Module - 1

1. Introduction

In general, chemical engineers deal with the processes which are defined as the change of state taking place in any system.

When we talk about a chemical processes the most important question are as follows:

1. How a chemical process is going on or going to be carried out?
2. How far a chemical process can be done?
3. How fast a process can be carried out?

1.1. Answer to Question 1-:

A chemical industry includes unit process and unit operations which depend on the nature of a process such as whether the change required is physical or chemical in nature. Chemical changes are followed by unit process and physical changes are followed by unit operations.

1.2. Answer to Question 2-:

How far is concerned with the thermodynamics limitations. It is the ultimate limit of conversion which must be known in order to decide the extent to which a process may be carried out.

Ex. – In case of any chemical reaction the equilibrium conversion must be known which helps in determining the optimum conversion.

1.3. Answer to Question 3-:

It deals with the rate at which a chemical reaction takes place. It is decided from the chemical kinetics. It also determines the completion of a process.

Hence, one should have the knowledge on unit operations, unit processes, thermodynamics and chemical kinetics which helps the better understanding in chemical technology.

1.4. Units Operations

The various unit operations used in chemical industries are classified according to the momentum transport, heat transport and mass transport. Each of the unit operations which are again categorized as follows:

1. *Size reduction:* Jaw crusher, Dodge crusher, Roll crusher, Hammer mill, Cone crusher, Crushing rolls, Ball mills, Rod mills.
2. *Material handling:* Screw conveyer, Belt conveyer, Bucket elevator, Pneumatic conveyer.
3. *Separation processes:* Screening, Elutriation, Jigging, Tabling, Electrostatic separation, Magnetic separation, Froth floatation, Sedimentation, Cyclone separator, Electrostatic precipitator, Bag filter, Filter press, Rotary vacuum filter, Centrifuge, Settling tank, Crystallization tank, Fixed bed, Fluidized bed fluidization, Moving bed pump, Jet ejector, Reciprocating pump, Centrifugal pump, Rotary pump, Solid-liquid separation (Leaching), Liquid-liquid extraction unit, Batch Distillation, Continuous Distillation, Packed type Distillation, Absorption, Adsorption, Stripping, Double pipe heat exchanger, Shell and tube heat exchanger, Re-boiler, Condenser, Jacketed kettles, Direct fired heater, Open pan evaporator, Single effect evaporator, Multiple effect evaporator, Agitation, Solid bonding, Gas holder, Storage tank, Pressurized cylindrical and spherical tank etc.

1.5. Unit processes

The unit processes are Halogenation, Sulphonation and Sulphation, Oxidation, Hydrogenation, Esterification, Hydrolysis, Alkylation, Polymerization, Nitration, Electrolysis, Gasification, Pyrolysis, Etherification, Desulphurization, Cracking, Amination, Calcination, Carbonization, Condensation, Fermentation, Decomposition, Reforming, Reduction etc.

1.5.1. Halogenation

The introduction of one or more halogen groups into an organic compound for making various chlorine, bromine, iodine, fluorine organic derivatives is known as halogenation. Some products produced by halogenation process are HCl, phosgene sulfuric chloride, hypochlorite, bromination, bromine, hydrobromic acid, bromide, bromated, alkaline, hypobromites. Classic

significant chlorinated products are: Ethylene dichloride, chlorinated methanes, Chloroform, Carbon tetra chloride etc.

1.5.2. Sulphonation and Sulphation

The introduction of sulphonic acid group or corresponding salt like sulphonyl halide into a organic compound is called Sulphonation. Various sulphonating agents include sulphur trioxide and compounds, sulphurdixide, sulphoalkylating agents. The introduction of (-OSO2OH or -SO4-) into organic compounds is known as sulphation. The sulphaming agents are sulphamic acid. Typical application of sulphonation and sulphation are production of lingo sulphonates, linear alkyl benzene sulphonate, Toluene sulphonates, phenolic sulphonates, chlorosulphonic acid, sulphamates for production of herbicide, sweetening agent (sidiumcyclohexy sulphamate).Production of saccharin is an example of sulphation process.

