Module # 4

DESIGN OF DRYERS: INTRODUCTION, TYPES OF DRIERS, DESIGN CONSIDERATION OF DRIERS

Lecture 1: INTRODUCTION AND TYPES OF DRIERS

1. INTRODUCTION

The term drying refers generally to the removal of moisture from a substance. It is one of the oldest, most commonly used and most energy consuming unit operation in the process industries. Drying is often necessary in various industrial operations particularly in chemical process industries to remove moisture from a wet solid, a solution or a gas to make it dry and choice of drying medium is depends on the chemical nature of the materials. Three basic methods of drying are used today 1) sun drying, a traditional method in which materials dry naturally in the sun, 2) hot air drying in which matrials are exposed to a blast of hot air and 3) freeze drying, in which frozen materials are placed in a vacuum chamber to draw out the water. The fundamental nautre of all drying porcess is the removal of volatile substances (mainly moisture) from mixture to yield a solid product. In general drying is accomplished by thermal techniques and thus involves the application of heat, most commonly by convection from current of air. Throughout the convective drying of solid materials, two processes occur simultaneously namely, transfer of energy from the local environemnt in the dryer and transfer of moisture from within the solid. Therefore this unit operation may be considered as simultaneous heat and mass transfer operation. Drying processes and equipment may be categorised according to several criteria, incuding the nature of material and the method of heat supply and the method of operation. For example In the sugar industry washed and centrifuged sugar crystals are dried to get finisehd product for packing. Drying is an important operation in food processing. Milk is dried in a spray chamber to produce milk powder. All the above examples indicates that wet material loses moisture in direct contact with hot air/gas. The hot air/gas supplies the energy required for drying and also carries away the moisture released by the solid. For heat sensitive materials much of the resistance to drying resides within the material. Unduly high heat and mass transfer rates applied at the surface only result in overheating or over drying of the surface layer resulting in quality problems without major increase in the drying kinetics. The rate of migration of the moisture from within the solid to the evaporation front often controls the overall drying rate. Therefore, drying may be defined as an operation in which the liquid, generally water, present in a wet solid is removed by vaporization to get a relatively liquid free solid product. Drying of a solid does not demand or ensure complete removal of the moisture. Sometimes it is desirable to retain a little moisture in the solid after drying. Dryer and drying process selection for a specific operation is a complex problem, and many factors have to be taken into account. Though, the overall selection and design of a drying system for a perticular material is dictated by the desire to achieve a favourable combination of a product quality and process

economics. In general, with respect to the rate and total drying time, dryer performance is dependent on the factors such as air characteristics, product cheracteristics, eqipment characteristics. But despite the many commercially available drying techniques at present most dehydrated products (i.e. fruits and vegetables) are still produced by the method of hot air drying. Because this is regarded as the simplest and most economical . There are other water/liquid removal processes such as filtration, settling, centrifugation, supercritical extraction of water from gels etc. In all these operations liquid is removed by mechanical means but a considerable amount of liquid is still retained in the solid. This residual liquid can be removed by drying. One such example is the production of condensed milk involves evaporation, but the production of milk powder involves drying. The phase change and production of a soild phase as end product are essential features of the drying process. Drying is an essential operation in chemical, agricultural, biotechnology, food, polymer, pharmaceutical, pulp and paper, mineral processing, and wood processing industries.

2. PHYSICAL MECHANISM OF DRYING

Drying does not mean only removal of the moisture but during the process, physical structure as well as the apperance has to be preserved. Drying is basically governed by the principles of transport of heat and mass. When a moist solid is heated to an appropriate temperature, moisture vaporizes at or near the solid surface and the heat required for evaporating moisture from the drying product is supplied by the external drying medium, usually air or a hot gas. Drying is a diffusional process in which the transfer of moisture to the surrounding medium takes place by the evaporation of surface moisture, as soon as some of the surface moisture vaporizes, more moisture is transported from interior of the solid to its surface. This transport of moisture within a solid takes place by a variety of mechanisms depending upon the nature and type of the solid and its state of aggregation. Different types of solids may have to be handled for drying crystalline, granular, beads, powders, sheets, slabs, filter-cakes etc. The mechanism of moisture transport in different solids may be broadly classified into (i) transport by liquid or vapour diffusion (ii) capillary section, and (iii) pressure induced transport. The mechanism that dominates depends on the nature of the solid, its pore structure and the rate of drying. Different mechanisms may come into play and dominate at different stages of drying of the same material.

