graph for NCV of clean and raw coal 154
Vapour pressure of paraffinic hydrocarbon 68	Cooling tower 212
Chlorination of water for disinfection 126	– Types 212
	– Natural draft 213
Chromite bricks, properties 104 Chromite magnasite bricks properties 104	 Mechanical draft 213
Centrifugal pump 135	– Spray pond 214
- Total head 135	– Design criteria 213
- Suction and disch. heads 135	– C. T. fan 214
- Characteristic curves 137	- Performance Co-eff. 213
– N P S H 138	- Wet bulb temp. calculation 215
- Pump construction 138	- Pressure drop in cir. water 215

- Make up water flow 216
- Rating of a cooling tower 216
- Blow down rate 215
- Treatment of purge water
 (blow down) 216

Condensate polishing 123

Conversion factors 328

SI units and relationship 334

Contracts for project 307

- Types 307
- Unit price/item rate 308
- Escalation/penalty clauses 308
- Cost ranges for installation of a chem. plant and depreciation rates 306

Critical path method 254

Composition of clean dry air at sea level 261

Crude tar distillation 99

- Composition of crude tar 96
- Yield of fractions and temp. 97
- Pitch types and softening temp. 97
- Roadtar BS std. 97
- Refined products yield 98
- Plant and types 99
- Flow sheet for tar distillation 100
- Tar, Refined products 101
- Process 99
- pro-abid process 102
- Phenol recovery 102
- Naphthalene recovery 102
- Pure naphthalene 102
- Coumarene resin 101
- pitch for electrode binder 98

Crude oil refining 70

- Process 70
- Coaking process 73

Solubility curves for 241 inorganic salts for

Crystallisation : AgNO₃, KI

KNO₃, Pb(NO₃)₂, NH₄Cl, CuSO₄ NaCl, KClO₃, HgCl₂, Na₂SO₄1OH₂O

Cooling conditions in industry and trade – (see p103, Vol–IIA)

Cooling media data for CaCl₂, NaCl
Ethylene and methylene glycols
(see T130 to 133, Vol–IIA)

Calculation of calorific value of solid fuel 153

Graph for chimney draught calculation 67

Combustion calculation of NG fired boiler 62

D

Demineralisation of water by

- ion exchangers 119
- selection of exchanger resins 119
- resin exchangers resin for
 DM water 121
- Flowsheet for demineralisation and silica removal 120
- Degasification of water 118
- Decarbonisation of water 122
- Partial demineralisation 122
- Mixed bed exchanger 122
- Condensate polishing 123

Depreciation rates 306

Desalination of sea water 123

Dry ice manufacture 181

Desulphurisation (catalyst) see p. 142 Vol. II-A 107

Dew Point eqn. (Carrier) 257

Dyes and intermediates 170

- Types of dyes 170
- Dye intermediates 171

_	Dyeing Process 171	E
_	Banned dyes 171	Effluent treatment methods for
_	Detonators 107	industries 265
Detail	project cost estimation 298	 Fertiliser plants 265
_	Various cost heads 298	– D M plants 266
_	Preliminary expenses 299	 Steam utility plants 266
_	Total civil cost factors 300	Sewage treatment 266
_	P and M cost 300	 Solid weste disposal 263
_	Misc. fixed cost 301	Food industry waste 267
_	Auxiliary utility costs 301	- Cement industry 269
_	Cost of effluent treatment plants 302	- Porcelain industry waste 269
	including C. T. purge water	- Iron and steel industry waste 269
	treatment	Metal pickling waste 270Electroplating industry 270
_	Cost of oil pollution monitoring instrument 304	Soda ash plant waste 270
_	Cost of air pollution abatement	Pharma industry waste 270
	scheme 304	 Inorganic dye and colourant/
_	Sound pollution limits and measuring instrument 303	intermediate plants waste 270
_	Fees for know-how, drawing	 Organic dye and intermediate industry 271
	checking, license etc. 304	 Pulp and paper industry waste 266
_	Project management charges including statutory fees 304	- Dairy effluent treatment 271
	Erection charges 305	Sugar mill effluent 271Waste water with mercurry 271
_	· ·	 waste water with increarry 271 Controlling acts against water
_	Incidental charges 305 Erection supervision charges 305	and air EPA 1986 272
_	Township, welfare and medical	Effluent permissible limits for fertiliser plants
	expenses 305	- Liq. effluents 267
_	Margin money on working capital 305	– MINAS 267
_	Interest charges on borrowed	– IS 2490–74 267
	money 306	 Assam pollution control board 267
_	Commissioning expenses 363 Escalation or contingencies 306	 Ambient air quality as per Air Act 1981 303
Dittus	- Boltier eqns of heat transfer 27	 Delay pond stipulation for treated
	tric constants of textile glasses 259	effluents 272
	ot. – temp chart for flue gases 158	Public views on new industrial plant location and public hearing.
_	ot.— temp chart for flue gases a SO ₂ 158	plant location and public hearing at SDO's office 272

- Air pollution causes 273
- Green house gases and ozone hole in Antarctica 260, 268
- Anti pollution measures for air pollution 273, 268
- Inversion of temp due to atmospheric unstability 260
- Monitoring stations for air pollution and wind velocity measurant/indication 304
- Suction air filters for air blowers/ compressors 273
- Atmospheric temp above sea level 267
- Solar energy distribution on earth 260

Environment and Pollution, Air and Water 260

- Methods of control of liq effluents 261
- Chemical methods 261
- Biological methods 262
- Solid waste disposal 263
- Segregation of waste streams 263

Electroplating

- Faraday's law 207
- Std. Oxdn-reduction potentials see T-18 vol. IIA
- Rack plating 208
- Barrel plating 208
- Spot plating or brush plating 208
- Pulse plating 208
- Non electrolytic deposition 238
- Various plating processes
- Gold plating 208
- Tin plating 209
- Cadmium plating 209
- Chromium plating 209
- Copper plating 209
- Bright gold deposit 210
- Pure Aluminium prodn. 210
- Other considerations in electro plating 211

- Cathode and anode Coating 211
- Evacuation of a vessel as a function of time 69

Electrophoresis 181

separation of materials 181
Electrolytic chlorinator 183
Ethyl benzene, products from 165
Ethylene, products from 164
Ethylene oxide, products from 164
Expanded or foamed plastics 177

Explosives 107

- Classification 108
- Gaseous explosion and explosion due to pr. vessel failures 107
- Detonation of an explosive 107
- Detonation velocity table 108
- Names of some primary explosives 109
- Secondary explosives for industrial uses and high explosives 108
- Properties of high explosives 109
- Plastic explosives 110
- Impact sensitivity of secondary explosives 109
- Functional groups in explonives 110

