Unit Operations in Chemical Industries

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Unit Operations in Chemical Industries

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ABSTRACT
The unit operation like distillation, absorption, evaporation, filtration, drying, etc. are most important factors. Distillation is a purification method for liquids and can separate components of a mixture if they have significantly different boiling points. Absorption is a physical or chemical phenomenon. Evaporation can be defined as the process where liquid is transformed into a gaseous state. Evaporation can occur only when water is available. Drying is an important unit operation in a type of chemical process industries (CPI) sectors. Food, pharmaceuticals, chemicals, plastics, timber, paper and other industries use drying equipment to eliminate moisture during product processing.

Keywords: *Distillation, Absorption, Evaporation, Filtration, Drying*

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INTRODUCTION
Unit operations gives idea about science related to specific physical operation different equipment-its design, material of construction and operation and calculation of various physical parameters (mass flow, heat flow, mass balance, power and force, etc.). The main unit operation is discussed below.

DISTILLATION
Distillation is a purification method for liquids and can separate components of a mixture if they have significantly different boiling points. In a distillation, a liquid is boiled in the distilling flask then the vapors travel to another section of the apparatus where they come into contact with a cool surface. The vapors condense on this cool surface and the condensed liquid drips into a reservoir separated from the original liquid. In the simplest terms, a distillation involves boiling a liquid, then condensing the gas and collecting the liquid elsewhere.

Types of Distillation
Simple Distillation
Simple distillation may be used when the boiling points of two liquids are significantly different from each other or to separate liquids from solids or non-volatile components. In distillation, the mixture is heated to change the volatile compounds from liquid material to vapors. The vapor rises and passes into a condenser. Usually, the condenser is cooled to promote condensation of the vapor, which is collected.

Steam Distillation
Steam distillation is used for temperature sensitive materials. It is popular for laboratory method for purification of

organic compounds but has become less common due to the proliferation of vacuum distillation. Steam distillation is important in certain industrial sectors.

Fractional Distillation

Fractional distillation is used for the boiling points of the components of a mixture are close to each other as determined using Raoult's law. A fractionating column is used to discrete the components used a sequence of distillations called rectification. In fractional distillation mixture is heated, vapor rises and enters the fractionating column. Then vapor cools and condenses on the packing material of the column. The heat of rising vapor causes this liquid to vaporize again, moving it along the column and yielding a higher purity sample of the more volatile component of the mixture.

Vacuum Distillation

Vacuum distillation is used for separate that components which have high boiling points. Lowering the pressure of the apparatus also lowers boiling points. Vacuum distillation is used for normal boiling point exceeds decomposition temperature of a compound.

Batch Distillation

Batch distillation refers to the use of distillation in batches. A mixture is distilled to separate it into its component fractions before the distillation still is again charged with more mixture and the process is repeated described in Figure 1. Batch distillation is versatile and commonly employed for producing biochemical, biomedical and/or pharmaceutical products, in which the production amounts are small but a very high purity and an ultra-clean product is needed.

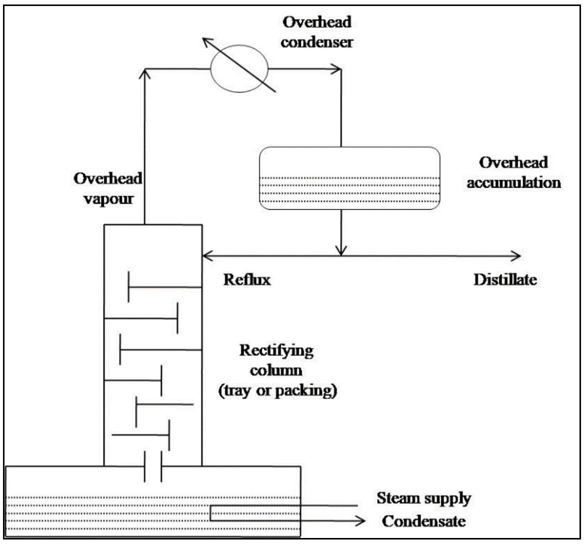

Fig. 1. *Batch distillation.*

Separation of Azeotropes

Separation of azeotropic mixtures is a topic of industrial interest. Most liquid mixtures of organic components form no ideal systems. The presence of some specific groups, particularly polar groups (oxygen, nitrogen, chlorine and fluorine) often results in the formation of azeotropes. Azeotropic mixtures are effectively separated by distillation with the adding a liquid material to the system. In chemistry, azeotropic distillation any of a range of techniques used to break an azeotrope in distillation. An azeotrope mixture of two or more liquids whose proportions cannot be changed by simple distillation.

Plate Columns and Packed Columns

A plate column is chemical equipment used to carry out unit operations where it is necessary to transfer mass between a liquid phase and a gas phase. It is a gas-liquid contactor. The individuality of this gas-liquid contactor is that the gas comes in contact with liquid through different stages. Plate towers consist of a vertical column with flowing liquid from the top and out the bottom. Inside of the column are trays or plates. Trays are force the liquid to flow back and forth horizontally while the vapor bubbles up through holes in the trays. The purpose of these trays is to increase the amount of contact area between the liquid and vapor phases. Applications of plate columns are for the distillation, gas-liquid absorption and liquid-liquid extraction. Vapor phase enters to the bottom of the column and exits to the top. Packed bed columns are mostly employed for absorption, desorption, rectification and direct heat transfer processes in chemical and food industry.

ABSORPTION

In absorption, there is transfer of one or more species from the gas phase to the liquid solvent. It is a physical or chemical phenomenon. It is process in which atoms, molecules or ions enter some bulk phase that is liquid or solid material. The species transferred to the liquid phase are known as solutes or absorbate. Absorption involves no change in the chemical species present in the system. Absorbers are normally used with strippers to permit regeneration and recycling of the absorbent.

Equipment of Absorption

Gas absorption is most commonly practiced in packed towers at industrial purpose. Packed tower is basically a piece of pipe set. On its end and filled with inert material or tower packing. Liquid poured into the top of the tower and trickles down through the packing. Gas is pumped into the bottom of the tower flows and moving counter currently upward. The contact between gas and liquid achieved in this way effects the gas absorption. Analyzing a packed tower involves both mass transfer and fluid mechanics.

Packed Columns

A packed bed column is a chemical processing consisting of a hollow tube, pipe or other vessel that is filled with a packing material shown in Figure 2. The packing can be randomly filled with small objects and it can be specifically designed structured packing. Packed bed columns are largely employed for absorption, desorption, rectification and direct heat transfer processes. In chemical and food industry, environmental protection and also processes in thermal power stations like water purification, heat utilization and SO_2 removal. Their usage also for direct heat transfer between gas and liquid, increase their importance.