The following term are commonly used in designing of drying systems.

Moisture content of a substance which exerts as equilibrium vapour pressure less than of the pure liquid at the same temperature is refered to as *bound moisture.*.

Moisture content of the solid which exters an equillibrium vapour pressure equal to that of pure liquid at the given temperature is the *unbound moisture.*

The moisture content of solid in excess of the equilibrium moisture content is refered as *free moisture.* During drying, only free moisture can be evporated. The free moisture content of a solid depends upon the vapour concentration in the gas.

The moisture contents of solid when it is in equilibrium with given partial pressure of vapour in gas phase is called as *equilibrium moisture content*. Similalry, the moisture content at which the constant rate drying peroid ends and the falling rate drying period starts is called *critical moisture content*. During the *constant rate drying period*, the moisture evporated per unit time per unit area of drying surface remains constant and in *falling rate drying period* the amount of moisture evporated per unit time per unit area of drying surface continuously decreases.

3. CLASSIFICATION OF DRYERS

Drying equipment is classified in different ways, according to following design and operating features.

It can be classified based on mode of operation such as batch or continuous, In case of batch dryer the material is loaded in the drying equipment and drying proceeds for a given period of time, whereas, in case of continuous mode the material is continuously added to the dryer and dried material continuously removed. In some cases vacuum may be used to reduce the drying temperature. Some dryers can handle almost any kind of material, whereas others are severely limited in the style of feed they can accept. Drying processes can also be categorized according to the physical state of the feed such as wet solid, liquid, and slurry. Type of heating system i.e. conduction, convection, radiation is another way of categorizing the drying process. Heat may be supplied by direct contact with hot air at atmospheric pressure, and the water vaporized is removed by the air flowing. Heat may also be supplied indirectly through the wall of the dryer from a hot gas flowing outside the wall or by radiation. Dryers exposing the solids to a hot surface with which the solid is in contact are called adiabatic or direct dryers, while when heat is transferred from an external medium it is known as non-adiabatic or indirect dryers. Dryers heated by dielectric, radiant or microwave energy are also non adiabatic. Some units combine adiabatic and non adiabatic drying; they are known as direct-indirect dryers.

To reduce heat losses most of the commercial dryers are insulated and hot air is recirculated to save energy. Now many designs have energy-saving devices, which recover heat from the exhaust air or automatically control the air humidity. Computer control of dryers in sophisticated driers also results in important savings in energy.

4. DRYING EQUIPMENT

4.1 Batch Type Dryers

4.1.1 Tray Dryer

Schematic of a typical batch dryer is shown in figure 2.1. Tray dryers usually operate in batch mode, use racks to hold product and circulate air over the material. It consists of a rectangular chamber of sheet metal containing trucks that support racks. Each rack carries a number of trays that are loaded with the material to be dried. Hot air flows through the tunnel over the racks. Sometimes fans are used to on the tunnel wall to blow hot air across the trays. *Even b*affles are used to distribute the air uniformly over the stack of trays. Some moist air is continuously vented through exhaust duct; makeup fresh air enters through the inlet. The racks with the dried product are taken to a tray-dumping station.