F

Fatty acids conc. in oils, fats and milk – (see Table 150 Vol–IIA)

Fertilisers 1

Ferro alloys 232

- Production processes 232
- Composition of ferro alloys 233

Fire fighting network 177

- Classes of fire (see T34 vol-II B) -
- underground fire water hydrant system 177
- Fire pump and booster pumps 177
- Slandby diesel fire pump 178

- Foam fire installation 178 - Fire engine or tender 178 - Fire engine or tender 178 - Fire water storage, over head/surface reservoir 178 - TAC approval of fire water hydrant systems 178 - Empty bag storage-auto sprinkler system 178 - Empty bag storage-auto sprinkler system 178 - Ionisation smoke detection chamber 175 - Ionisation smoke detection chamber 175 - Photo electric cell for smoke detection 176 - Fusible alloy water sprayers 176 - Float glass 179 - Pilkington float glass process 179 - Uses 179 - Inorganic 195 - Inorganic 195 - Trade names and manufacturers 195 - Trade names and manufacturers 195 - Trade names and manufacturers 195 - Trade names 174 - Names 174 - Names 174 - Physical action 174 - Application 174 - Application 174 - Physical for bleaching, FWA no. 194 - LD ₅₀ limit 173 - Uses 173 - Water for H. Es (see T63 Vol. IIA) - Furfural 282 - Properties 282 - Handling and storage 284 - Uses 284 - Use 284 - Danger criteria for fertilisers 1 - Danger criteria for fertilisers 2 - Raw materials for fertilisers 1 - Danger criteria for fertilisers 2 - Raw materials for fertilisers 1 - Danger criteria for fertilisers 1 - Danger criteria for fertilisers 2 - Raw materials for fertilisers 1 - Danger criteria for fertilisers 2 - Raw materials for ferti	 Fire fighting accessories 178 	 Raw materials and Manufacture 282
Fire water storage, over head/surface reservoir 178 TAC approval of fire water hydrant systems 178 Empty bag storage-auto sprinkler system 178 Fire detection alarms 175 Ionisation smoke detection chamber 175 Photo electric cell for smoke detection 176 Fusible alloy water sprayers 176 Float glass 179 Pilkington float glass process 179 Pilkington float glass process 179 Organic 195 Trade names and manufacturers 195 Trade names and manufacturers 195 Trade names and manufacturers 196 Flame retardants 174 Names 174 Names 174 Physical action 175 Pilorescent or optical whitening agents 172 Material for bleaching, FWA no. 194 LD _{So} limit 173 Uses 173 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Furfural 282 Foamed plastics and rubber 177 Fertiliser Types of inorganic fertilisers 2 Raw materials for fertilisers 2 Raw materials for fertilisers 1 Danger criteria for fertilisers 2 Raw materials for fertilisers 1 Danger criteria for fertilisers 1 Danger criteria for fertilisers 1 Danger criteria for fertilisers production 3 Brief process steps 3 Detail process for ammonia from NG 4 Process for ammonia from NG 4 Process for ammonia from NG 4 Process for ammonia production 14 Process for ammonia production 16 Process for ammonia from NG 4 Process for ammonia production 17 Associated NG analysis 17 Urea plant-process brief 12 Stamicarbon CO ₂ stripping process 14 Flowsheet for Snam NH ₃ , stripping process 15 TEC's ACES process for urea 15 Montedison IDR urea process 16 Specific consumptions comparision in urea process 17 Comparative statement on energy consumption 18 By product CO ₂ from ammonia production from NG a	 Foam fire installation 178 	 Handling and storage 284
surface reservoir 178 TAC approval of fire water hydrant systems 178 Empty bag storage-auto sprinkler system 178 Fire detection alarms 175 Ionisation smoke detection chamber 175 Photo electric cell for smoke detection 176 Fusible alloy water sprayers 176 Float glass 179 Pilkington float glass process 179 Pilkington float glass process 179 Pilkington float glass process 179 Inorganic 195 Inorganic 195 Trade names and manufacturers 195 Trade names and manufacturers 195 Trade names and manufacturers 196 Industry wise use of flocculants 196 Industry wise use of flocculants 196 Flame retardants 174 Names 174 Names 174 Physical action 174 Physical action 174 Application 174 Fluorescent or optical whitening agents 172 Material for bleaching, FWA no. 194 LUSE 173 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Furfural 282 Fertiliser Types of inorganic fertilisers 2 Raw materials for fertilisers 2 Raw materials for fertilisers 1 Danger criteria for fertilisers 2 Raw materials for fertilisers 1 Danger criteria for fertilisers 2 Raw materials for fertilisers 1 Danger criteria for fertilisers 2 Raw materials for fertilisers 1 Danger criteria for fertilisers 2 Raw materials for fertilisers 1 Danger criteria for fertilisers 1 Danger criteria for fertilisers 2 Raw materials for fertilisers 1 Danger criteria for fertilisers 1 Danger criteria for fertilisers 2 Raw materials for fertilisers 1 Detail process for arm gas (CO+H ₂) producton 5 (UOP, and BASF) Detail process for arm gas (CO+H ₂) producton 5 (UOP, and BASF) Detail process for arm gas (CO+H ₂) producton 100 in uran process comparison 10 Application 174 Functions 195 Specific consumption is ammonia production from NG and LSHS 6, 8 Tred detection 176 Process for arm gas (CO+H ₂) product CO ₂ from ammonia production from NG and LSHS 6, 8	- Fire engine or tender 178	– Uses 284
- TAC approval of fire water hydrant systems 178 - Empty bag storage-auto sprinkler system 178 Fire detection alarms 175 - Ionisation smoke detection chamber 175 - Photo electric cell for smoke detection 176 - Fusible alloy water sprayers 176 Float glass 179 - Pilkington float glass process 179 - Diagnic 195 - Inorganic 195 - Trade names and manufacturers 196 - Industry wise use of flocculants 196 - Industry wise use of flocculants 196 Flame retardants 174 - Names 174 - Physical action 174 - Application 174 - Application 174 - Functions 172 - FWA nos. and R groups 172 - Material for bleaching, FWA no. 194 - LD ₅₀ limit 173 - Uses 173 Fouling factors for different cooling - water for H. Es (see T63 Vol. IIA) Furfural 282 - Raw materials for fertilisers 2 Raw materials for fertilisers production 3 Brief process steps 3 Detail process for raw gas (CO+H ₂) prodn. by partial oxdn. of fuel oil/LSHS 7 CO ₂ removal processes comparison 9 (UOP, and BASF) Uhde ammonia synthesis loop data 9 Sp. consumption in ammonia plant (NGbased) and energy requirement 10 - Process data for Kellog reforming exchanger 10 - Ammonia synthesis and steam network 11 - Associated NG analysis 17 - Urea plant-process brief 12 Stamicarbon CO ₂ stripping process-urea 13 - Snam NH ₃ stripping process 15 - TEC's ACES process for urea 15 - Montedison IDR urea process 16 - Specific consumptions comparision in urea process 17 - Comparative statement on energy consumption 18	_	_