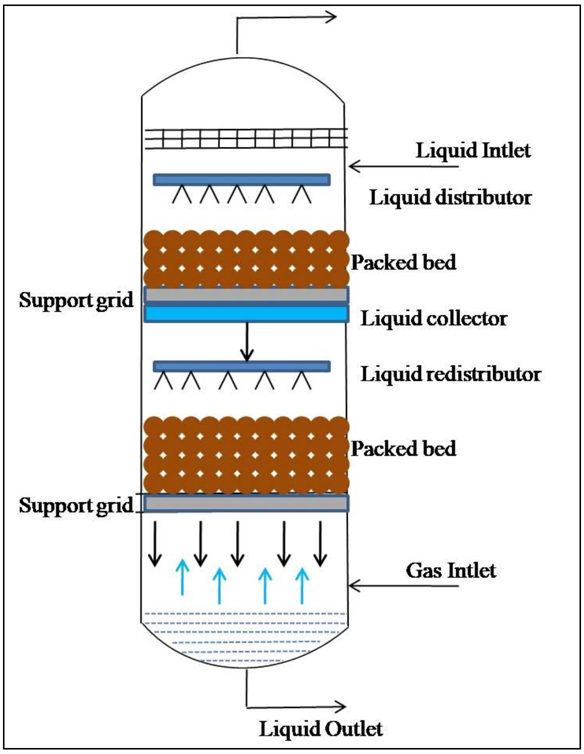

Fig. 2. *Packed column.*

Spray Columns

A Spray Column is a gas-liquid contactor used to achieve mass transfer between a continuous gas phase and a dispersed liquid phase shown in Figure 3. It consists of an empty cylindrical vessel made of steel/plastic and nozzles that spray liquid into the vessel. The inlet gas stream usually enters at the bottom of the tower and moves upward, while the liquid is sprayed downward from one or more levels. This flow of inlet gas and liquid in opposite directions is called counter current flow. Theoretically, the smaller the droplets formed, the higher the collection efficiency achieved but the liquid droplets must be large enough not to be carried out of the scrubber by the scrubbed outlet gas stream. To maintain low gas velocities, spray towers must be larger than other scrubbers that handle similar gas-stream flow rates [1].

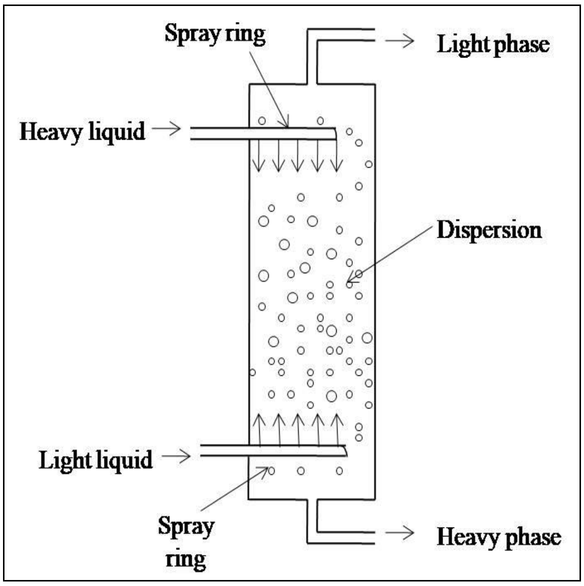

Fig. 3. *Spray column.*

Bubble Columns

Bubble columns are multiphase reactors where the gas phase is dispersed into a continuous phase in the form of a non-coalescence-induced bubble or of coalescence-induced structures. In particular, two-phase bubble columns are widely used in petrochemical, biochemical and chemical industries owing to their advantages in both operation and system design. The simplest bubble column layout contains a vertical cylinder without internals, in which the gas enters at the bottom through a gas sparger (*i.e.* porous gas sparger, perforated plate, ring gas sparger or spider gas sparger), and the liquid phase is supplied in batch mode or it may be led in either counter-currently or co-currently to the upward gas stream shown in Figure 4. Eventually, reactions between gas and liquid components may be observed in some practical cases *viz.* hydrogenation oxidation, chlorination and alkylation. Despite the simple system design, bubble columns are characterized by complex fluid dynamic interactions. For this reason, their correct design and operation rely on the precise knowledge of the fluid dynamic phenomena on different scales.

Molecular Scale

At the molecular-scale, fundamental chemistry is required to study the interfacial phenomena, catalysts and gas conversion processes and to frame mass transfer models.

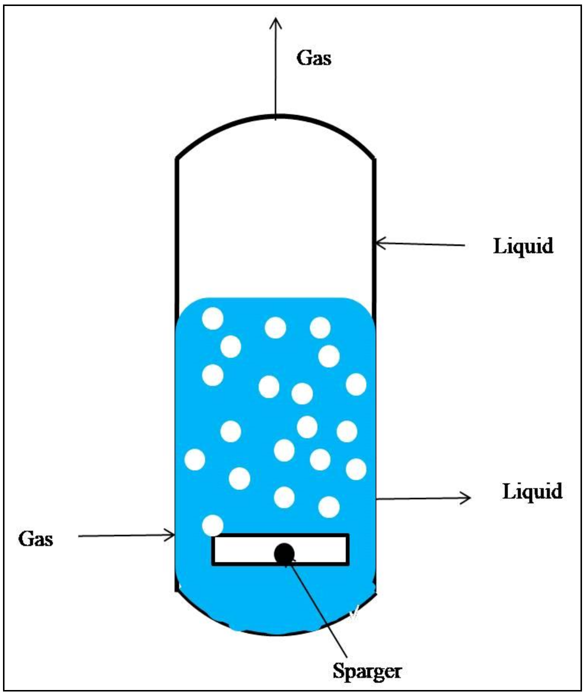

Fig. 4. *Bubble column.*

Bubble Scale

At the bubble-scale, experimental and theoretical works have proposed quantifying and understanding bubble size distributions (BSDs), bubble shapes, single bubble dynamics, non-coalescence-induced bubble dynamics and coalescence-induced behaviour as models of break-up and coalescence.

Reactors Scale

The phenomena at the bubble-scale influence the medium-scale circulation and the large-scale circulation, which characterize the reactor-scale. In reactor-scale, the flow patterns, mean residence time of the dispersed phase, dynamics of mesoscale clusters, liquid recirculation and fluid back mixing have been studied.

Industrial Scale

Industrial-scale reactors are based on the laboratory-scale experiment facilities. Generally scale up methods is applied to estimate the fluid dynamics of industrial-scale.

Mechanically Agitated Contactors

Mechanically agitated contactors (MAC) are very versatile for conducting a variety of gas-liquid operations with or without chemical reaction and in the presence or absence of solid particles. Mechanically agitated contactors are suited for those situations where the superficial gas velocities are relatively low. Mechanically agitated contactors provide good values of mass and heat transfer coefficients and excellent mixing. The liquid phase residence time can be varied over a wide range. The knowledge of the extent of the liquid phase mixing is important for the determination of overall rates of reactions. This is particularly true when the values of mixing time and reaction time are comparable.

EVAPORATION

Evaporation can be defined as the process where liquid is transformed into a gaseous state. Evaporation can occur only when water is available. Evaporation requires that the humidity of the atmosphere is less than the evaporating surface. Kinetic energy is the collective motion of water molecules in the water. The kinetic energy of the molecules measures the water temperature. Molecules have the highest kinetic energy. So, it can break the hydrogen bonds and escape the water surface. Reducing the water temperature, average kinetic energy is reduced.

The rate of evaporation is depended on the following:

Vapour Pressure

$EL = C (ew – ea)$

Where, EL = rate of evaporation (mm/day)
C = a constant
ew = the saturation vapour pressure at the water temperature in mm of mercury
ea = the actual vapour pressure in the air in mm of mercury

This equation is known as Dalton’s law of evaporation.

Temperature

The rate of evaporation increases with the increase in water temperature.

Wind

The rate of evaporation increases with the wind speed. The critical speed beyond which any further increase in the wind speed has no influence on the evaporation rate.

Atmospheric Pressure

Decrease in the barometric pressure with high altitudes, increases evaporation.

Soluble Salts

Solute is dissolved in water, the vapour pressure of the solution is less than that of pure water and hence causes reduction in the rate of evaporation.

Heat Storage in Water Bodies

Deep-water bodies have more heat storage than surface ones.