Inlet air

Exhaust

Hot side
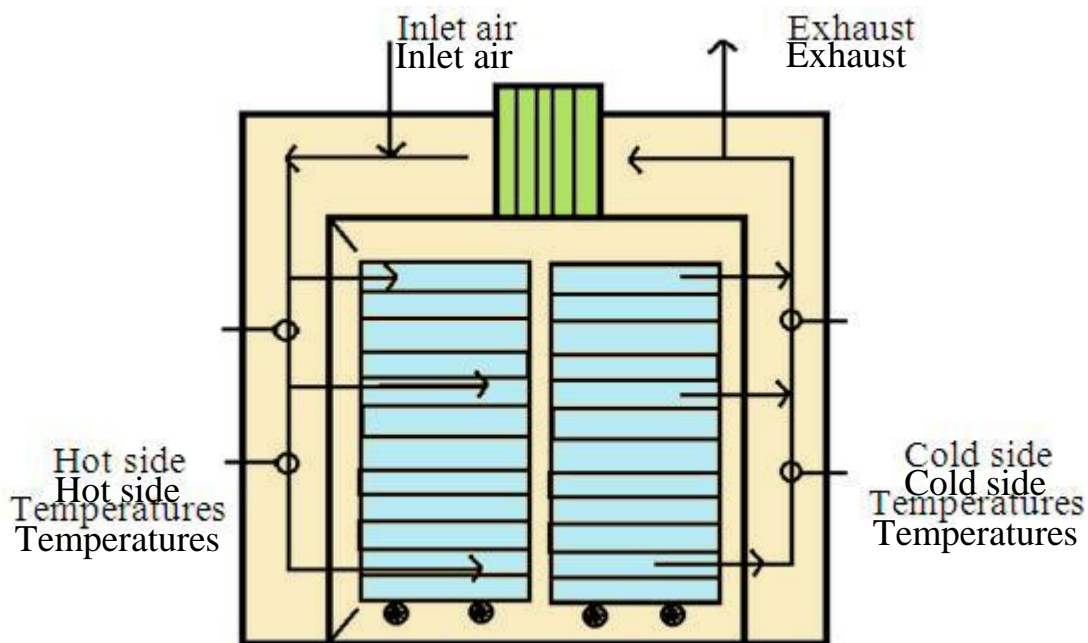Temperatures

Cold side
Temperatures

Figure 2.1: Tray dryer

These types of dryers are useful when the production rate is small. They are used to dry wide range of materials, but have high labor requirement for loading and unloading the materials, and are expensive to operate. They find most frequent application for drying valuable products. Drying operation in case of such dryers is slow and requires several hours to complete drying of one batch. With indirect heating often the dryers may be operated under vaccum. The trays may rest on hollow plates supplied with steam or hot water or may themselves contain spaces for a heating fluid. Vapour from the solid may be removed by an ejector or vacuum pump. *Freeze-drying* involves the sublimation of water from ice under high vacuum at temperatures well below $0^{o}C$. This is done in special vacuum dryers for drying heat-sensitive products.

4.1.2 Pan Dryer

The atmospheric pan drier has a jacketed round pan in which a stirrer or mill revolves slowly, driven from below. The slow moving stirrer exposes fresh surfaces and thereby raises the rate of evaporation and, hence, of drying. The pan drier is a batch machine and is limited to small batches. Pan driers may be used first to evaporate a solution to its crystallizing concentration and then can function as a crystallizer by sending cold water instead of steam into the jacket. The effect of the stirrer during crystallization prevents the growth of large crystals and promotes formation of small, uniform crystals. The mother liquor is then drained off and the crystals dried in the same apparatus.

4.1.3 Agitated Vacuum Dryer

The agitated vacuum dryer is one of the most versatile in the range and is similar in principle to a pan dryer. The dryer essentially consists of a jacketed cylindrical vessel arranged for hot water, steam or a suitable thermal fluid flow through the jacket for heating. Doors are provided on the shell, at the top for loading the feed material and at the bottom for discharging. The dryers are available in variety of sizes. The entire drying chamber is well machined to insure small clearance with the agitator blade. Thus ensures proper shuffling of the material and avoids localized over heating. Due to the agitation of the product in the agitated vacuum dryer the drying time is substantially reduced. A choice of the agitator design which can be arranged with or without heating depends on the material characteristics and process requirements. While designing the shell one has to consider the external pressure and the shaft

designing includes fatigue consideration. Designing the impeller needs consideration of characteristics of the material before and after drying.