Fire detection alarms 175 - Ionisation smoke detection chamber 175 - Photo electric cell for smoke detection 176 - Fusible alloy water sprayers 176 Float glass 179 - Pilkington float glass process 179 - Uses 179 - Uses 179 Flocculants 195 - Inorganic 195 - Trade names and manufacturers 195 - Trade names and manufacturers 195 - Industry wise use of flocculants 196 - Industry wise use of flocculants 196 Flame retardants 174 - Names 174 - Physical action 174 - Application 174 - Physical action 174 - Functions 172 - FWA nos. and R groups 172 - Material for bleaching, FWA no. 194 - LD ₅₀ limit 173 - Uses 173 Fouling factors for different cooling - water for H. Es (see T63 Vol. IIA) Furfural 282 Brief process steps 3 - Detail process for ammonia from NG 4 - Process for raw gas (CO+H ₂) prodn. by partial oxdn. of fuel oil/LSHS 7 CO ₂ removal processes comparison 9 (UOP, and BASF) - Uhde ammonia synthesis loop data 9 - Sp. consumption in ammonia plant (NGbased) and energy requirement 10 - Process for raw gas (CO+H ₂) prodn. by partial oxdn. of fuel oil/LSHS 7 - CO ₂ removal processes comparison 9 (UOP, and BASF) - Uhde ammonia synthesis loop data 9 - Sp. consumption in ammonia plata 9 - Sp. consumption in ammonia plata 9 - Sp. consumption in ammonia producesses comparison on to NG 4 - Process for raw gas (CO+H ₂) prodn. by partial oxdn. of fuel oil/LSHS 7 - CO ₂ removal processes comparison 9 (UOP, and BASF) - Uhde ammonia synthesis loop data 9 - Sp. consumption in ammonia plata 9 - Sp. consumption in ammonia producesses comparison on to NG 4 - Process for raw gas (CO+H ₂) prodn. by partial oxdn. of fuel oil/LSHS 7 - CO ₂ removal processes comparison of UOP, and BASF) - Uhde ammonia synthesis and steam network 11 - Associated NG analysis 17 - Urea plant-process brief 12 - Stamicarbon CO ₂ stripping process - urea 13 - TEC's ACES process for urea 15 - Montedison IDR urea process 16 - Specific consumptions comparision in urea process 17 - Comparative stateme	systems 178 – Empty bag storage-auto sprinkler	 Danger criteria for fertilisers 2
- Ionisation smoke detection chamber 175 - Photo electric cell for smoke detection 176 - Fusible alloy water sprayers 176 Float glass 179 - Pilkington float glass process 179 - Uses 179 - Pilkington float glass process 179 - Uses 179 - Inorganic 195 - Inorganic 195 - Trade names and manufacturers 195 - Testing Parametres for flocculants 196 - Industry wise use of flocculants 196 - Flame retardants 174 - Names 174 - Physical action 174 - Application 174 - Application 174 - Fluorescent or optical whitening agents 172 - Functions 172 - Material for bleaching, FWA no. 194 - LD ₅₀ limit 173 - Uses 173 - Uses 173 - Water for H. Es (see T63 Vol. IIA) - Furfural 282 - Detail process for ammonia from NG 4 - Process for raw gas (CO+H ₂) prodn. by partial oxdn. of fuel oil/LSHS 7 - CO ₂ removal processes comparison 9 (UOP, and BASF) - Uhde ammonia synthesis loop data 9 - Sp. consumption in ammonia plant (NGbased) and energy requirement 10 - Process data for Kellog reforming exchanger 10 - Associated NG analysis 17 - Urea plant-process brief 12 - Stamicarbon CO ₂ stripping process-urea 13 - Snam NH ₃ stripping process 15 - TEC's ACES process for urea 15 - Montedison IDR urea process 16 - Specific consumptions comparision in urea process 17 - Comparative statement on energy consumption 18 - By product CO ₂ from ammonia plant 17 - Flowsheet for ammonia production from NG and LSHS 6, 8	•	_
 Photo electric cell for smoke detection 176 Pisible alloy water sprayers 176 Float glass 179 Pilkington float glass process 179 Uses 179 Uses 179 Floculants 195 Inorganic 195 Trade names and manufacturers 195 Testing Parametres for flocculants 196 Industry wise use of flocculants 196 Flame retardants 174 Names 174 Physical action 174 Physical for bleaching, FWA no. 194 LD₅₀ limit 173 Uses 173 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Process for raw gas (CO+H₂) prodn. by partial oxdn. of fuel oil/LSHS 7 CO₂ removal processes comparison 9 (UOP, and BASF) Uhde ammonia synthesis loop data 9 Sp. consumption in ammonia plant (NGbased) and energy requirement 10 Process data for Kellog reforming exchanger 10 Ammonia synthesis and steam network 11 Associated NG analysis 17 Urea plant-process brief 12 Stamicarbon CO₂ stripping process urea 13 Snam NH₃ stripping process 14 Flowsheet for Snam NH₃₊stripping process 15 TEC's ACES process for urea 15 Specific consumptions comparision in urea process 17 Comparative statement on energy consumption 18 By product CO₂ from ammonia plant 17 Flowsheet for ammonia production from NG and LSHS 6, 8 		
- Fusible alloy water sprayers 176 Float glass 179 - Pilkington float glass process 179 - Uses 179 - Uses 179 Flocculants 195 - Inorganic 195 - Organic 195 - Trade names and manufacturers 195 - Testing Parametres for flocculants 196 - Industry wise use of flocculants 196 - Industry wise use of flocculants 196 - Industry wise use of flocculants 196 Flame retardants 174 - Names 174 - Physical action 174 - Application 174 - Application 174 - Fluorescent or optical whitening agents 172 - FWA nos. and R groups 172 - Material for bleaching, FWA no. 194 - LD ₅₀ limit 173 - Uses 173 Fouling factors for different cooling - water for H. Es (see T63 Vol. IIA) - CO ₂ removal processes comparison 9 (UOP, and BASF) - Uhde ammonia synthesis loop data 9 - Sp. consumption in ammonia plant (NGbased) and energy requirement 10 - Ammonia synthesis and steam network 11 - Associated NG analysis 17 - Urea plant-process brief 12 - Stamicarbon CO ₂ stripping process- urea 13 - Snam NH ₃ stripping process 14 - Flowsheet for Snam NH ₃₊ stripping process 15 - TEC's ACES process for urea 15 - Montedison IDR urea process 16 - Specific consumptions comparision in urea process 17 - Comparative statement on energy consumption 18 - By product CO ₂ from ammonia plant 17 - Flowsheet for ammonia production from NG and LSHS 6, 8	 Photo electric cell for smoke 	 Process for raw gas (CO+H₂) prodn.
- Pilkington float glass process 179 - Uses 179 - Inorganic 195 - Inorganic 195 - Trade names and manufacturers 195 - Testing Parametres for flocculants 196 - Industry wise use of flocculants 196 - Names 174 - Physical action 174 - Application 174 - Application 174 - Fluorescent or optical whitening agents 172 - FWA nos. and R groups 172 - FWA nos. and R groups 172 - Material for bleaching, FWA no. 194 - LD ₅₀ limit 173 - Uses 173 - Unde ammonia synthesis loop data 9 - Sp. consumption in ammonia plant (NGbased) and energy requirement 10 - Ammonia synthesis and steam network 11 - Associated NG analysis 17 - Urea plant-process brief 12 - Stamicarbon CO ₂ stripping process-urea 13 - Snam NH ₃ stripping process 14 - Flowsheet for Snam NH ₃ , stripping process 15 - TEC's ACES process for urea 15 - Montedison IDR urea process 16 - Specific consumptions comparision in urea process 17 - Comparative statement on energy consumption 18 - By product CO ₂ from ammonia plant 17 - Flowsheet for ammonia production from NG and LSHS 6, 8	 Fusible alloy water sprayers 176 	2
- Uses 179 Flocculants 195 - Inorganic 195 - Organic 195 - Trade names and manufacturers 195 - Testing Parametres for flocculants 196 - Industry wise use of flocculants 196 - Industry wise use of flocculants 196 Flame retardants 174 - Names 174 - Physical action 174 - Application 174 - Functions 172 - FWA nos. and R groups 172 - Material for bleaching, FWA no. 194 - Uses 173 Fouling factors for different cooling - water for H. Es (see T63 Vol. IIA) Furdural 282 Process data for Kellog reforming exchanger 10 - Ammonia synthesis and steam network 11 - Associated NG analysis 17 - Urea plant-process brief 12 - Stamicarbon CO ₂ stripping process-urea 13 - Snam NH ₃ stripping process 14 - Flowsheet for Snam NH ₃₊ stripping process 15 - TEC's ACES process for urea 15 - Montedison IDR urea process 16 - Specific consumptions comparision in urea process 17 - Comparative statement on energy consumption 18 Fouling factors for different cooling - water for H. Es (see T63 Vol. IIA) Furfural 282		 Uhde ammonia synthesis loop data 9