Short Tube Evaporator

Short-tube vertical evaporators are the oldest type evaporator widely used in sugar industry for evaporation of cane-sugar juice. These are also known as Calandria or Robert evaporators. It became so common in process industry; this evaporator is sometimes known as standard evaporator. Short-tube vertical evaporators contain of a short tube bundle (about 4 to 10 ft. in length) enclosed in a cylindrical shell. The feed is introduced above the upper tube sheet and steam is introduced to the shell or steam container of the calandria. Solution is heated and vaporized in tubes. The central tube in a calandria is of longer diameter. Typically, it's down comer area is taken as 40 to 70% of the total cross-sectional area of tubes. The circulation rate through the down comer/down take is many times the feed rate. The flow area of the down take is approximately equal to the total tubular flow area.

Forced Circulation Evaporators

Forced circulation evaporators are usually costlier than natural circulation evaporators. However, the natural circulation evaporators are not suitable under some situations such as:

1. Highly viscous solutions due to low heat transfer coefficient,
2. Solution containing suspended particles,
3. For heat sensitive materials.

Problems may be occurred when the liquid is dispersed at high velocity in the heat exchanger tubes to improve the heat transfer rate and prevent particle deposition. Evaporator that can use pump to ensure higher circulation velocity is known as forced circulation evaporator. The main components of a forced circulation evaporator are a tubular shell and tube heat exchanger (horizontal or vertical), a flash chamber (separator) mounted above the heat exchanger and a circulating pump. The solution is heated in the heat exchanger without boiling and the superheated solution flashes off at lower pressure are reduced in the flash chamber. The pumps feed and liquor from the flash chamber and force it through the heat exchanger tubes back to the flash chamber. It is commonly used for concentration of caustic and brine solutions. It can also use in evaporation of corrosive solution.

Falling Film Evaporators

In the falling film evaporator, liquid is fed on the top of the tubes in the vertical tube bundle. The liquid is allowed to flow down through the inner wall of the tubes as a film. As the liquid travels down the tubes, the solvent vaporizes and the concentration slowly increases. Vapor and liquid are generally separated at the bottom of the tubes and the thick liquor is taken out. Evaporator liquid is recirculated in tubes by pump below the vapor-liquid separator. The circulation of liquid in the inner wall of the tubes affects the performance of this type of evaporator. The falling film evaporator is largely used for concentration of fruit juices and heat sensitive materials because of the low holdup time. The device is suitable for scale-forming solutions as boiling occur on the surface of the film.

Wiped (Agitated) Film Evaporators

Agitated thin film evaporator involves a vertical steam-jacketed cylinder. The feed solution flows down as a film beside the inner surface of large diameter jacket. Liquid is circulated on the tube wall by a rotating assembly of blades mounted on shaft placed co-axially with the inner tube. The blades maintain the close clearance of around 1.5 mm or less from the inner tube wall. The main advantage is that rotating blades permits handling of extremely viscous solutions.

FILTRATION

Filtration plays an important role in the natural treatment of groundwater as it percolates through the soil and also treatment of water. It is the major part of most water treatment. Water filtration is a mechanical or physical process of separating suspended and colloidal particles from fluids by interposing a medium through which only the fluid can pass. Medium used is the granular material in which water is passed. In the conventional water treatment process, filtration generally follows coagulation, flocculation and sedimentation. Filtration can be compared to the sieve or micro-strainer that traps suspended material between the grains of filter media.

Plate and Frame Filter Press

Plate-and-frame presses are normally used in solid-liquid separation processes. After discharging the cake from a cell of the plate-and-frame press from a prior filtration cycle, a suspension is pumped under pressure into an empty cell. During this period, some filtration occurs. After filling the cell, filtration proceeds as the pump pressure increases. The mechanism is surface filtration. The slurry enters the frame by pressure and flows through the filter medium. The filtrate is collected on the plates and sent to the outlet. The number of frames and plates are used for surface area increases and consequently large volumes of slurry can be processed simultaneously with or without washing. The frame and plate process can be described in two steps, namely filtration and washing of the cake [2]. Line diagram of plate and frame filter press shown in Figure 5.

Nutsche Filter

Agitated nutsche filter (ANF) is a closed vessel designed to separate solid and liquid by filtration under pressure or vacuum and cake squeezing by mechanical means. ANF works on the principle of nutsche. Slurry feed into the filtration chamber which has the filter media at the bottom. Filtrate is sucked out by the application of vacuum on the other side. The stirrer is provided for squeezes the cake smoothens. The stirrer is designed for press and smoothen the cake during filtration, agitate the cake during washing, scrap the cake during discharge. The stirrer has axial movement along with rotational movement. Filter media is well supported and can be made of filter cloth in cotton or synthetic fiber, metallic screens, sintered plates. The process is fully enclosed, hygienic and safe which make it ideal for processing toxic and hazardous material without human contact. Cake Discharge is done with the help of stirrer. Provision for spraying wash liquor is built in the equipment. This equipment can be operated under pressure/vacuum or combination of both. It can be used as a drier to reduce further the moisture content. Step less regulation of speed. A totally hydraulic operation makes it simple and easy for operation and compact in design.

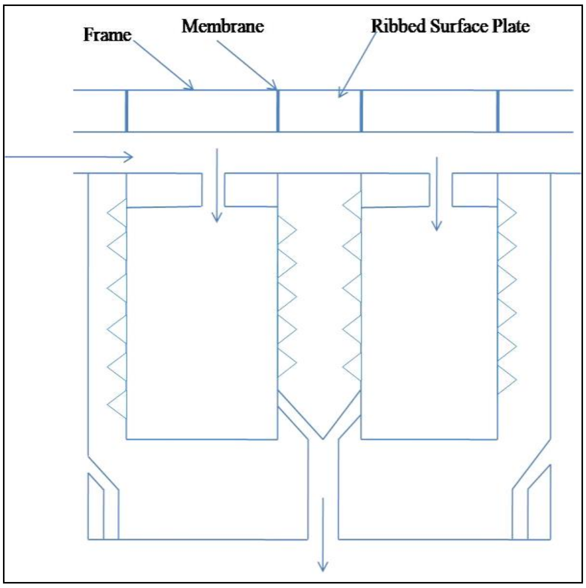

Fig. 5. *Plate and frame filter press.*

Advantages

- Minimum floor space is required.
- When several unit operations upstream and downstream filtration, such as

reaction and thermal drying are required by the process flow scheme.

- When handling saturated brines or process conditions require elevated temperatures the vessel, filter floor and paddles may be heated.
- When re-slurry washing, being more efficient than in-situ displacement washing, is required.
- Sharp separation between the mother and wash solutions is required.
- The cake tends to avoid the wash liquid, air or gas purge from bypassing.

Disadvantages

- When cakes are slow to form.
- When the cake is sticky and does not part readily from the filter medium.
- When the process chain is continuous.
- When the product deteriorates during long downtime.

Rotary Drum Filter

Rotary vacuum filter drum consists of a drum rotating in a tube of liquid to be filtered. The rotary vacuum drum filter belongs to the bottom feed group and is one of the oldest filters applied to the chemical process industry shown in Figure 6. Rotary vacuum drum filters are certainly used the best part of solid liquid separation process. The removal of solid particles from the fluid by passing fluid through the filtering medium on which solids are deposited is said to be filters. Solid liquid separation is the separation of two phases from a suspension. The technology for carrying out this process is often referred to as mechanical separation because the separation is accomplished by purely physical means.