1.5.3. Oxidation

Oxidation used extensively in the organic chemical industry for the manufacture of a large number of chemicals. Oxidation using oxygen, are combinations of various reactions like oxidation via dehydrogenation using oxygen, dehydrogenation and the introduction of oxygen and destruction of carbon, partial oxidation, peroxidation, oxidation in presence of strong oxidizing agent like KMnO4, chlorate, dichromate, peroxides H_2O_2, PbO_2, MnO_2; nitric acid and nitrogen tertra oxide, oleum, ozone. Some of the important products of oxidation are aldehyde, ketone, benzyl alcohol, phthalic anhydride, ethylene oxide, vanillin, bezaldehyde, acetic acid, cumene, synthesis gas from hydrocarbon, propylene oxide, benzoic acid, maleic acid, benzaldehyde, phtathalic anhydride. Oxidation maybe carried out either in liquid phase or vapour phase.

1.5.4. Hydrogenation

Hydrogenation involves the reaction of a substance with hydrogen in the presence of a catalyst. Some of the other reactions involving hydrogen are hydrodesulphurisation, hydrcracking, hydroformylation, oxosynthesis, hydroammonylsis, and synthesis of ammonia. One of the important applications is that the oxygen content of biomass pyrolytic oil can be reduced followed by hydrogenation process.

1.5.5. Nitration

Nitration involves the introduction of one or more nitro groups into reacting molecules using various nitrating agents like fuming, concentrated, aqueous nitric acid mixture of nitric acid and sulphuric acid in batch or continuous process. Nitration products find wide application in chemical industry as solvent, dyestuff, pharmaceuticals, explosive, chemical intermediates. Typical products: TNT, Nitrobenzene, m-dinitrobenzene, nitroacetanilide, alpha nitronaphthalene and nitroparaffins.

1.5.6. Hydrolysis

Hydrolysis is used both in inorganic and organic chemical industry. Typical application is in oil and fats industry during soap manufacture where hydrolysis of fats are carried out to obtain fatty acid and glycerol followed by addition of sodium hydroxide to form soap. Other application is in the manufacture of amyl alcohols. Some of the major product using hydrogen is ethylene from acetylene, methanol, propanol, butanol, production of alcohol from olefins (eg. Ethanol from ethylene). Various types of hydrolysis reaction may be pure hydrolysis, hydrolysis with aqueous acid or alkali, dilute or concentrated, alkali fusion, hydrolysis with enzyme and catalyst.

1.5.7. Alkylation

Alkylation involves the introduction of an alkyl radical into an organic compound by substitution or reduction. Products from alkylation find application in detergent, lubricants, high octane gasoline, photographic chemicals, plasticizers, synthetic rubber, chemicals etc. Some of the alkylating agents are olefins, alcohols, alkyl halides. Although sulphuric acid and phosphoric acid were commonly used as catalyst in alkylation process, however due to the corrosive nature of these acid now solid acid catalyst is finding wide application in new alkylation processes.

1.5.8. Polymerization

Polymerization is one of the very important unit processes which find application in manufacture of polymer, synthetic fibre, synthetic rubber, polyurethane, paint and petroleum industry for high octane gasoline. Polymerization maybe carried out either with single monomer or with co-monomer. Polymerization reaction can be addition or condensation reaction. Various

Polymerization methods may be bulk, emulsion, solution, suspension. Typical important product from polymerization are, Polyethyelene, PVC, poly styrene, nylon, polyester, acryic fibre, poly butadiene, poly styrene, phenylic, urea, melamine and alkyd resins epoxy resin, silicon polymers, poly vinyl alcohol etc.

2.1. Role of Chemical industries in daily life

Products	Applications
1. Plastics and Polymers	Agriculture, Water treatment, Packing, Automobiles, Telecommunications, Health and hygiene, Education and Domestic
2. Synthetic Rubber	Transportation, Textile, Industrial equipment
3. Soap and Detergent	Domestic and Industrial use
4. Industrial Chemicals	Pesticides, Explosives, Pharmaceutical, Surface loading, Adhesive, Anti-oxidant, Metal extraction, Ink, Paint and Varnish
5. Sugar and Alcohol	Food, Chemical feed stock for alcohol production, Bio-fuel production.
6. Fertilizer	Agriculture, Chemical Industries
7. Pulp and Paper	Newspaper, Writing paper, Tissue paper, Packaging paper.
8. Agrochemicals	Pesticides and insecticides
9. Mineral acids	Organic and Inorganic industries

3.1. Structure of a Chemical Industry:

If we think about a process industry, it is obvious that the industry must have any final product. However, the final product may be directly used by the consumer or used as a feed stock for production of other products. Hence, the selections of raw materials are very important. The raw materials convert into products followed by different steps. This steps involved during the conversion process is shown in Fig. 1.