 Inorganic 195 Organic 195 Trade names and manufacturers 195 Testing Parametres for flocculants 196 Industry wise use of flocculants 196 Industry wise use of flocculants 196 Names 174 Physical action 174 Application 174 Fluorescent or optical whitening agents 172 FwA nos. and R groups 172 Material for bleaching, FWA no. 194 LD₅₀ limit 173 Uses 173 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Ammonia synthesis and steam network 11 Associated NG analysis 17 Urea plant–process brief 12 Stamicarbon CO₂ stripping process—urea 13 Snam NH₃ stripping process 14 Flowsheet for Snam NH₃₊stripping process 15 TEC's ACES process for urea 15 Specific consumptions comparision in urea process 17 Comparative statement on energy consumption 18 Followsheet for ammonia production from NG and LSHS 6, 8 		
- Trade names and manufacturers 195 - Testing Parametres for flocculants 196 - Industry wise use of flocculants 196 - Urea plant–process brief 12 - Stamicarbon CO ₂ stripping process—urea 13 - Snam NH ₃ stripping process 14 - Flowsheet for Snam NH ₃₊ stripping process 15 - TEC's ACES process for urea 15 - Montedison IDR urea process 16 - Specific consumptions comparision in urea process 17 - Comparative statement on energy consumption 18 - Water for H. Es (see T63 Vol. IIA) - Flowsheet for ammonia production from NG and LSHS 6, 8		
 Testing Parametres for flocculants 196 Industry wise use of flocculants 196 Urea plant–process brief 12 Stamicarbon CO₂ stripping processurea 13 Snam NH₃ stripping process 14 Fluorescent or optical whitening agents 172 Functions 172 FWA nos. and R groups 172 Material for bleaching, FWA no. 194 LD₅₀ limit 173 Uses 173 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Associated NG analysis 17 Urea plant–process brief 12 Stamicarbon CO₂ stripping process-urea 13 Snam NH₃ stripping process 14 Flowsheet for Snam NH₃₊stripping process 15 TEC's ACES process for urea 15 Specific consumptions comparision in urea process 17 Comparative statement on energy consumption 18 By product CO₂ from ammonia plant 17 Flowsheet for ammonia production from NG and LSHS 6, 8 Van press, temp curve for ammonia 20 	· ·	
 Industry wise use of flocculants 196 Urea plant-process brief 12 Stamicarbon CO₂ stripping processurea 13 Names 174 Physical action 174 Application 174 Fluorescent or optical whitening agents 172 Functions 172 FWA nos. and R groups 172 Material for bleaching, FWA no. 194 LD₅₀ limit 173 Uses 173 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Urea plant-process brief 12 Stamicarbon CO₂ stripping process urea 13 Snam NH₃ stripping process 14 Flowsheet for Snam NH₃₊stripping process 15 TEC's ACES process for urea 15 Specific consumptions comparision in urea process 17 Comparative statement on energy consumption 18 By product CO₂ from ammonia plant 17 Flowsheet for ammonia production from NG and LSHS 6, 8 Van press temp curve for ammonia 20 		 Associated NG analysis 17
Flame retardants 174 - Names 174 - Physical action 174 - Application 174 Fluorescent or optical whitening agents 172 - Functions 172 - FWA nos. and R groups 172 - Material for bleaching, FWA no. 194 - LD ₅₀ limit 173 - Uses 173 Fouling factors for different cooling - water for H. Es (see T63 Vol. IIA) Furfural 282 - Stamicarbon CO ₂ stripping process—urea 13 - Snam NH ₃ stripping process 14 - Flowsheet for Snam NH ₃₊ stripping process 15 - TEC's ACES process for urea 15 - Montedison IDR urea process 16 - Specific consumptions comparision in urea process 17 - Comparative statement on energy consumption 18 - By product CO ₂ from ammonia plant 17 - Flowsheet for ammonia production from NG and LSHS 6, 8		- Urea plant-process brief 12
 Physical action 174 Application 174 Fluorescent or optical whitening agents 172 Functions 172 FWA nos. and R groups 172 Material for bleaching, FWA no. 194 LD₅₀ limit 173 Uses 173 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Snam NH₃ stripping process 14 Flowsheet for Snam NH₃₊stripping process 15 TEC's ACES process for urea 15 Montedison IDR urea process 16 Specific consumptions comparision in urea process 17 Comparative statement on energy consumption 18 By product CO₂ from ammonia plant 17 Flowsheet for ammonia production from NG and LSHS 6, 8 Van press temp curve for ammonia 20 	Flame retardants 174	
Fluorescent or optical whitening agents 172 - Functions 172 - FWA nos. and R groups 172 - Montedison IDR urea process 16 - Specific consumptions comparision in urea process 17 - LD ₅₀ limit 173 - Uses 173 Fouling factors for different cooling - water for H. Es (see T63 Vol. IIA) Furfural 282 Fluorescent or optical whitening agents 172 - TEC's ACES process for urea 15 - Montedison IDR urea process 16 - Specific consumptions comparision in urea process 17 - Comparative statement on energy consumption 18 - By product CO ₂ from ammonia plant 17 - Flowsheet for ammonia production from NG and LSHS 6, 8	- Physical action 174	 Flowsheet for Snam NH₃₊stripping
 Functions 172 FWA nos. and R groups 172 Material for bleaching, FWA no. 194 LD₅₀ limit 173 Uses 173 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Furfural 282 Montedison IDR urea process 16 Specific consumptions comparision in urea process 17 Comparative statement on energy consumption 18 By product CO₂ from ammonia plant 17 Flowsheet for ammonia production from NG and LSHS 6, 8 Van press, temp curve for ammonia 20 	••	
 FWA nos. and R groups 172 Material for bleaching, FWA no. 194 LD₅₀ limit 173 Uses 173 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Furfural 282 Montedison IDR urea process 16 Specific consumptions comparision in urea process 17 Comparative statement on energy consumption 18 By product CO₂ from ammonia plant 17 Flowsheet for ammonia production from NG and LSHS 6, 8 Van press temp curve for ammonia 20 		_
 Material for bleaching, FWA no. 194 LD₅₀ limit 173 Uses 173 Comparative statement on energy consumption 18 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Furfural 282 Specific consumptions comparision in urea process 17 Comparative statement on energy consumption 18 By product CO₂ from ammonia plant 17 Flowsheet for ammonia production from NG and LSHS 6, 8 Van press temp curve for ammonia 20 		_
 Uses 173 Fouling factors for different cooling water for H. Es (see T63 Vol. IIA) Furfural 282 Sometimes of the consumption of the consump		
 water for H. Es (see T63 Vol. IIA) Furfural 282 Flowsheet for ammonia production from NG and LSHS 6, 8 Van press temp curve for ammonia 20 	30	-
 water for H. Es (see T63 Vol. IIA) Furfural 282 Flowsheet for ammonia production from NG and LSHS 6, 8 Van press temp curve for ammonia 20 	Fouling factors for different cooling	 By product CO₂ from ammonia plant 17
Van press temp curve for ammonia 20	- water for H. Es (see T63 Vol. IIA)	<u>.</u>
	- Properties 282	