Sparkler Filter

Sparkler filter press also known as horizontal filter, redefine filtration through compactness, ease of operation and robust engineering. Which are ideally suited for filtration of syrup, liquid, chemicals, oil beverages, etc. The filter presses are completely enclosed and leak proof assembly. Horizontal filter press, filter cartridge assembly made of no. of disc-type filter plates perforated filter screens, filter media, inter locking cups with pump and piping, mounted on trolley. The swing bolt design ensures airtight sealing and

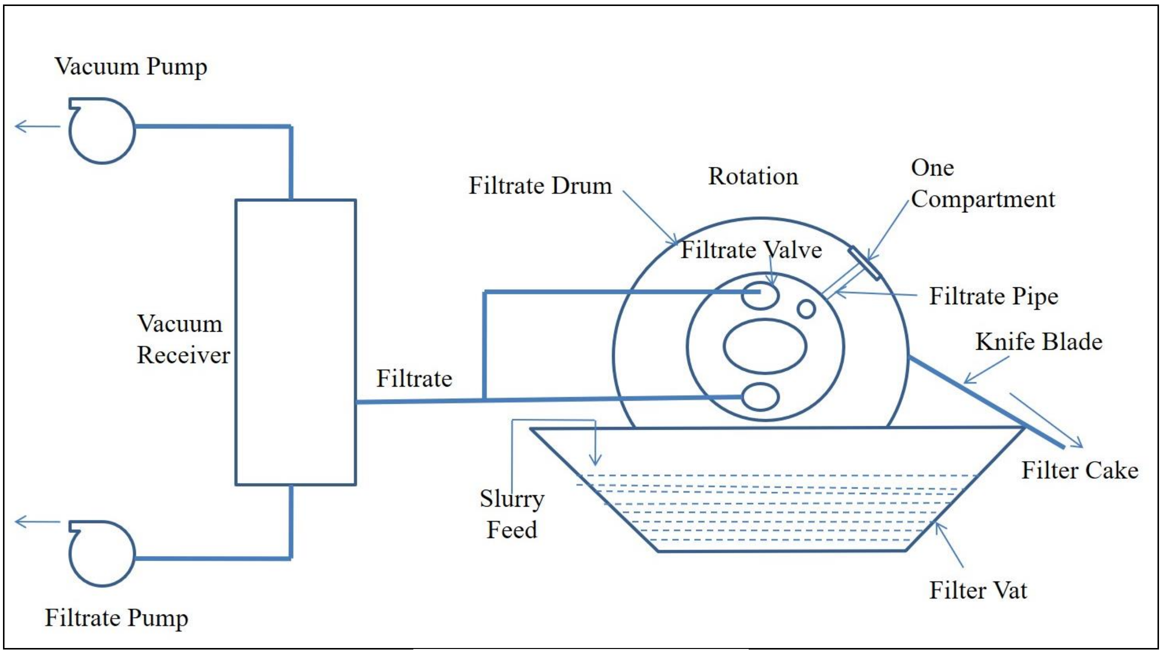

Fig. 6. *Rotary drum filter.*

also gives the operator the ability to quickly assemble and disassemble the filtration system. Jacketing can be provided for heating/cooling the product. The zero hold up models ensures all the fluid is transferred to the filtrate side without any holdup. Skid mounted assembly ensures portability and compactness. The filter presses are available in several MOC to suit the product to filter and process should be required [3].

Candle Filter

Candle filters (cylindrical element filters) have cylindrical elements (candles) mounted in parallel, vertically. The diameter of the tubes is usually between 25 – 75 mm and the length is usually up to 2 m. The larger types can contain 250 or more sleeves and filtration area of up to 200 m^2. The three major components of the candle filter are the vessel, the filtering elements and the cake discharge mechanism. The tubes are usually made of metal or cloth-covered metal, but can be made of stoneware, plastics, sintered metal or ceramics. The slurry is fed into the vessel under pressure and filtration takes place with solids being deposited on the outside of the tubes. The liquid passes through the drainage system and out of the filter. The filtration cycle time is determined by the pressure available, cake capacity or batch capacity [4].

Bag Filter

A fabric filter consists of one or more isolated compartments containing rows of fabric bags in the form of round, flat or shaped tubes. Particle laden gas passes up along the surface of the bags then radially through the fabric. Particles are retained on the upstream face of the bags and the cleaned gas stream is vented to the atmosphere shown in Figure 7. During cleaning, dust that has accumulated on the bags is removed from the fabric surface and deposited in a hopper for subsequent disposal. The layer of dust or dust cake, collected on the fabric is primarily responsible for such high efficiency. The cake is barrier with twisting pores that trap particles as they travel through the cake. Fabric filters are used where high efficiency particle collection is required. Limitations are imposed by gas characteristics and particle characteristics that affect the fabric or its operation and that cannot be economically accommodated. Fabric filters are usually made of woven needle punched felts sewn to the desired shape, mounted in plenum with special hardware and used across a wide range of dust concentrations.

Advantages

- Insensitivity to gas stream variations and large changes in inlet dust loadings.
- Recirculation of filter outlet air.
- Dry recovery of collected material for subsequent processing and disposal.
- No corrosion problems.
- Simple maintenance, flammable dust collection in the absence of high voltage.
- High collection efficiency of smoke and gaseous contaminants with the use of selected fibrous or granular filter.
- Relatively simple operation.

Disadvantages

- Temperatures in excess of 290°C.
- Need for fabric treatment to remove collected dust and reduce seepage.
- Relatively high maintenance requirements.
- Explosion and fire hazard of explosive dusts.
- Reduced fabric life at elevated temperatures and in the presence of acid or alkaline particulate or gas.
- Potential crusty caking/plugging of the fabric or need for special additives due to hygroscopic materials, moisture condensation or tarry adhesive components.
- Respiratory protection requirement for fabric replacement.
- Medium pressure drops.

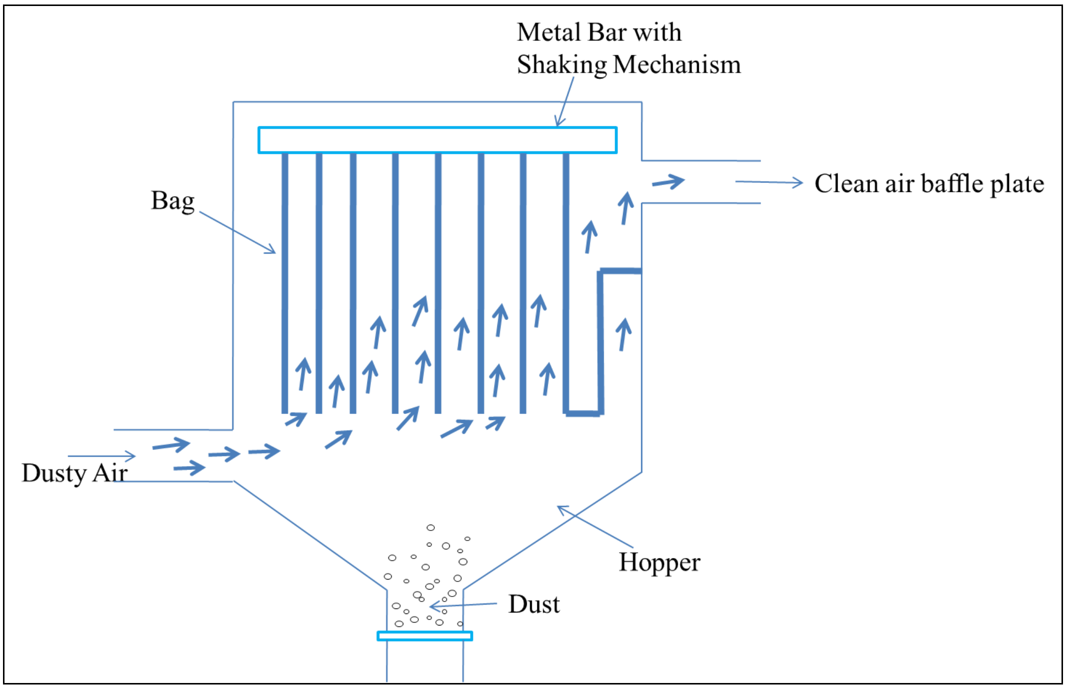

Fig. 7. *Bag filter.*

DRYING

Drying is an important unit operation in the variety of chemical process industries (CPI) sectors. Food, pharmaceuticals, chemicals, plastics, timber, paper and other industries use drying equipment to eliminate moisture during product processing. Most dryers are classified as direct dryers, where hot air is used to supply the heat to evaporate water or other solvents from the product. Another important dryer category includes vacuum dryers, involves the use of a reduced-pressure atmosphere to surround the product.