4.2 Continuous Dryer

4.2.1 Rotary Dryer

The rotary drier is basically a cylinder, inclined slightly to the horizontal, which may be rotated, or the shell may be stationary, and an agitator inside may revolve slowly. In either case, the wet material is fed in at the upper end, and the rotation, or agitation, advances the material progressively to the lower end, where it is discharged. Figure (2.2) shows a direct heat rotary drier. Typical dimensions for a unit like this are 9 ft diameter and 45 ft length. In direct-heat revolving rotary driers, hot air or a mixture of flue gases and air travels through the cylinder. The feed rate, the speed of rotation or agitation, the volume of heated air or gases, and their temperature are so regulated that the solid is dried just before discharge.
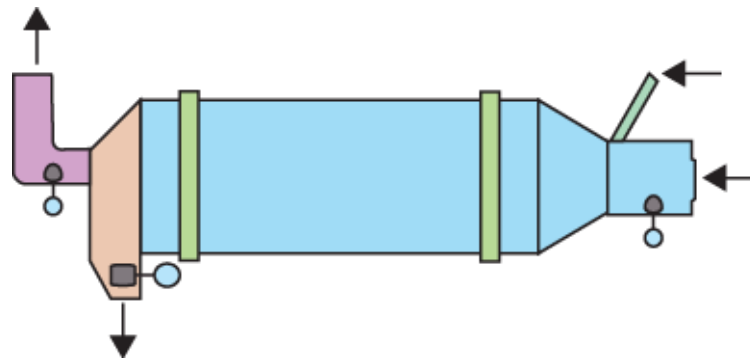

Figure 2.2: Counter current direct heat rotary dryer

The shell fits loosely into a stationary housing at each end. The material is brought to a chute that runs through the housing; the latter also carries the exhaust pipe. The revolving shell runs on two circular tracks and is turned by a girth gear that meshes with a driven pinion. The inclination is one in sixteen for high capacities and one in thirty for low ones. As the shell revolves, the solid is carried upward one-fourth of the circumference; it then rolls back to a lower level, exposing fresh surfaces to the action of the heat as it does so. Simple rotary driers serve well enough when fuel is cheap. The efficiency is greatly improved by placing longitudinal plates 3 or 4 in. wide on the inside of the cylinder. These are called lifting flights. These carry part of the solid half-way around the circumference and drop it through the whole of a diameter in the central part of the cylinder where the air is hottest and least laden with moisture. By bending the edge of the lifter slightly inward, some of the material is delivered only in

the third quarter of the circle, producing a nearly uniform fall of the material throughout the cross section of the cylinder. The heated air streams through a rain of particles. This is the most common form of revolving rotary cylinder. It has high capacity, is simple in operation, and is continuous.

Table 2.1: Rotary dryers practical ranges of dimension and operating parameters

Shell i.d. : D = 1 to 10 ft	Length, L = 4 D to 15 D
Radial flight height: D/12 to D/8; shell rpm: 4 to 5	Pripheral shell speed: 50 – 100 ft/min
The flight count per circle: 2.4D to 3 D	
Inclination of the shell to the horizontal: up to 8cm/m	Avg. solid retention time: 5 min to 2h
Mass flow rate of the drying gas: 300 to 5000 lb/h.ft^2	Drying capacity: 0.4 to 2.5 lb moisture/(h) (ft^3 dryer volume)
Number of heat transfer units in the dryer (NT): 1.5 to 2	Solid hold up m(i.e. fraction of the shell volume occupied by the solid at any time): 5-15%

Courtesy: Principle of Mass Transfer and Separation Processes, B.K. Dutta, 2007.

Lecture 2: INTRODUCTION AND TYPES OF DRIERS (CONT.)