- Viscosity of ammonia and ammonia vapour 21, 22
- Thermal conductivity of liq. ammonia 23
- Viscosity of urea aq. soln. 24
- Storage for Fertiliser 16

G

Galvanic series of metals and graphite – (see T-66 vol IIA)

Grog 106

Green strength 106

Glass and textile glass fibres 258

- Types of glasses and uses 258
- E glass 258
- C glass 258
- A glass 258
- E C R glass 258
- R glass 258
- D glass 258
- S glass 258
- ISO nos for textile filament 259
- Composition of glasses 259
- Use of textile glass fibres 259
- Dielectric constants of Tex glasses at 1 MHz 259

Н

Halons – fire extinguishing chemicals 175

- Types 175
- Characteristics 175
- Uses 175
- Toxicity 175

Heat exchangers

- Convection heat transfer 25
- Temp. difference, mean/LMTD 26
- Graph for LMTD determination 36
- Reynolds no, Prandtl no. and
 Nusselt no.-convection 27

- Dittus Boltier eqn. for film co–eff, heatingfluid–turbulent flow 27
- Heat transfer eqn. for forced convection, film co-eff. at perpendicular to banks of staggerd tubes 27
- Heat transfer eqn. for film co-eff for condensing vapours in horizontal tubes 27
- Heat transfer eqn. for film co-eff for vertical tubes 27
- Overall heat transfer co-eff, for multipass heat exchangers 28
- Fouling factors and temp. appln.
 ranges 28
- Shell side/Tube side 26
- Bafflecut and baffle spacing 26
- Sketch for annular and segmental cut baffles with symbols 58
- Types of heat transfer equipment 29
- Cascade flow coolers for gases 30
- Radiant flow heat transfer equation 35
- Mechanical codes for Heat exchanger construction 26
- Heat transfer by conduction 31
- Tube pitch and tube layout 30
- No. of tubes for triangular pitch 34
- Layout as a function of shell diameter tube spacing 35
- Approx. overall heat transfer co-eff. for common H.Es 32, 33
- Root–sum– square norms for heat transfer area selection 28
- Typical calculation of a shell and tube heat exchanger (steam heater) in urea plant 55
- Nomograph for LMTD for H.Es