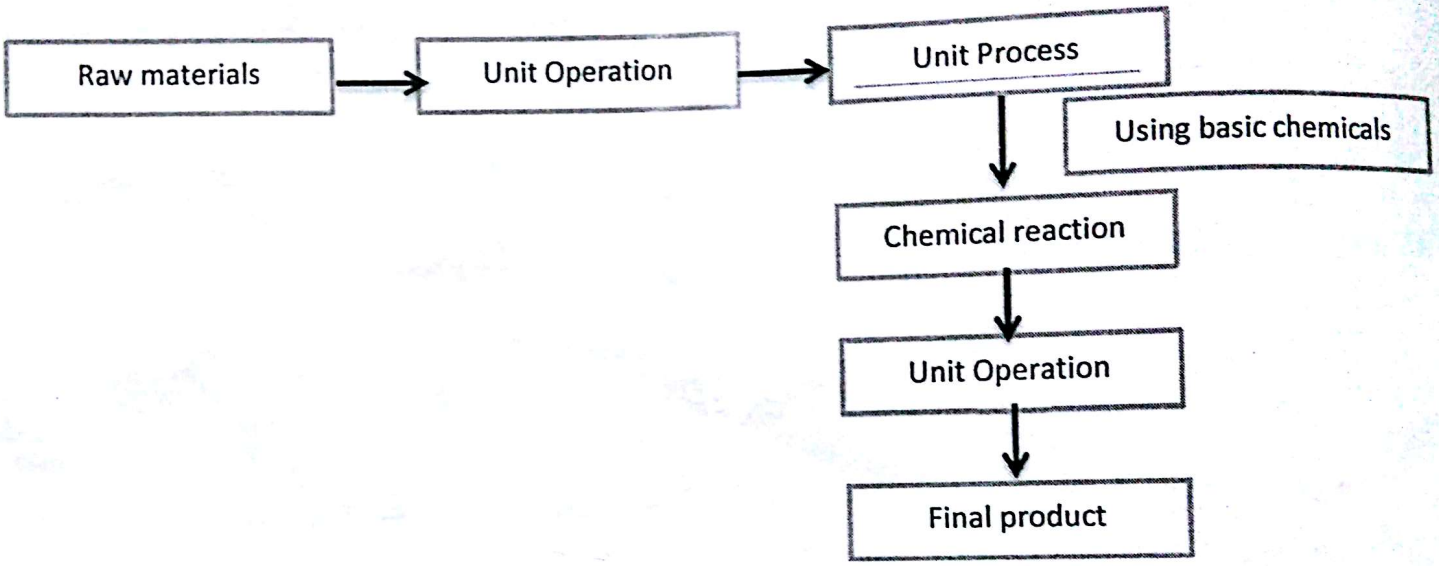


Fig. 1. General Structure of a Chemical Industry

4.1. Global and Indian chemical Industries

Chemicals industries are the one of the largest economy sector in the world. The various chemical industries contribute our economy are as follows:

- Pharmaceutical- 16 %
- Agrochemical- 11 %
- Textile-10 %
- Petrochemical- 39 %
- Performance chemicals- 16 %
- In-organic chemicals- 7 %
- Other chemicals- 1 %

5.1. Driving force for Chemical industries

The key driving force required to run a chemical industry depend on various factors such as Land, Population, Coastal line, Port traffic, Road length, Railway track, Growth of population, and Growth of vehicles etc.