4.2.2 Drum Dryer

In drum dryers (Fig 2.3a, b) a liquid containing dissolved solids or slurry carrying suspended solids forms a thin layer on the outside surface of a large rotating drum. For a single drum unit thickness of the film can be controlled by an adjustable scraping blade. In case of a double drum unit thickness can be controlled by the gap between the drums (figure 2.3a). A gas, normally air may be blown over the surface for rapid removal of moisture. The rotation of the drum adjusted so that all of the liquid is fully vaporized and a dried deposit can be scrapped off with the help of flexible or adjustable knife. This type of dryer mainly handles the materials that are too thick for a spray dryer and too thin for a rotary dryer. The solid collects on an apron in front of the knife and rolls to a container or to a screw conveyor. The operation of the drum drier is continuous. The drum is rotated continuously by a gear driven by a pinion that receives its motion through a belt, a chain, or a reduction gear from. The speed of the drum may be regulated by a variable-speed drive to adopt the speed to any slight variation in the feed quality. The speed of the drum regulated depending upon the nature of materials (i.e wet or dry), if the product material is wet/dry quite a distance before the knife is reached, the speed should be decreased/increased. The design of the components is similar to that of drum filter. The knife may be held just against the surface. It may be brought closer by turning the adjusting wheels. The knife supports may be turned through part of a circle so that the angle of the blade of the knife relative to the drum surface may be selected for the greatest shearing effect. In recent years, double drum dryers have replaced single drum dryer in several applications (figure 2.3b), due to their more efficient operation, wide range of products and high production rates.
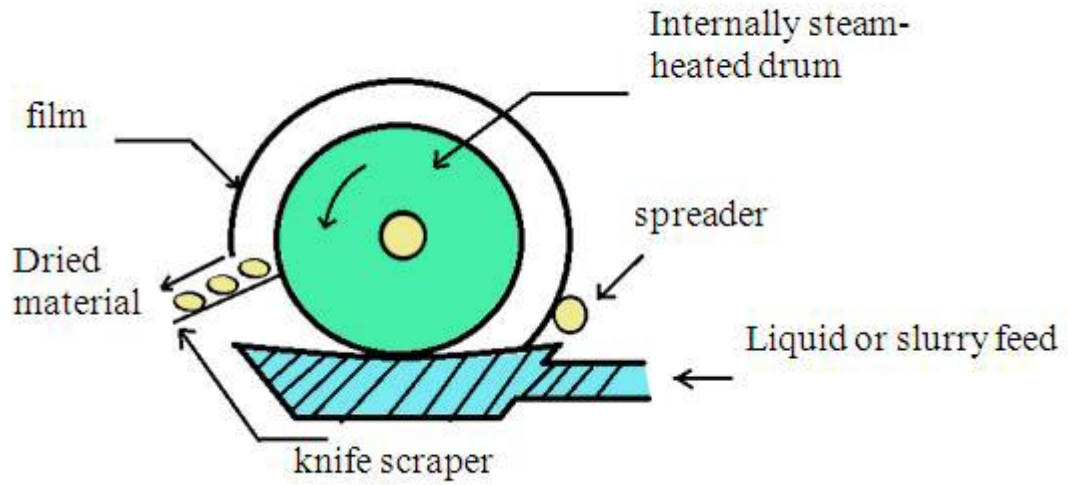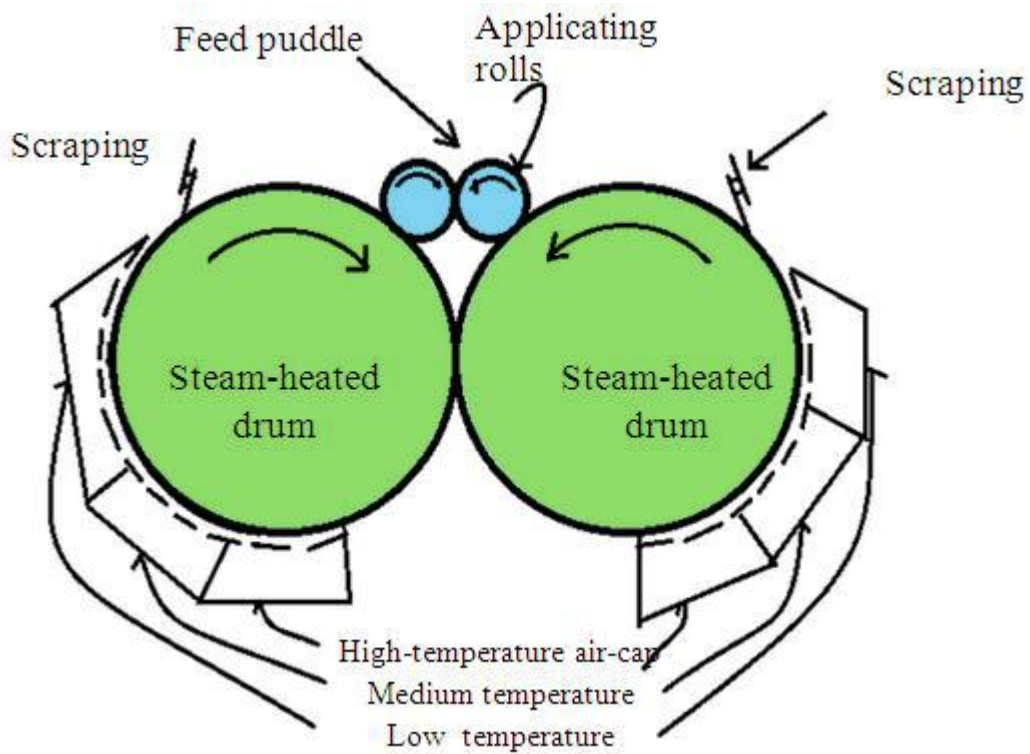
Figure 2.3a: Single drum dryer