ı

Insecticides or Pesticides 243

- Properties 243

- Classification 244

- Efficiency of producer gas

_	Grades of insecticides 244	generators 145
_	Insecticides group A – Acaricides 244	 Cleaning of producer gas 146
_	Insecticide group C – Molluscicides 246	– Uses 145
_	Pesticides group B – Insecticides 244	 Slagging ash producer gas
_	Fumigants – Group D 247	generators 146
_	Fungicides – Group E 247	 Water gas or blue water gas 146
_	Herbicides – Group F 248	 Composition and cal. value 147
_	Slimicides – Group G 249	- Uses of water gas 147
_	Rodenticides – Group H 249	- Carburated water gas or town gas 147
_	Nematicides – Group I 249	 Petro fuel used – Diesel oil 147
_	Banned pesticides 250	 Composition and cal. value 148
_	Toxicity of pesticides nomenclature 250	– Uses 148
_	Solvents/emulsifier for pesticides 250	- Semiwater gas 148
_	Nonionic emulsifiers 251	- Generator operation 148
_	Cationic emulsifiers 251	 Raw material used 148
_	Anionic emulsifiers 251	 Composition and cal. value 148
_	Solid inorganic emulsifiers 251	- Cleaning of raw gas 149
_	Natural emulsifiers 251	– Use 149
-	Additives and stabilisers for	- Blast furnace gas 149
	pesticides 251	 Composition and cal. value 149
_	Criteria of selection of specific emulsifier 251	- Cleaning of B.F. gas 149
_	HLB value of emulsifier (non–ionic) 252	- Coal gas 150
_	Wood insects 253	 Raw material specification 150
_	Manufacture of neem (margosa)	 Process of manufacture
	based pesticides 253	(H.T. coal carbonisation) 150
_	Industrial and town gases 143	 Composition and Cal. value 151
_	Producer gas 143	Analysis of coke 151
_	Wellman gas producer 143	- Uses of coke 151
-	Coppee gas producer 144	International paper sizes (see vol. II B
_	Composition and cal. value 144	T-31) –
_	Comparison of composition	Ionic load in water 124
_	Cal. value when different fuel	Iron and steel industry development 182
	materials are used 144	Iron Oxide Pigments (synthetic) 167
_	Operation problems of gas generators 145	- Processes of manufacture 167
	generators 145	- Properties 168

- Uses as colouring material 169
- International spec. of iron oxide 169

ISO-9000 series quality assurance system 320

- Fields of application of EN ISO
 9000 series 320
- Corresponding BS and Indian Standard 320
- EAC guide lines on appln. of EN 45012 321
- Nodal agencies for accreditation of certifying organisation 321
- Ten steps for quality assurance and control for TQC 321
- Q M S lines of departments 321
- Application clauses of ISO-9000 series for TQC (ISO-9001, ISO-9002 and ISO-9003) for manufacturing cos. 322
- Preliminary procedure for ISO-9000 certification 322
- Preliminary audit (check list) 323
- Submission of quality audit survey manual 322
- Installation of quality system and final audit 323
- Submission of final audit report to nodal agency for approval 323
- Post visit for survey and compliance 327
- Appln. for formal registration
 by co. to certifying agency 326
- Total time period reqd. for ISO-9000 certification 327
- Qualification and experience bar of auditors as per ISO-1001-Part 1 327
- Validity of ISO–9000 series certification 327

J

Joules Law

Joules cycle in gas tubines,
 Open cycle gas turbine generator
 (see Vol. II P. 55)

ı

- L. N. G Production 159
 - Pretreatment of NG 159
 - NG liquefaction processes 159
 - Base load and cascade processes 159
 - Detail cascade liquefaction process using methane propane and ethylene as refrigerants 159
 - Physical data of propane, ethylene and methane 159
 - Flow sheet 160
 - Volumetric refrigerating effect 161
 - Storage of L N G (one shore) 161
 - Other L N G (data) 161

Light reflection factors of paints (see T–78 in vol–IIA)

Lime softening process by clariflocculator 116

M

Magnetic filtration of water 124

Manganese dioxide 130

- Types of MnO₂ 130
- Spec. of activated MnO₂ 130
- Activated manganous ore process 130
- Chemical MnO₂ 130
- Sedemar process for CMD 131
- Electrolytic MnO₂(EMD) 131
- Spec. of EMD 131
- Manufacture of EMD 132
- Uses of Manganese dioxides 132
- Chrome Magnesite bricks, properties 104

_	Mullite b	ricks,	prope	rties,	Magnesite
	bricks,	prope	erties	105	

Mixed bed exchangers 122

Mineral wool – glass fibres types, properties 187

- Chemical analysis 188

Metal cleaning processes 128

- Metal degreasing by organic chemicals 128
- Acid pickling 128
- Comp. and process for pickling 128
- Compressor lube oil circuit (refr.) 128
- Compr. suction lines etc. cleaning
- Cathodic cleaning for nonferrous items 129
- Anodic cleaning for ferrous items 129
- Anodising for Al items 129

N

Natural gas liquefaction 159

- Cascade process for LNG 159

Neutral ion exchanger resins 122

- Energy consumption in Fertiliser plants 18
- Ammonia-urea complex 18
- Non-Carbonate hardness of water 113

Net calorific value of clean and raw coal (See T-70, Vol-II A)

Net colorific value of clean and raw coal 154

0

Optical whitening agents 172

Oligomers 285

Off shore oil transportation pipe line 242

Р

Paints and Painting 217

 Purposes and painting, decorative and protection 217

- Significance of painting 217
- Typical components of paints and lacquers 217
- Paint vehicles 217
- Pigment colours and types 218
- Hiding units of pigments 220
- Solvents 219
- Dryers 218
- Additives 219
- Appln. of paints 221
- Uses 221
- Lacquers 218, 219
- Synthetic resin paints 221
- Industrial paints, types 221
- Colour wheel 222

Pesticides

- Insecticides 243

Petroleum Refinery 70

- Refinery category 71
- Crude oil types 70
- Products from crude oil 70
- Brief Process steps 70
- Flowsheet for primary crude distillation 72
- Chem. Engg. Operating system 71
- Cracking/Reforming Process 71, 72
- Coking Process 73
- Flowsheet for coking process 73
- Desulphurisation 73
- Lubricating oils 74
- Bitumen/Asphalt 74

Plasticity of refractory 106

- Phosphoric acid 198
- Rock Phosphate ores 198
- Analysis of rock Phosphate (Florida) 199
- Selection of rock phosphate ores and limits of ores 200

- Chemical reactions 198
- Conc. Sulphuric acid requirement and heat dissipitation 200
- Dihydrate and Monohydrate phosphoric acid, CaSO₄ limits 199
- Phosphoric acid manufacture (dihydrate) 199
- Digestor or Reactor 201
- Key Process parameters 202
- Parameters of crystal form of different processes 231
- Phosphoric acid sludge 233
- Hemihydrate process 202
- Hemihydrate-Dihydrate process 203
- Concentration and clarification of phosphoric acid 203
- Super phosphoric acid, chemical composition 204
- Material of construction 205
- Speed of fluids/chemical factors 205
- Analysis of single super-phosphate 205
- TSP (46% P₂O₅) 206
- Capital cost break-up 206

