

Lecture 2

Physical processes used in chemical industries

Every industrial chemical process relies on two core components: unit operations (physical treatments) and unit processes (chemical transformations) to economically convert raw materials into desired products. Raw materials first undergo physical steps to make them suitable for chemical reactions, which is why understanding unit operations like mixing, heat transfer, and fluid flow is essential. Unit operations are based on fundamental physical and physicochemical principles, and involve the design, materials, and functioning of various types of equipment. These operations include processes such as heating, cooling, drying, distillation, crystallization, filtration, extraction, and separation, with key calculations involving mass flow, heat transfer, force, and energy requirements.

Unit operation

A unit operation is any part of potentially multiple-step procedure that can be considered to have a single function. It is a necessary step in a procedure. Unit operations engage bringing a physical change these as separation, crystallization, evaporation, and filtration and so on. For instance, in milk processing: homogenisation, pasteurisation, chilling, and packaging are entity unit operations that are connected to create the overall process. A process may have many unit operations to obtain the desired product.

After preparing raw substances via physical treatment, such undergo chemical conversion in a reactor. To perform chemical conversion basic knowledge of stoichiometry, reaction kinetics, thermodynamics, chemical equilibrium, energy balance and mass balance is necessary.

Designing a chemical reactor involves evaluating multiple alternatives. While one option may have a lower reactor cost, it could lead to higher downstream separation and purification costs. Therefore, overall process economics are crucial in selecting the most efficient design. Every chemical process is a series of systematically arranged physical and chemical steps, developed through the

combined expertise of engineers, chemists, technologists, and economists. These steps often share common scientific principles—for example, heat transfer plays a key role in operations like evaporation, drying, and crystallization.

A process designer designs a chemical procedure depend on the subsequent:

- (1) Efficiency of procedure and equipments
- (2) Safety by respect to the procedure, raw chemicals, finished products and long term consequence on environment
- (3) Financial viability of the products as demanded through the purchaser.

The subsequent are several instances of physical processes:

(a) Sugar Manufacture:

Sugar cane → crushing → sugar extraction → thickening of syrup → evaporation of water → sugar crystallization → filtration → drying → screening → packaging.

(b) Pharmaceutical Manufacture:

Formulation of chemicals, mixing, granulation → drying of granules → screening → pressing tablet → packaging.

(c) Salt Manufacture:

Brine transportation → evaporation → crystallization → drying → screening → conveying → packaging.

Unit process

A unit procedure is a step in manufacturing in which chemical reaction takes place, for example the oxidation of para xylene to terephthalic acid is a unit process, and the hydrogenation of vegetable oil to ghee is a unit process. Others include, nitration, sulphonation, hydroformylation e.t.c.

Unit operations and unit processing form the main principles of all kinds of chemical industries and are the foundation of designs of chemical plants, factories, and equipment used.

Industrial processes

Large processes are broken into unit operations in order to make them easier to analyse. The key thing to remember about them is that the conservation laws apply not only to the process as a whole but also to each individual unit operation. Examples of such processes are discussed below.

Mixing

Mixing can be termed as the preparation of mixture of substances either in solids, liquids, or gaseous form. It is an essential part of most production processes in chemical and allied industries covering all processing stages from the preparation of reagents to the final blending of products. The equipment used depends on the nature of the materials and the degree of mixing required. Mixing process can be considered under three stages.

(a) **Gas Mixing:** Specialized equipment is seldom needed for mixing gases, which mix easily because of their low viscosities. The mixing given by turbulent flow in a length of pipe is usually sufficient for most purposes. Turbulent promoters, such as orifices or baffles can be used to increase the rate of mixing. In most cases, in-line mixers are always used.

b) **Liquid Mixing:** The following factors must be taken into account when choosing equipment for mixing liquids:

- (i) Batch or continuous operation.
- (ii) Nature of the process whether is miscible or immiscible liquids or dispersion liquid.
- (iii) Degree of mixing required.
- (iv) Physical properties of the liquid, particularly the viscosity.
- (v) Whether the mixing is associated with other operations such as reaction, heat transfer and so on.

(c) **Solids and Pastes:** Mixing of solid is carried out by using various types of highly specialized equipment. Such equipment include cone blenders which are used for free flowing solids, ribbon blender for dry solid and for

blending liquids with solid while Z-blade mixers and pan mixers are used for kneading heavy pastes and dough.