Figure 2.3b: Double drum dryer

4.2.3 Flash Dryer

The flash driers (figure 2.4), also called pneumatic dryers, are similar in their operating principle to spray dryer. The materials that are to be dried (i.e. solid or semisolid) are dispersed in finely divided form in an upward flowing stream of heated air. These types of dryer are mainly used for drying of heat sensitive or easily oxidizable materials. The wet materials that are to dried can be passed into a high-temperature air stream that carries it to a hammer mill or high-speed agitator where the exposed surface is increased. The drying rate is very high for these dryers (hence the term *flash dryers*), but the solid temperature does not rise much because of the short residence time. A flash dryer is not suitable for particles which are large in size or heavy particles. The special advantage of this type of dryer is that no separate arrangement is required for transporting the dried product. The fine particles leave the mill through a small duct to maintain the carrying velocities (drying gas) and reach a cyclone separator. A solid particle takes few seconds to pass from the point of entry into the air stream to the collector. The inlet gas temperature is high and varies from 650°C to 315°C, for example, in 2 seconds, or from 650°C to 175°C in 4 seconds. The thermal efficiency this type of dryer is generally low. A material having an initial moisture content of 80 % may be reduced to 5 or 6 % in the dried product.
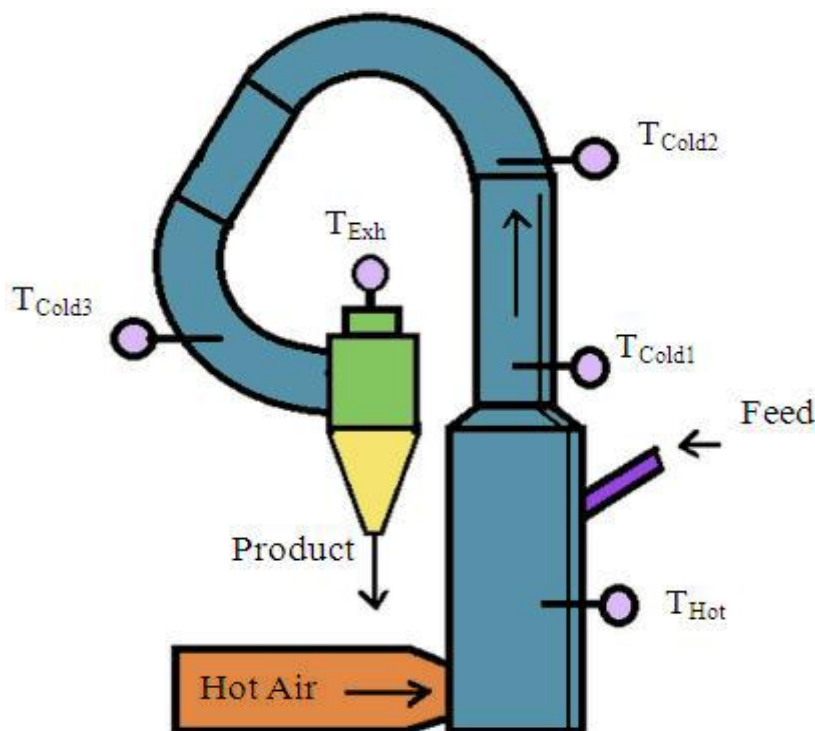

