Lecture 1

The chemical process industry

The chemical process industry plays a central role in the transformation of raw materials into valuable commercial products through a combination of chemical reactions and physical operations. It serves as the backbone of numerous sectors including petrochemicals, pharmaceuticals, fertilizers, food processing, and consumer goods.

The core objective of chemical processing is to convert inexpensive, abundant feedstock such as air, water, petroleum, natural gas, and minerals—into end products that are chemically and economically viable. This transformation involves multiple stages such as raw material preparation, reaction, separation, purification, product formulation, and waste management.

Modern chemical processes are influenced not only by chemistry and engineering principles, but also by environmental regulations, energy economics, raw material availability, and market demands.

With its crucial roles, the chemical industry is one of the biggest sectors globally. The profit of this sector in 2022 reached USD 5.72 trillion, with the pharmaceutical industry as the segment with the most sales value.

The profits were getting higher despite overcoming the pandemic in 2020–2022. This reveals that the chemical industry keeps revolving and relevant to humans' daily needs.

Then, why is the chemical industry important for daily life? When you wake up in the morning, almost all products you use, such as body wash, detergent, toothbrushes, plates, and so on are made from complex chemical processes.

Not only that, but the chemical industry also contributes to the technology and health development with innovations on medicines as well as medical tools beneficial for human beings.

This industry also contributes to the country's Gross Domestic Product (GDP) by providing job openings, encouraging innovations, and fulfilling society's needs.

Several key factors significantly affect chemical processes and must be considered during process design and operation. These include:

1. Yield vs Conversion

- **Conversion** is how much of the reactant is changed in a single pass.
- **Yield** is how much of the raw material ends up as the desired product.
- Often, conversion < yield because unreacted material may be recycled.
- Small improvements in yield can have large economic benefits, since raw materials are often the largest cost.

2. Equilibrium and Reaction Conditions

- Some reactions are limited by chemical equilibrium; you can't convert everything in one pass if equilibrium is unfavourable
- To shift equilibrium, you can adjust **temperature**, **pressure**, or **use excess reactant** or **remove product**. But each change often carries cost or engineering challenges.

3. Kinetics / Reaction Rate

- How fast the reaction proceeds is critical for determining reactor size, cost, and whether a process is feasible.
- Catalysts play a big role in speeding up reactions without changing equilibrium, so that equipment can be smaller or residence times lower.

4. Batch vs. Continuous Processing

Batch processes: good for small-scale, variable products, flexible, easier to start, less investment in instrumentation.

- Continuous processes: more efficient per unit production, more uniform product quality, less material in process at any time, but require more precise instrumentation and control.

5. Materials of Construction and Corrosion

Choosing materials that resist corrosion or erosion is essential, because chemical plants often handle reactive, acidic, basic, or oxidizing agents

- Impurities in raw materials (even trace amounts) can dramatically affect corrosion. Tested materials under real industrial conditions are better than testing with pure lab chemicals.

6. Control, Instrumentation, Process Monitoring

- Instruments are needed to **measure**, **control**, **record**, and **optimize** process variables (temperature, pressure, composition, flows, etc.).
- Good instrumentation allows uniform conditions which improve product quality and safety. Batch processes tend to need more human supervision; continuous processes benefit more from automated controls.

7. Economic Factors

- Raw material costs are usually the largest single cost in chemical manufacturing. Improving yield (thus reducing waste) can greatly improve profitability.
- Energy costs: many chemical processes are energy-intensive. Changes in energy prices can make or break the viability of a process. Shreve emphasizes energy efficiency and possibilities of redesign to minimize energy consumption.

8. Safety, Hazards, Environmental, Legal Constraints

Handling of toxic, flammable, or otherwise hazardous materials demands safety considerations in design (e.g. fire prevention, ventilation, personal protection). Environmental constraints: waste treatment, emissions control, water conditioning, disposal of by-products, legal regulations which may shape how a plant operates.

9. Scale and Plant Layout

- Larger scale often has economies of scale: unit costs typically reduce as production scale increases. However, scaling up introduces technical and financial risk.
- Plant layout, segregation of units (for safety, or to limit cross-contamination), material flows, logistics (raw materials in, product out), utilities, etc., are all significant.