Phenol recovery by tar distillation 102
Porosity of refractory bricks 106

Phenol for disinfection 230

- Phenols types 230
- Phenols classification as per germicidal value 230
- Testing of phenols 230
- Phenol co-eff. test as per BS 231
- Names of manufacturing process 231
- Toxicity 231
- Waste water treatment for phenol recovery 231

Polyethylene terephthalate resin 285

- Specification of PET (Food grade bottle) 287
- Manufacturing Process 285

- Recycle of PET bottles 287

Pigments, iron oxide 167

- Synthetic Iron oxide Pigments 167, manufacture 168
- International specification 169
- Properties 168

Pulp and Paper 37

- Grades of paper 37
- Paper sizes 38
- Test parameters for paper 38
- Raw materials soft wood and hard wood 38
- Non wood fibres for pulping 38
- Textile fibres for pulping 38
- Manufacturing process 39
- Kraft or sulphate process 39
- Sulfite process 42
- General steps for chemical pulping 39
- Bleaching of pulp 40
- Bleaching steps for Kraft pulping 41
- Pulp beating and filtration 41
- Chemical recovery of Kraft digestor liquor 41
- Chemical recovery of sulphite digestor liquor 42
- Bleaching steps 43
- Mechanical Pulping process 43
- Deinking of waste paper 43
- Speciality paper 43
- Bamboo Pulp 43
- Bagasse and corn stalk pulp 44
- Paper making by Hollander machine 44

Plastics 190

- Types of plastics 190
- Physical properties of common plastics (see T–165, Vol. II A) 191
- Density of plastics (see T–160, Vol. IIA)

- Additives for plastics 191
- Antistatic agent in plastics 192
- Solvents for plastics (see T–101, Vol. II A)
- Glass transition temp and M.P of plastics (see T-163, Vol. II A)–
 Specific heat and thermal conductivity of plastics (see T-161, Vol. II A)
- Linear thermal expansion of some plastics (see P 219, Vol. II A) –
- Burning characteristics of some plastics (see T- 162, Vol. IIA)-
- Outline of plastics manufacturing processes 193, 192
- Processes for polyethylene manufacture 194
- Foamed plastics-manufacturing process 193
- Plastics fabrication machines 193
- Plastics materials for packaging 194, 193

Producer gas 143

Process equipment (selected design) 53

Pre requirements

- Various calculation formulae 63-65
- Sizing of a vapour–liquid separator for urea plant service 53
- Sizing of a steam heater in urea plant 55
- Combustion calculation for NG fired boiler furnace 62

Project Financial Management 309

- Internal rate of return (IRR) 309
- Procedure for determining IRR/ NPV and cash flows 309, 314
- Cost-benefit analysis 310
- Pay back period 311
- Rate of return Vs cost of capital 311
- Reqd. rate of return (ROR) 311

- Profitability index (PI) 312
- Break even point (BEP) 312
- Cut-off point of cost of capital 313
- Return on capital employed (ROCE) 313
- Rate of return (ROR) and ROE 214
- Compound interest 314
- Simple interest 314
- Term loan 315
- Fund provision by D/E ratio 315
- Promoter's contribution 315
- Security margin on term loan 316
- Unsecured loan 316
- Secured loan 316
- Cash credit (on inventory) 316
- Chattel mortgage 317
- Trust receipt loan 317
- Ware house (field) loan 317
- Terminal ware house receipt loan 317
- Compensating balance 317
- Line credit 317
- Revolving credit 317
- Transaction loans 317
- Definitions of some financial terms 318
- Sketch for impingement type separator as per Pastonisi 76

Equation for run-off rate of rainfall 63

Formula for bubble cap plant gas velocity through triangular slot/cap 63

Bernoulli's theorem for determination of pumping head 64

Friction drop calculation using Fanning eqn. 64

Estimation of H. E area/volume of a vessel for similar process as per rule of three 65 Estimation of nozzle sizes of equipment when similar plant's capacity and nozzle size are known 65

Six tenth rule calculation for costing 65

Formula for steam jacket pressure of pipe line when inner pipe material data and working pressure are known 66

Process evaluation of a chem. plant 228

- Preliminary check list 228
- Capacity checks of limiting equipment 288
- Material and Heat balance checks 288
- Utility balance and steam network checks 289
- Cooling water balance and C. T. heat load 289
- Process checks 292
- Design checks 291
- Instrument air and auxiliary air spec. 290
- Basic site data sent to designer as per agreement 338
- Process control system provided 293
- Whether pneumatic, electronic or DCS 296
- Pollution (Water and air) to be tackled and quantified by designer 341
- Waste water treatment scope by designer or client 290 and 293
- CPCB and SPCB pollution (air and water) limits applicable for discharges 290
- Graph for vessel evacuation time 80
- Graph for chimney height 78
- Statutory clearances 290
- Instrumentation and central control room 293
- Plant operating safety 291

R

Rayon 50

- Cotton linters as raw materials 50
- Processes for manufacture 50
- Viscose process 50
- Cellulose acetate process 52
- Cuperammonium process 51
- Cellulose nitrate process 52

Refrigeration 78

- Types of refrigeration process 78
- Vapour compression 78
- Absorption refrigeration 82
- Co-efficient of performances of refrigarants 78
- Types of refrigerant and R no. 78
- Application of refrigerants with temp ranges (see table 120 Vol. IIA) 91
- Alternate refrigerants in place of HFCs and CFCs volumetric refrigent effect 81
- Environmental hazards and TLVs for refrigerants 81
- Units of refrigeration 82
- Heat pump typical output of heat 82
- Physical properties of common refrigerants 85
- Discharge temp. in single stage ammonia compressor 86
- Procedures for measuring refrigeration capacity 9
- Lubricating oils refrigeration
 (DIN 51503) 93
- Properties of lube oils 94
- Sec. cooling liquids as per evaporating temp. (See T-127 Vol. IIA)
- Vap. compression circuit 79

_	Layout of vap. compre	ssion
	refrigeration system	80

- Layout of absorption refrigeration system 83
- Vapour press. temp curves for refrigerants 90
- Power requirement in refri. plant using reciprocating compressor 86
- Power consumption in single stage absorption refri. system for 100,000 Kcal/hr cooling load 87, 88