Figure 2.4: Flash dryer

4.2.4 Fluidised Bed Dryer

Fluidized bed dryer consist of a steel shell of cylindrical or rectangular cross section. A grid is provided in the column over which the wet material is rests. In this type of dryer, the drying gas is passed through the bed of solids at a velocity sufficient to keep the bed in a fluidized state. Mixing and heat transfer are very rapid in this type of dryers. The dryer can be operated in batch or continuous mode (figure 2.5). Fluidized bed dryer are suitable for granular and crystalline materials. If fine particles are present, either from the feed or from particle breakage in the fluidized bed, there may be considerable solid carryover with the exit gas and bag filters are needed for fines recovery. The main advantage of this type of dryer are: rapid and uniform heat transfer, short drying time, good control of the drying conditions.

In case of rectangular fluid-bed dryers separate fluidized compartments are provided through which the solids move in sequence from inlet to outlet. These are known as *plug flow dryers;* residence time is almost the same for all particles in the compartments. But the drying conditions can be changed from one compartment to another, and often the last compartment is fluidized with cold gas to cool the solid before discharge.
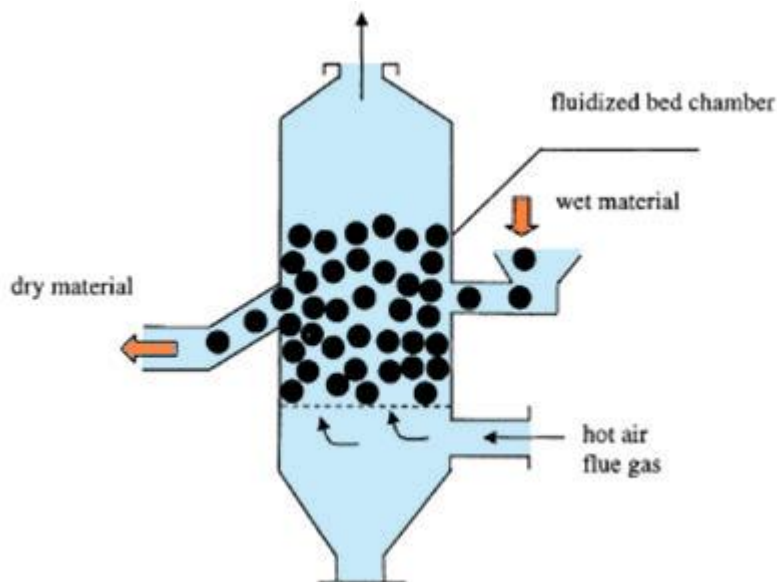