10. Labour, Operation, and Maintenance

Skilled labourA is essential. Even with automation, human oversight, maintenance, troubleshooting, and process optimization rely heavily on experienced operators and engineers.

- Maintenance of equipment, including preventing corrosion, ensuring safe operation, and avoiding breakdowns, is crucial for reliability and cost control.

11. Reactant Purity, Impurities, and Raw Material Properties

- Purity of reactants affects reaction rates, catalyst life, product quality, corrosion, etc. Impurities may be harmful, cause side-reactions or require extra purification.
- Physical properties (phase, particle size, reactivity) are important. For example, solid reactants or heterogeneous catalysts: surface area matters.

In general, the chemical industry produces three types of products, which are basic chemicals, special chemicals, and consumer chemicals. Here are the complete explanations:

1. Basic Chemicals

Basic chemicals are divided into petrochemical products (from petroleum, natural gas, and coals), polymers, and basic inorganic materials. Basic chemicals are typically sold to chemical industries and other industries as raw materials. The example of basic chemicals is polymers, caustic soda, nitric acid, chlorine, and many more. Generally, basic chemical products like petrochemicals are produced with special technology that alters hydrocarbons into basic chemicals.

2. Special Chemicals

Special chemicals are usually used to produce paints, inks, dyes, and agricultural materials. That's why they are widely distributed to the textile, engineering, and paper industries for further manufacturing. Special chemicals are frequently developed to offer maximal function and benefits. It can be seen from how wall paints are developed from organic solvent-based to water-based paint.

3. Consumer Chemicals

The chemical industry also manufactures products that are directly sold to consumers, such as soaps and cleaning fluids. The products are also developed to meet various needs, such as plant-based soap, soap for sensitive skin, and many more. Aside from these three, the chemical industry makes fine and bulk chemicals for industry. Bulk or commodity chemicals are big-scaled products for global markets, such as polymers and fertilizers.

Moreover, fine chemicals are materials with a high degree of purity that are only made in limited amounts by conforming to preset requirements. An example of a fine chemical is glutaric anhydride.

Types of the Chemical Industries

Now, you already figured out the products from the chemical industry. From the materials above, there are also types of chemical industries with their respective specializations, including:

1. Pharmaceutical Industry

The first type is the pharmaceutical industry. It works to develop and produce medicines. The workers study, produce, develop, and sell various drugs, such as antivirals, antibiotics, and many more.

2. Food and Beverages Industry

The chemical industry does not only produce chemicals and synthetic materials but also the food and beverages industry. It manufactures foods and preserves. In a food and beverage product, you may find additional materials, such as food preservation, sweeteners, emulsifiers, and dye. These ingredients must be tested before they are allowed to be added to food.

3. Detergent and Soap Industry

This industry makes cleaning products, such as soap and detergents. Cleaning products also undergo development to match the community's needs, such as being able to clean hard stains, having a certain fragrance, being safe for sensitive skin, and so on.

4. Paper Industry

The paper industry transforms wood into thin layers of sheets that are functional for humans. To make papers, the wood must be extracted and combined with other chemicals.

5. Cosmetic Industry

The cosmetic industry produces beauty and body care products, such as makeup, moisturizers, anti-aging creams, and many more. Because the products are directly applied to the skin, they must be tested strictly.

6. Coating and Paint Industry

This industry works on producing coatings and paints for construction, such as wall paints, iron coatings, wood coatings, and so on. Similar to other chemical industries, the coating and paint industry undergoes development to match consumer's needs.

7. Textile Industry

The textile industry manufactures textile products, such as cloths and attires. The manufacturing process includes printing, dipping the fabric in dye, and mixing it with other chemicals, such as waterproofing agents.

8. Petrochemical Industry

This industry is one of the important sectors of the global market because it transforms petroleum and natural gas into basic chemicals. The petroleum and natural gas will be manufactured into olefin, aromatic, propylene, and many more to be distributed to other chemical industries, such as plastics and synthetic fibers.