Free Moisture

This is the liquid in excess of the equilibrium moisture content for the specific temperature and humidity condition of the dryer. It is the liquid content removable at given temperature and humidity.

Bound Moisture

Moisture of the substance which employs as equilibrium vapour pressure less than of the pure liquid at the same temperature is known as bound moisture. Moisture content of the solid which enters an equilibrium vapour pressure equal to that of pure liquid at the given temperature is the unbound moisture. This is the amount of liquid in the solids that shows a vapor pressure less than normal for the pure liquid.

Drying Curve

This curve is referred to as the drying curve for a specific product in drying method. Variations in the curve will occur mostly in rate relative to carrier velocity and temperature. The curve is particularly valuable in understanding characteristics associated with the drying of each unique product. For each and every product, there is a representative curve that describes the drying characteristics for that product at specific temperature, velocity and pressure conditions. This curve is referred to as the drying curve for a specific product [5]. Variations in the curve will occur principally in rate relative to carrier velocity and temperature shown in Figure 8.

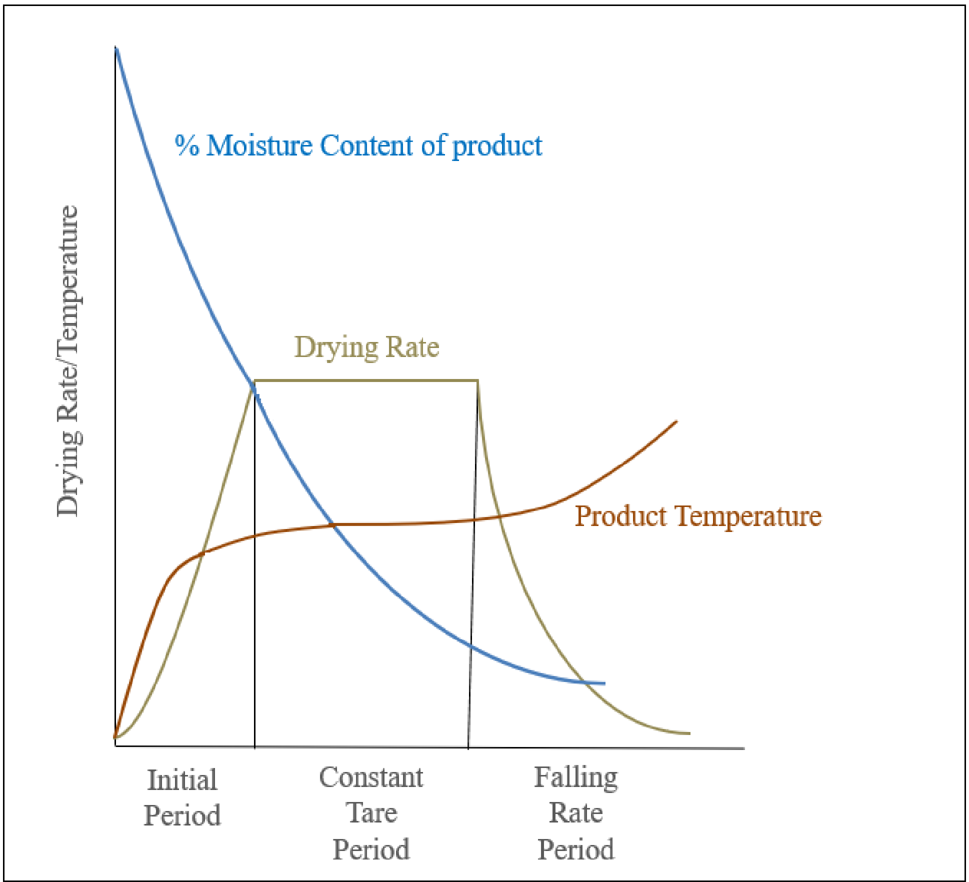

Fig. 8. *Drying curve.*

Initial Period

- Sensible heat is transferred to the feed that contained moisture.
- Heating the feed from the inlet to the process condition.
- The rate of evaporation increases dramatically during this period with moistly free moisture being removed.
- Pre-processing can reduce or eliminate this phase.

Constant Rate Period

- Free moisture persists on the surface.
- Rate of evaporation is very little as the moisture content reduces.
- Drying rates are high.
- There are gradual and relatively small increases in the product temperature.
- Time scale of the constant rate period may determine and affect the rate of drying in the next phase.

Falling Rate Period

- Migration of moisture content from the particles to the outer surface becomes the limiting factor which can reduce the drying rate.

Equipment

Tray Dryer

A dryer employed for drying of the wet products include crude drugs, chemicals, powders or the granules, etc. is known as tray dryer. A laboratory oven is the elementary form of it which contains cabinet with the heater at the bottom. The values of these ovens are very less because of its uncontrollable heat transfer or humidity meter. A tray dryer is convectional drying equipment with enclosed insulated chamber and trays placed on top of each other in a trolley. The driers are used in processes where drying and heating are a crucial part of the industrial manufacturing process such as in the food products, pharmaceutical, dye stuff and chemicals manufacturing among others. The materials to be dried are either solid or wet and placed on the trays described in Figure 9.

The heat through the trays is transferred via hot air circulation by a stream in a radiator coli or electrical heater. The transfer of heat, as well as the proper circulation of the heat, is facilitated by the installed blower fans. Additionally, the equipment has a control panel for temperature control as well as other parameters fixed outside the equipment and assist in its functioning. The basic working principal of this incredible machine is the continuous circulation of hot air. In the tray fryer, moisture is removed from the solids that are placed in the tray by a forced convectional heating. The moist air is removal is conducted partially but in a simultaneous fashion. Primarily, the wet solids are loaded into the trays and then trays placed in the dryer chambers. There is then the introduction of fresh air through the inlet, the air passes through the heater where it is heated up. The objective of the heating is to ensure that the heated air reaches the wet solids on the tray; therefore, the fans in the tray dryer are used to circulate the hot air at a speed of two to five m/s. The turbulent airflow reduced atmospheric partial vapour pressure and the thickness of the layers of the air boundary.

The heated air picks up water. During water evaporation from the surface, there is diffusion of the water from the interior of the solids by a capillary action. All the above-mentioned events happen in a single pass of air. There is a short contact time and only a small amount of water is picked in a single pass and as a result, the discharge air to the rate of 80 to 90 % is circulated back through the fans and only a maximum of 20% of fresh air is introduced. The moisture discharge occurs through the outlet. So, uniform airflow and constant temperature over the solid materials can maintained for achieving uniform drying. In the event the materials to be dried are wet granules such as in capsule or table drying, drying is continued until the desired moisture content is attained. At the completion of the drying process, the drying trucks or trays are pulled out of the chamber and taken to the dumping station.