6.1. Types of chemical industries

1. Inorganic industries: Caustic chlorine, Soda ash, Sodium bicarbonate, Carbon black, Titanium oxides, Sulphuric acids and Hydrochloric acid etc.
2. Organic industries: Acetic acid, Acetic anhydride, Aetone, Phenol, Methanol, Formaldehyde, Nitro-benzene, Aneline, Chloro-methane, Acetaldehyde, Ethanol and Amines.
3. Petrochemicals: Olephins, Aromatics such as Benzene, Tolune, Xylene, Propylene, Caprolactum, Adipic acid, Hexamethylene and Diamine etc.
4. Fertilizer: N, P, K
5. Special chemical industries: Paint and varnish, Textile chemicals, Dyestuffs, Catalyst, Plastics additives, Adhesive and other industrial gases.
6. Pharmaceutical, biotechnological and agrochemicals.

7.1. Contribution of chemical industry towards the GDP (Gross Domestic Product)

Indian chemical industries contribute 3 % of our GDP.

1. Agricultural - 25 %
2. Industry – 24 %
3. Service – 51 %

7.1.1. Indian Chemical Industries and their market value

Type 1:- Basic Chemicals; contribution: 49.05 %; Market value: 32.78 USD

It includes inorganic industries, organic industries, petrochemical industries, fertilizer industries.

Inorganic industries- Caustic Chlorine, Soda ash, Sodium bicarbonate, Carbon black, Titanium Oxide, Sulphuric acid, Fuel and industrial gases,

Type 2:- Special Chemicals; contribution: 24.69 %; Market value: 16.50 USD

Type 3: - Knowledge Chemicals; contribution: 26.6 %; Market value: 17.55 USD

8.1. Weakness of Indian Chemical Industries

- The major weakness of Indian chemical industries which reduces increases the cost of production as well as the energy requirements are follows:
- Use of older units
- High cost structure
- High raw materials cost
- Long gestation period
- Integration and infrastructures inadequacies
- Low process development
- Low investment in R & D

9.1. Issues in Indian Chemical Industries

These are some typical issues that should be minimized in the chemical industries to increase the efficiency, production of good quality of products.

- Reduce emissions from industries
- Waste minimization and reduce waste
- Treatment of waste water and save water
- Minimization of waste water
- Increase the out puts
- Meet the new product specifications
- Reduce the operating cost
- Improve the efficiency of the industry
- Introduction of new plant
- Improve utility systems

- Save energy and process integration

10.1. Feed stocks for chemical industries

- Gaseous: Natural gas, Refinary gas, Methane produced from coal
- Liquid: Naptha, Solvents and other distilled products
- Solid: Coal, Coke, Wax, Petroleum residues
- Biomass: Agricultural waste and Algae

10.1.1 Ethanol

There are three types of feed stocks for ethanol production

Sugars: Molasses, cane sugar, beat sweet sorghum and fruits

Starches: Corn, wheat, rice, potatoes, cassava and sweet potatoes etc.

Ligno-cellulosic: Straw, bagasse, other agricultural residues, wood, energy crops

Algae: Ethanol production

10.1.2. Ethanol from Algae

Direct to Ethanol technology, a novel technology used to produce ethanol by photosynthesis from CO_2, H_2O and sunlight instead of producing carbohydrates

10.1.3. Coal

Coal is another promising feed stock as huge amount of coal reserves is available in India and other part of the world. Based on the production of coal gasification unit it will be possible to produce large number of chemicals. Possibility Coal as a source of petrochemicals, which again explored all over the world. Coal was the original feed stock for production of large number of chemicals through coke oven plants, synthesis gas from gasification, acetylene from calcium carbide route. However, due to availability of petroleum based raw material presently more than 90% of chemicals are produce from petroleum and natural gas. Due to volatile market of crude oil and dwindling petroleum resources, coal is emerging as alternative feedstock for