Agitation

Agitation refers to the induced motion of a material in a specified way, usually in a circulatory pattern inside some sort of container. Agitation involves both homogeneous and heterogeneous phases while mixing is used for heterogeneous phase. For example, water in a cup can be agitated but cannot be referred to as mixed. Thus, agitation isn't the same as mixing.

Separation processes

There are different types of separation processes. These include: distillation, extraction, absorption, membrane filtration, and so on. Each of these can also be used for purification, to varying degrees.

(a) Separation by Flashing

A mixture of two liquids—or a liquid and its vapour—can be separated using a flash drum operated at a set temperature and pressure. The mixture reaches equilibrium inside the drum, where vapour exits from the top and liquid from the bottom, partially separating the components. This method is effective when the temperature is between the boiling points of the components at the given pressure. The degree of separation depends on the mixture composition, component concentrations, and the operating conditions. Useful data like vapour pressures or fugacity values help determine optimal settings. Since the vapour phase contains more of the lower-boiling component, partial boiling enables separation based on volatility differences.

(b) Distillation

Distillation is the most common separation method in the chemical industry, used to separate liquid mixtures based on differences in boiling points. It operates through multiple equilibrium stages where vapor and liquid phases contact each other, allowing volatile components to concentrate in the vapor phase and less volatile ones in the liquid.

A distillation column consists of several trays or stages, with liquid flowing downward and vapour rising upward. The feed can enter as liquid, vapour, or a mixture, and products can be withdrawn from the top (distillate) and bottom (bottoms), with possible side draws. The column is divided into two sections: the rectification section above the feed, where vapour is enriched by reflux, and the stripping section below, where less volatile components are removed.

Heat is supplied at the bottom by a reboiler to generate vapour, while a condenser at the top cools vapour back to liquid, part of which returns as reflux to improve separation. The operation is controlled by adjusting feed, reflux, boil-up rates, and product withdrawals.

Distillation effectively separates mixtures but has limitations with azeotropes, where vapour and liquid compositions are identical, requiring additional techniques for further separation. Examples include petroleum refining—separating crude oil into fractions—and alcohol production, enriching ethanol content.

(c) Gravitational Separation

Gravitational separation relies on density differences between substances. In a mixture of immiscible liquids, the less dense liquid floats, while the denser one settles and can be drained from the bottom. This method also works for separating insoluble solids from liquids. However, it is only effective when the components do not dissolve in each other.

(d) Extraction

Extraction is a separation method that uses differences in solubility to move a substance from one liquid to another. For example, caffeine is extracted from tea or coffee using a solvent in which caffeine is more soluble. Then, by adjusting temperature and adding water, the caffeine transfers into the water phase. Extraction is also used for purification, where a pollutant is removed by contacting it with a clean solvent. A common type is acid-base extraction, where pH is adjusted to shift compounds between polar and non-polar solvents based on their ionization state.

(e) Membrane Filtration

Membranes are barriers that allow some substances to pass more easily than others. They typically separate based on molecular size or diffusivity. For example, a vacuum cleaner filter traps dust but lets air pass—similar to large-scale baghouse filters used in pollution control. Some advanced membranes separate hydrogen from gas mixtures using tiny pores, allowing only small molecules through. Others work by diffusivity, letting one substance (like water) pass faster than another (like ethanol), enabling separation or enrichment.

Purification methods

To bring a product to market, proper purification is essential to ensure safety, effectiveness, and accuracy. Without it, products may cause harm or lead to invalid results. Common separation methods, along with other purification techniques, are used to achieve the required purity.

(a) Adsorption

Adsorption is a surface-based separation process where components adhere to a solid material, unlike absorption, which involves volume uptake. In an adsorption column, a fluid passes through a packed material that captures contaminants on its surface, effectively purifying the fluid. However, the adsorbent has a saturation point—once reached, it can no longer remove impurities and must be replaced to continue the process.

(b) Re-Crystallization

Recrystallization is a purification method that relies on changes in solubility with temperature. An impure compound is first dissolved in a hot solvent, then slowly cooled. As temperature drops, the main compound crystallizes out first—leaving most impurities in the solution. This works best when cooling is done gradually. Although time-consuming, recrystallization is often one of the most effective methods for obtaining pure solids.