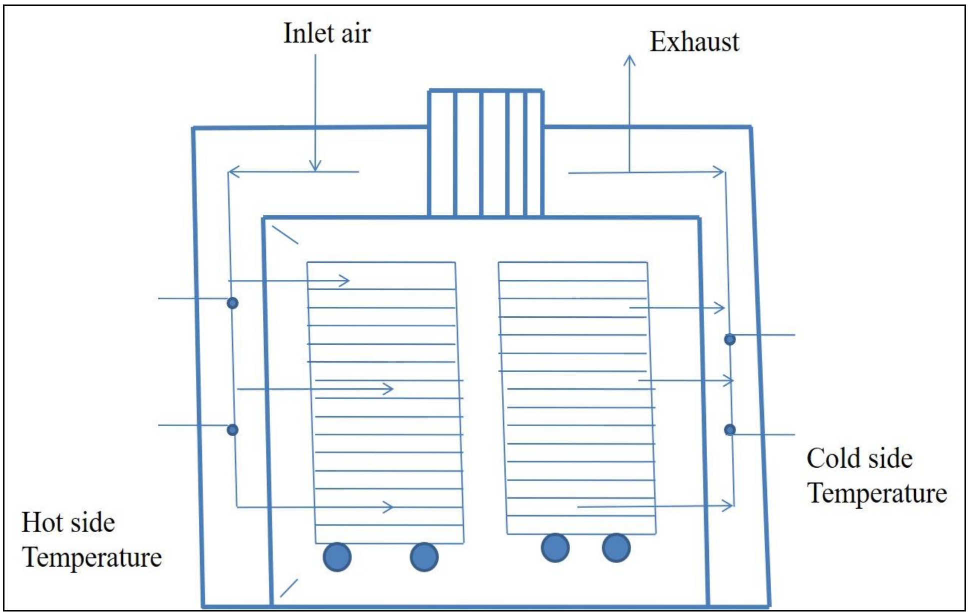

Fig. 9. *Tray dryer.*

Rotary Dryer

Most organic materials that actually use for something hold too much moisture in their natural state to do us any good. A rotary dryer is the distinguished roll of removing that unwanted water to turn the organic material into a useable, more desired product. Rotary drum dryers can be the most affordable and economic choice when considering the new and used industrial dryer. Rotary drum dryers can be chosen depend on projects large and small. They come in all sizes to accommodate many products, quantities and moisture content ranges. Rotary dryer described in following Figure 10.

Rotary drum dryers can be designed to withstand extremely high temperatures and/or corrosive materials. A basic carbon steel drum is designed to withstand inlet temperatures from 1,000°F–1,100°F. Rotary drum dryers can handle higher inlet temperatures. Stainless steel can be used in place of carbon steel if the product is corrosive. Rotary drum is the primary material handling mechanism in a drum. Flighting can be designed to accommodate different flow characteristics of the materials to be dried. Some materials and potentially form balls which need to be broken up, while others flow easily and must be separated at a higher frequency per flight. Other pieces might be long and stringy and can easily get trapped. Different flighting designs can solve these and other problems.

Flash Dryer

Flash dryers are an efficient method of drying products such as slurries, pastes and sludge friable filter cakes, powders and granules describe in Figure 11. The feed must have a relatively consistent particle size to allow for transfer without segregation and build-up. Flash dryers operate effectively on throughput rates varying from a few kilograms per hour up to several hundred tons per hour. Depending on throughput, they may be small, unnoticed pieces of equipment located inconspicuously in the plant or they may require large, independent structures for support. The resulting product may have residual moisture that varies from 0% to upwards of 12% depending on operating parameters or the percentage of bound moisture contained in the feed.

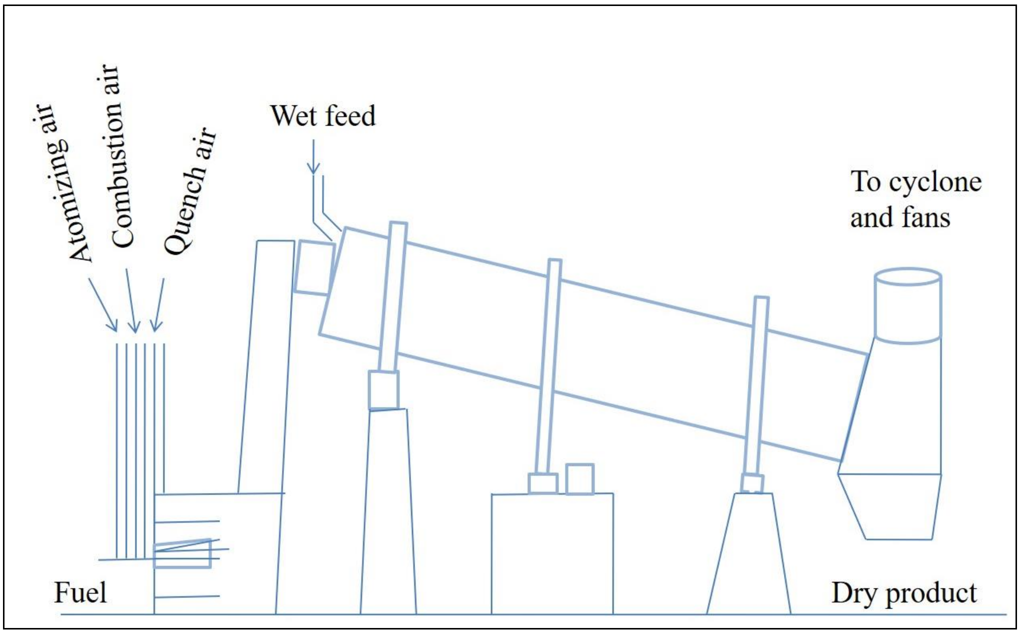

Fig. 10. *Rotary dryer.*

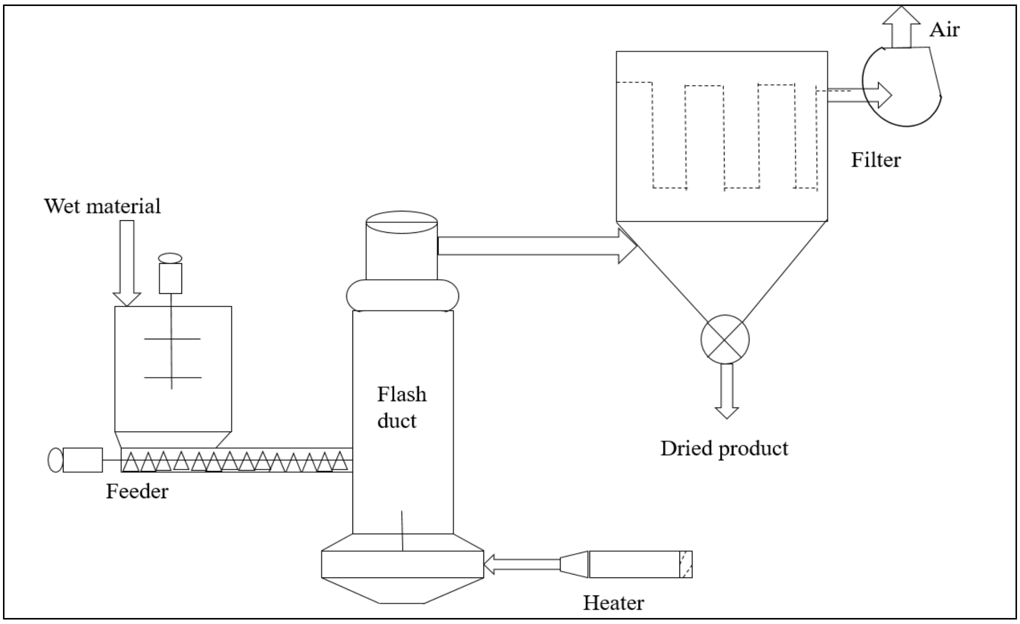

Fig. 11. *Flash dryer.*

Flash drying is a continuous process with the dryer being either directly or indirectly fired. They are inherently co-current dryers with the hottest air contacting the wettest product. They operate at inlet temperatures varying from ambient dehumidified air for sensitive products to more than 1,100°F (600°C) for robust products. Because the system has relatively low residence time and the moisture is flashed off, a significant amount of evaporative cooling takes place in the system. It allows higher inlet temperatures to be used than in many other dryers without overly heating the product. Higher inlet temperatures also increase the overall dryer efficiency.