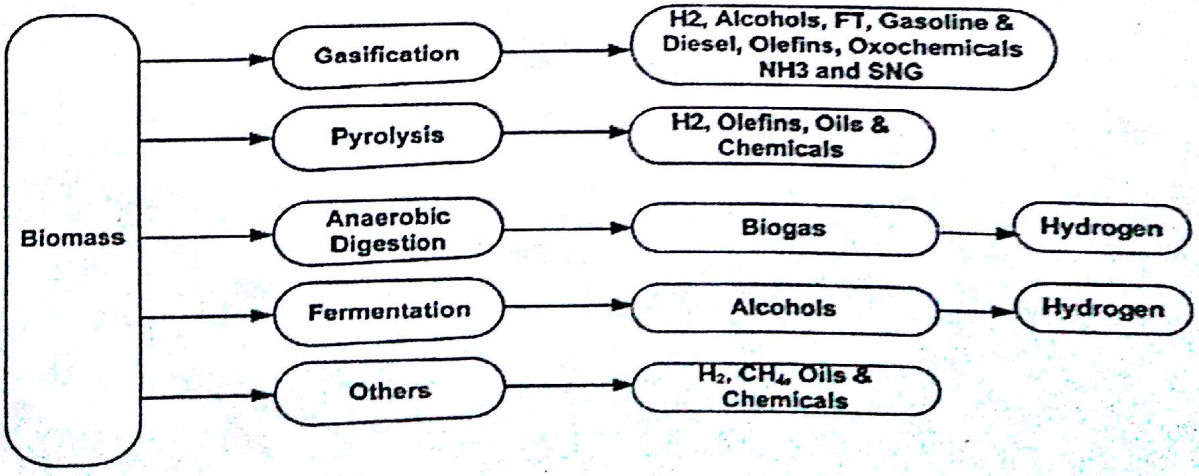
chemical industry as huge coal reserves are available all over the world. Various routes for utilization of coal as chemical feedstock and fuel are: Gasification, Coal to fuel through FT process, Coal to methanol technology, Liquid phase Methanol process from coal (LPMEOHTM), Methane to MTO plus Olefin cracking process (OCP), Coal to Olefin technology and Coal to Plastic technology.

10.1.4. Petrocoke

Due to the use of heavy crude oil, huge amount of petrocoke is being produce from the thermal cracking process in the refinery. Although petrocoke is being used as fuel in cement industry however it can be a promising raw material for production of synthesis gas, hydrogen, methanol through petrocoke gasification. Through FT synthesis the synthesis gas can be converted to fuel also. Utilization of petrocoke offers an alternative to handle high sulfur and metal containing residues in a refinery with value addition. Reliance is already in process of implementing petrocoke gasification to utilize its petrocoke.

10.1.5. Biomass

Biomass can be also used a feedstock for methanol production and hydrogen through synthesis gas produced from biomass gasifiers. Biomass resources like crop residues, forage, grass, crops, wood residues, forest residues, short rotation energy crops and cellulosic components of municipal solid waste can be used as alternative feedstock for production of synthesis gas, ethanol, and naphtha through FT process. Alternative energy resources will play a growing role and biofuels mainly ethanol are expected.



11.1. Basic Principles of a Chemical Process

All the chemical processes are interrelated. At the initial stage the raw materials are fed to the reaction zone where the product formed in presence of various catalysts. The reaction conditions are maintained to carry out the chemical reactions. Later the product is separated from the reaction zone and purified to get the final product.

- Transfer of reactants into the reaction zone
- Chemical reactions involving various unit operations
- Separation of products from the reaction zone using various unit operations.
- The chemical process may be homogeneous of heterogeneous
- The reaction condition may be endothermic of exothermic
- The can be performed in presence of absence of catalyst
- The reaction may be reversible or irreversible in nature

12.1. Factor affecting to proceed a chemical reaction

- Temperature
- Pressure
- Composition of feed
- Type and amount of catalyst
- Stability and activity of catalyst
- Batch or continuous process of operation
- Mass transfer and heat transfer effect
- Size of feed material used

13.1. Basic need that determines the conversion, yield and kinetics

- Material and energy balance
- Raw material and its energy consumption per ton of product
- Batch of continuous process
- Chemical process selection which includes design and operation, plant data, equipment requirement and materials consumption
- Chemical process control and instrumentation

- Economy of the chemical process
- Material and energy cost
- Labor cost
- Overall cost of production
- Market evaluation: purity of product and uniformity of product
- Plant location
- Environmental, health, safety and hazards
- Construction, erection and commissioning
- Management for productivity and activity
- Research and developments and process intensification