Refractory bricks 103

- Types 103
- Properties (B. D., Porosity) temp.
 and uses of refractory bricks 106
- Silica bricks 103
- Dolomite bricks 103
- Chromite bricks 104
- Chrome magnesite bricks 104
- Alumino Silicate bricks 104
- Silimanite bricks 104
- Alumina bricks 104
- High Alumina bricks 104
- Magnesite bricks 105
- Fire clay bricks 105
- Mullite bricks 105
- Thermal expn. of refractory bricks 105
- Sizes of refractory bricks 10
- Thermal conductivity of refractory bricks

(see T 106, Vol-II A)

- Green strength 106
- Porosity 106
- Plasticity 106
- Eqn. for modulus of rupture 106
- Mechanical properties of refractory bricks (see T 107, Vol. II A)

Riot chemicals 110

Road Tar 97

Rock wool 187

- Raw materials 188
- Composition of mineral fibres 188
- Chemical analysis of Rock wool and glass wool 188
- Outlines of manufacturing process 188
- Physical properties 189
- Use (insulating material) 187, 189
- Thermal conductivity of mineral wool 187

Rubbers and expanded plastics 177

- Natural Rubber latex 176
- Rubber blends for tyre treads 177
- Glass transition temp, T_g (see T-163, Vol. IIA) 201

S

Semi water gas 148

Solar energy 260

Sound decibel level 303

Sodium Chloride specification (Impurities) 48

SI-Metric units conversion factors 334

Synthetic iron oxide pigments 167

Strongly basic ion exchanger resins 121

Storage temp and R. H in cold storage (see T 129, Vol. II A)

Sugars 225

- Analysis of cane juice 225
- Manufacture of cane sugar 225
- Crushing of cane and extraction of juice 225
- Screening of juice 225
- Removal of suspended matter in juice 225
- Non sugar dispersoids in juice 225
- Clarification processes for raw sugar juice by liming processes 226

- Cold liming 226
- Hot liming 227
- Fractional liming 227
- Fractional liming and double heating process 227
- Carbonation process, single or double after liming 227
- Sulphitation process by SO₂ 228
- Evaporation of clarified juice for crystallization 228
- Separation of crystals by centrifugation and washing 228
- Drying of sugar crystals and direct bagging 228
- By product molasses and use of molasses 228
- Comparison of different clarification processes 228
- Manufacture of beet sugar 229

Sp. heat-true and mean of dry flue gases for hard Bituminous coal 155

Sp. heat –true and mean of dry flue gases for coke oven gas 155

Sp. heat -true and mean of dry flue gases for fuel oil 156

Sp. heat-true and mean of dry flue gases for natural gas 156

Sp. air and fluegas volumes-hard bituminous and soft coals 157

Sizing of vapour-liquid separator 53

T

Tar composition 99

- Coal Tar distillation process 97
- Refined product from tar distillation 10
- Refined products manf. process 101
- Tar distillation plant designers 99
- Pro-abid process 99
- Mazor differences in plants 99

- Coumarene resin recovery 101
- Phenol recovery 102
- Naphthalene recovery 102
- Pure naphthalene by chemical process 102
- Flow sheet for Tar distillation 100
- Pitch types and softening points 97
- Road tar BS standard 97

Town gas or carburated water gas 147

U

Units of hardness in water (see T–96, Vol. II A)

Urea prills spec. as per FPO 1969–70 (see T– 137, Vol. II A)

Usual spec. of urea prills (F–G) (see T–139, Vol. II A)

Urea Tech. grade spec. (IS-1781-71) (see T-138, Vol. II A)

Urea Fertilizer prodn processes 12

V

Valves used in chemical industries 236

- Criteria of selection 236
- ASTM standards for materials 271
- Lubricant for valves used in O₂ service 236
- Vapour-liq separator-typical design as per Pastonisi (Vol. I and II) 53

Vegetable oils 275

- Names of Vegetable oils 275
- Properties of vegetable oils 275
- Oil seeds storage limitation 275
- Manufacturing process of ria bran oil 276
- Crude oil extraction by mech. expellers 275
- Flowsheet for vegetable oil refining 275

- Rice bran oil - solvent extraction 276	 Softening process by clarifloc- culator 116
Rice bran oil detail spec. 281Refining process for crude veg. oils 277	- Removal of iron and manganese salts
Degumming process 278Alkali neutratiosation 278	in water by aeration 116 – Demineralisation by ion exchange methods 118
 Bleaching operation 279 Deodourisation process 279 Hydrogenation of vegetable oils 281 Smoke, flash and fire points of 	 Degasification of water 118 Ion exchange resins exchanger for DM water 118 Water for boiler and other uses 119
veg oils – (see T–154, Vol II A) – Fatty acids conc. in veg oils – (see T–156, vol–II A)	 Selection of cation and anion exchanger resin 119 Debasification resin (H exchanger) 121
 Empirical eqns for physical data – of vegetable oils (see T-155, vol – II A) 	 Dil Acid (HCL) reqd for regeneration (H exchanger) 121 Block diagram for river water
Velocity of heat transfer media (HTM) – (see T–80, Vol – II A)	treatment 133 - Ionic load 124
 Veg. oil specification (see T-158, Vol II A) Flowsheet for solvent extraction 	 Anion exchanger resin (OH resign) 121 Partial diminerallisation of water exchanger 122
process 277 V.P. of paraffinic hydrocarbons 67	 Strongly basic and weekly basic anion exchanger dil. NaOH soln. requirement 139
Water treatment 111	 Total demineralisation with silica removal for DM water for H.P. 122
Impurities in raw water 111pH value 112	 Flowsheet for total demineralisation of water 120
 Alkalinity 112 Titration results table 112 Proforma with units for detail analysis of water 113 	 Neutral exchanger resin (Na exchange) and its regeneration brine solution required quantity 122 Mixed bed exchangers 122
 Permanent and Temporary hardness 114 Water softening 114 Quantity of chemicals reqd. 114 	Condensate polishing 123Zeolite resins 141
 Sedimantation of precipitates on chemical dosing by Ferric–Alum 115 Settling velocity of particles in water 115 	 Desalination of sea water by Reverse osmosis 123 Eqn. for reverse osmosis 123 Water treatment by magnetic filtration 124

- limits for acceptable source of raw water 124
- Settling ponds requirements for river water with high turbidity 114
- EN 29000 std. for safe bottled drinking water
- Arsenic removal process based on As contamination 126
- IS14543–2003 for bottled drinking water specification 125

Water treatment basics 126