Flash drying works on the principle of air-filled transport using hot air. Wet product is introduced as high velocity air stream through a special venturi feeder. Highly turbulent airflow generates a powerful gas-solid thermal exchange and disaggregates the product. This allows a rapid evaporation in a few seconds residence time. Rapid drying process avoids overheating of product allowing the use of high temperature drying gases. At dryer outlet, dried product is recovered by means of gas-solid separator. Recycling of dried product in wet material can be considered as sticky product. This process is particularly suitable for fine products or filter cakes.

Fluid Bed Dryer

A fluid bed dryer (FBD) equipment is used for applications like drying of powders, mixing of powders and agglomeration. This is well employed for applications in chemical, pharmaceutical, dyestuff, foodstuff, dairy and various other process industries. Fluid bed dryers are often employed with the spray dryers and granulation systems for effective drying, mixing, granulation, finishing and cooling of powdered materials. These are preferred over rotary dryers for drying and cooling a wide range of polymer materials which require accurate control of residence time and temperature for effective processing. FBD is well known and widely used equipment in granulation area of pharmaceutical manufacturing described in Figure 12. It is used in the granulation process for drying the material to get desired moisture content in the tablet formulation granules required for perfect compression of tablets.

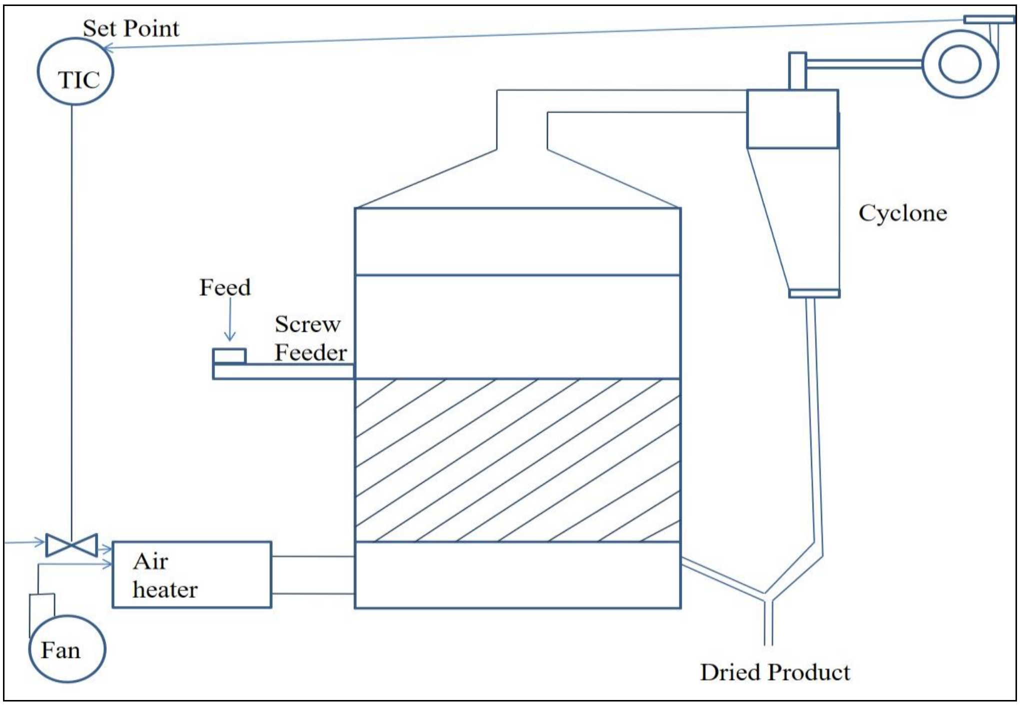

Fig. 12. *Fluid bed dryer.*

If air is allowed to flow through a bed of solid powdered material in the upward direction with the velocity greater than the setting rate of the particles, the solid particles is blown up and become suspended in the air stream. In this stage, the solid bed looks like the boiling liquid; therefore this stage is called as fluidized. Use of hot air to fluidizing the bed is increase the drying rate of the material. FBD contain a stainless-steel chamber having a removable perforated bottom known. Material to be dry is placed in this bowl. Air is introduced from the bottom of the bowl and heated at required temperature by the heaters. This air is filtered through the filter and then passes through the bed of the material. This airflow is generated by the fans fitted at the top of the equipment. The flow rate and the operating temperature are adjusted by the control panel. As the flow of air increases, the bed known as FBD bag expand and particles of power start a turbulent motion. The regular contact with air, the material gets dry. The air leaning the FBD passes through the filter to collect the fine particles of the material.

FBD has a high drying rate and the material is dried in a very short time. Material remains free-flowing and uniform. FBD bags are finger-like in structure to increase the surface area of the drying bed that helps to increases the drying rate and decrease the drying time during the fluidized bed drying process. Sometimes particles may develop an electrostatic charge. Outlet filter blockage is a common problem of the FBD equipment. It can cause increasing the pressure in the vessel that can cause an accident during operation. Therefore, handling of the equipment should be done carefully.

Drum Dryer

Drum drying is known as roll drying. It is a continuous process that creates dry powders and flakes from a liquid feedstock. The liquid feed is sprayed onto or in between two rotating drums. The drums are heated internally with steam to increase the surface temperature. As the material is sprayed onto the drums, it sticks and dries to the surface. To acquire the desired specifications, the drum's rotation speed, steam pressure and the gap between the drums can be varied. The dried material is peeled from the drums using a knife system.

Drum drying is one of the most energy efficient drying methods and it is particularly effective for drying of high viscous liquid. In a drying operation, liquid, slurry or pure material is applied as a thin layer on to the outer surface of revolving drums that are internally heated by steam. Three-quarters of the revolution from the point of feeding, the product is dried and removed with the static scraper. The dry product is collected and is transferred to a rotary hammer mill, reduced to the desired particle size and packaged. To ensure that the product is consistent and that it meets customer specifications. A delicate balance between feed rate, roll speed, steam pressure and roll gap must be achieved.

A drum dryer consists of one or two horizontally mounted hollow cylinder made of high-grade cast iron, fabricated steel or stainless steel, a supporting frame, a product feeding system, a scraper and auxiliaries. Drum dryer may have either single drum with smaller applicator rolls or double drums. The diameter of typical food drums ranges from 24 inches (60 cm) to 60 inches (152 cm) and lengths that go from 24 inches (60 cm) to 144 inches (365 cm).

Materials that are drum result in a flaky particle with variable bulk densities and a distinctive flavour note. The resulting particle size is larger than a spray dried particle, which is fairly spherical in nature and have a consistent bulk density [6].