14.1. Design and Development aspects to enhance the production

- Distillation, Azeotropic, extractive distillation, reactive distillation, membrane distillation
- Random packing to Structured Packing
- Single and two pass to Multiple down comer
- Rasching rings and berl saddles to Intalox sadles, pall rings, nutter rings, half rings, super rings
- Pan park to Wire gauge packing, Goodloe, Mellpark, Flexipack, Gempack, Intalox
- Fixed bed to Fluidised bed reactor
- Conventional reactor to Micro reactor
- Ball mill grinding to Vertical roller mill and press roll Mill
- Open circuit grinding to Closed circuit grinding
- Batch digester to continuous digester
- Low speed and low capacity cipper to High speed chipper and high capacity chipper
- Low speed Paper machine to high speed machine
- Drum displacer, Pressure diffuser, Displacement presses, Combined deknotting and Fine
- screening,
- High temperature screening before washing, Reverse cleaners
- Adsorption(Olex, Parex and Molex), Crystallisation and Membrane separation processes
- Solvent extraction processes and New solvents
- Conventional distillation Short path distillation, divided wall column

- Conventional bubble cap, sieve plate to valve tray
- Random packing to structured packing
- Axial flow reactor to radial flow reactor
- Conventional instrumentation to smart (intelligent) instrumentation

15.1. Equipment and their applications

a) Size reduction:

i. Jaw crusher:

Crushing is accomplished when the moveable jaw moves towards the fixed jaw. Used for crushing hard materials like lime stone and bricks.

ii. Dodge crusher: Produced more closely products. Used for crushing hard materials

iii. Roll crusher: Crushing is accomplished by pressure of teeth against the large lumps of the materials. Used for crushing soft materials like coal, gypsum and ice etc.

iv. Hammer mill: Crushing is accomplished by hammering the material against the breaks plane. Used for crushing soft materials such as coal and fibrous materials.

v. Cone crusher: Crushing is accomplished between two cones; the inner cone is rotating while the outer cone is stationary. Used for crushing coarse size hard feed materials.

vi. Crushing rolls: Crushing is done between two heavy cylinders revolving towards each other. Used for crushing coarse size hard materials.

vii. Ball mill and Rod mill: Size reduction is achieved by the impact of balls and Rods respectively. Used for the production of fine sized particles.

b) Solid handling:

i. Screw conveyer: Handling is affected by screw action which is operated under pressure. It is used to handle powder and sticky materials. Also materials like grains crushed coal and sand.

ii. Belt conveyer: Belt may be of steel, canvass or rubber and used to handle large volume over long distance economically.

iii. Bucket elevator: Used when the direction of travel is vertical and used for lifting grains, ashes, powdered or granular materials.

iii. Pneumatic conveyer: An airstream is used to affect the conveying. It is used for handling cement, powdered chemical and come etc.

c) Separation process:

Solid-Solid Separation:

i. Screening: Screens are made up of steel wire or platstics and used to separate particles of different sizes.

ii. Elutriation: The separation is accomplished by passing fluid counter currently to the feed materials and used to separate fine particles from the coarse particles.

iii. Jigging: Separation is followed by the terminal velocity and where the settling time is very small. It is used to separate lighter gangues from heavy minerals also the materials of different densities separated.

iv. Tabling: In this case separation is carried out by passing a dilute pulp over a table inclined from the horizontal direction. This is used to separate more dense gold from dense rock.

v. Electrostatic Separation: Different behavior of electricity is the cause of separation whichis used to separate the small particle of different solids when placed in a electric field.

vi. Magnetic separation: This is used to remove the iron pieces from the feed materials after grinding.

vii. Froth flotation: Separation is performed when the material is suspended in water in presence of a floating agent and bubbling with air. The froth is formed on the surface of water containing the desired materials.

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Fluid-solid separation:

Sedimentation: This is also known as thickener. This is a gravity separation process. Used to separate sludge and supernatant liquid from dilute slurry.

Cyclone separator: Separation is accomplished by introducing the stream tangentially providing suspend solid a spinning motion in the cylinder. The separation is achieved by centrifugal force. It is used to separate course size solid particles more efficiently and liquid droplets from the gases.

Electrostatic precipitator: Separation is accomplished by passing the gas between two electrodes which attracts the entrained particles. Mostly used to separate entrained solid or liquid particles from gases.

Bag filters: The separation is done by passing the gas stream passing through a battery of bags mounted in groups on the independent frames. Used to separate solid particles of gas such as air conditioning.

Filter press:

Follow the book (Dryden's Outlines of Chemical Technology) to know the details about process diagrams and their applications.

**********End Module 1**********