Spray Dryer

Spray drying is a method of producing a dry power from a liquid or slurry by rapidly drying with a hot gas. Spray drying is well-known method for particle production which comprises the transformation of the fluid material into dried particles and taking advantage of a gaseous hot drying medium, with clear advantages for the fabrication of medical devices shown in Figure 13. Spray-drying mechanism is based on moisture removal using for that a heated atmosphere to which the feed product is subjected. Spray drying is exclusive in its ability to produce powders with the specific particle size and moisture content without regard for the capacity of the dryer and the heat sensitivity of the product. This flexibility makes spray drying the process of choice for many industrial drying operations.

In spray dryers, a liquid material is pumped into a nozzle from feed source and is sprayed as small droplets into a drying chamber. On the other hand, hot air is circulated inside the chamber. Hot air contact with the liquid droplets leads to the heat and mass transfer between the droplets and the air followed by rapid evaporation of moisture. The produced powder and the air are sucked into cyclone and separated from each other by the centrifugal force. In the drying process, the produced powder exits from the bottom of the cyclone and the air exits from the top [6].

Essential Parts of Spray Dryers

Heating system: Inlet air heating system is designed by two direct and indirect methods. In the direct method, air is directly in contact with a heating source such as a flame. However, in the indirect method, air is indirectly heated by a heat exchanger. Airflow rate and temperature as well as air thermo-physical properties are the most important design parameters in the indirect method. The amount of required airflow rate is calculated through the mass and energy balances.

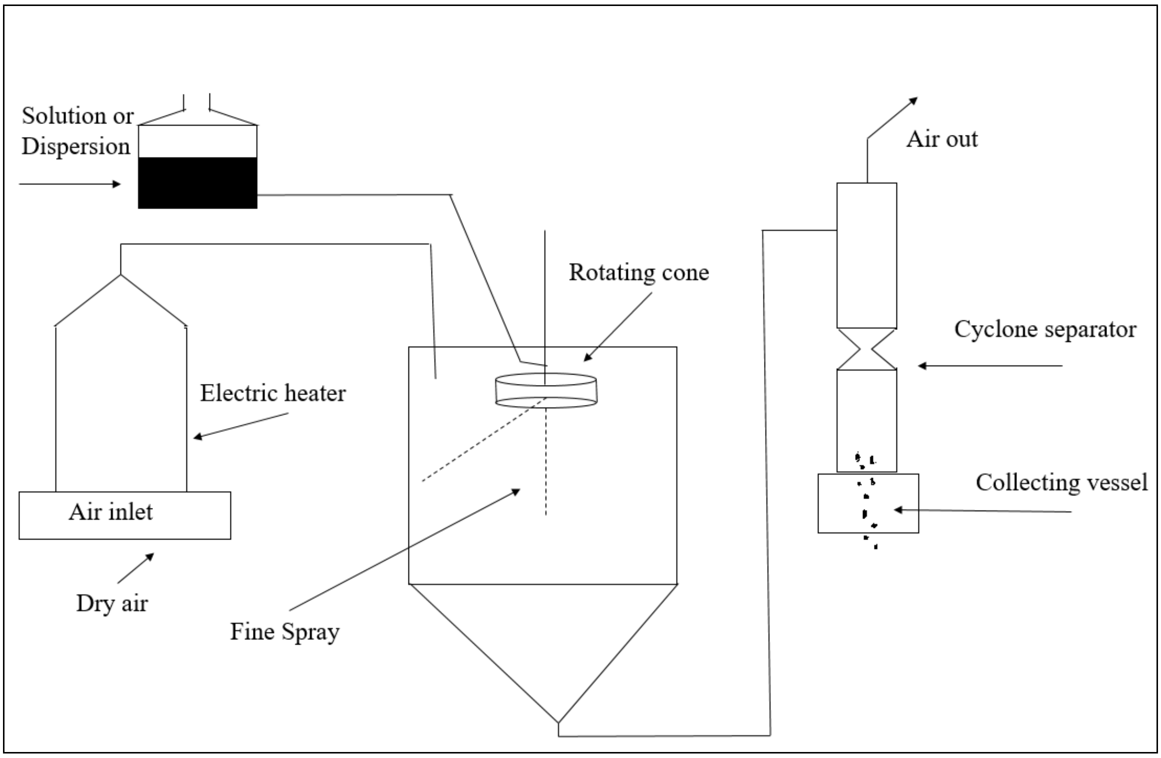

Fig. 13. *Spray dryer.*

Atomizer: Atomizer, used for optimizing the evaporation process, transforms the liquid into small droplets and help in producing a product with desirable properties. Different nozzles are designed based on the type of consumed energy for producing the droplets of among these nozzles, pressure, centrifugal and pneumatic nozzles can be referred.

Pressure Nozzles: Pressure nozzles are based on transformation of liquid pressure energy into kinetic energy of the flowing thin liquid layers. The liquid layers are separated from each other due to their physical properties and air friction effect. Also, pressure change is the controlling factor of the feeding rate and nozzle properties. The mean nozzle size is also directly proportional to the feeding rate and liquid viscosity. Application of pressure nozzles leads to reduction in sedimentation in the dryer chamber as well as to formation of powders with irregular coarse particles and high bulk density.

Centrifugal Nozzles: In centrifugal nozzles, the liquid moves toward center of a rotary disk by centrifugal force and the droplets are deformed by the disk blades. In this system, particle size is inversely related to the centrifuge disk diameter and rotary velocity and is directly related to viscosity, density and surface tension of the product. This system does not have the fouling and clogging problems and makes it possible to produce high viscosity products containing high amount of crystals.

Pneumatic Nozzles: In these nozzles, the liquid mass is atomized using high air velocity leading to formation of friction forces and thus, breaking the liquid mass into tiny droplets. Droplets formation using these nozzles is done in two stages; the first stage involves transformation of the liquid feed into coarse droplets and the second stage involves transformation of the coarse droplets into tiny droplets. Rheological properties of air and feed such as surface tension, density and viscosity determine the product final quality. Fouling and clogging problems are observed at these systems.

Drying Tower Chamber: Spray drying operation is carried out in the drying tower chamber. In this tower moisture is removed from a food material through spraying it as tiny droplets into hot air in the drying chamber. When the droplets are moved by hot air circulation, their moisture is evaporated and is exited from the drying chamber along with the air. The major part of the drying process happens at the constant rate period and the mass transfer on the droplet surface is regarded as the drying limiting factor. The moisture is reached to the critical moisture content; the structure of the dried food particles may determine that drying rate in the falling rate period. During this stage, moisture diffusion from the particles is the limiting factor of drying rate. It should be noted that size and dimensions of drying chamber depend on the feed rate and type of the food material.

Recovery System: Regarding that hot air exited from spray dryer contains some dried tiny particles, it is necessary to separate these particles from the hot air. Cyclonic separating systems based on centrifugal force are used. Efficiency of powder separation from the air is influenced by the mixture of powder and air in inlet shape as well as the cyclone number and dimension. Air and powder mixture inlets into the cyclone are in the shape of wrap-around and tangential. Wrap-around inlets are designed to enhance the amount of entered air and consequently, to increase air velocity and the system efficiency. The number of cyclones depends on the air and powder mixture rate. The best separation efficiency is obtained using cyclones which have diameters less than one meter. Provided that all the optimal conditions in designing cyclones are met, the separation efficiency of powder from the air will be about 95%.

CONCLUSION

In chemical engineering and associated fields, a unit operation is a simple step in a process. Unit operations include bringing a physical change such as separation, crystallization, evaporation, filtration etc. For example, in milk processing, homogenization, pasteurization, chilling, and packaging are each one unit operations which are related to create the whole process. A process may have numerous unit operations to achieve the desired product. In most of the unit operations faced in chemical and petroleum industries or more of the processes of momentum, heat and mass transfer involved. The chemical engineers must aware about all unit operation and its working principle before working in chemical industry.

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