Figure 2.5: Continuous fluidized bed dryer

4.2.5 Screen Conveyor Dryers

Screen conveyor dryer is also called a direct heat continuous type dryer. The solid to be dried are fed on to endless, perforated, conveyor belt through which hot air is forced. The belt is housed in a long rectangular drying chamber or tunnel (figure 2.6). The chamber is divided into series of separate sections, each with its own fan and air heater. Air may be recirculated through, and vented from each section separately or passed from one section to another counter current to the solid movement. The solid is carried through the tunnel and discharged at the opposite end. In order to prevent the higher flow rate of hot air through thinner regions of the bed a uniform feeding rate and distribution of the material over the conveyor is necessary. Coarse granular, flakey, or fibers materials can be dried by through circulation without any pretreatment and without loss of material through the screen. High drying rate can be achieved with good product quality control. Thermal efficiency of this type of dryer is high and with steam heating, the steam consumption for heating the drying gas can be as low as 1.5 kg per kg of water evaporated. Only disadvantage of this type of dryer are high initial cost and high maintenance cost due to the mechanical belt.
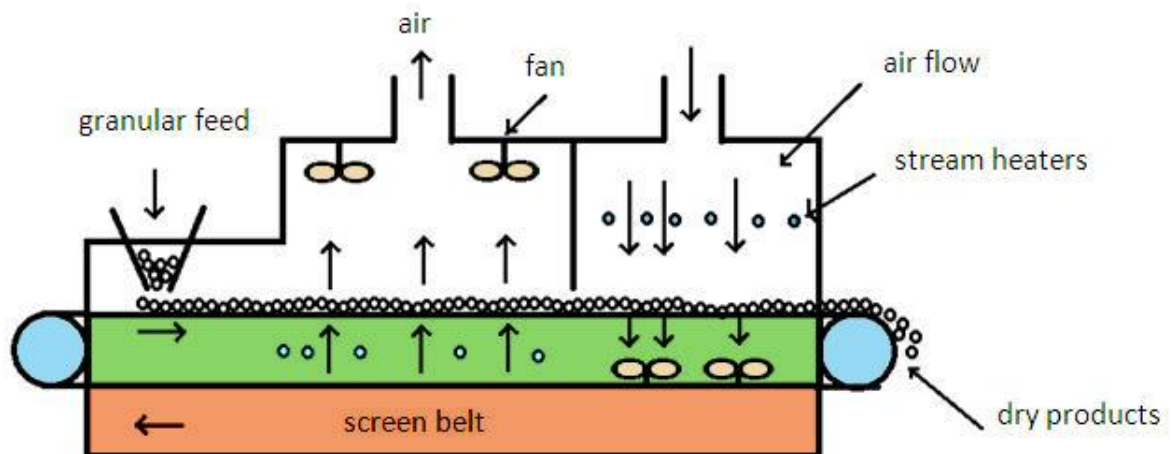

Figure 2.6: Screen conveyor dryer

6. NOVEL DRYING TECHNOLOGIES

Newer technologies focus on saving in energy consumption that result in considerable overall improvement in energy efficiency. In addition, the final quality of the product is greatly influenced by the drying technique and strategy. A brief overview of some novel drying techniques is given below:

5.1 Microwave Drying

Microwave heating is a direct drying method. High-frequency radio waves are utilized in microwave drying. A high-frequency generates the waves and wave channel guides them in to an oven that is designed to prevent the waves from leaving the chamber. In microwave drying, heat is generated by directly transforming the electromagnetic energy in to kinetic molecular energy, thus the heat is generated deep within the material to be dried. Selection of proper wavelength is necessary to ensure thorough penetration into the material. Apart from these, other parameters such as material type and depth of material being exposed also affect the penetration. Therefore, selection of proper wavelengths and dehydration condition for each product is selected individually.

This type of heating is instantaneous, uniform and penetrating throughout the material, which is a great advantage for the processing of pharmaceutical compounds. In case of microwave drying the waves bounce from wall to wall, until the product absorbs eventually all of the energy, generating heat within the material, resulting in dehydration. Vapour from the liquid evaporating inside the product is emitted through the pore structure of the solid material's macro-capillary system, resulting in a high drying rate. This type of dryer is highly efficient and power utilization efficiencies are generally greater than 70 %. Important commercial aspects of this dryer includes the ability to maintain colour, moisture and quality of the natural food.

6.2 Supercritical Fluid Extraction and its application to Drying

The supercritical fluid (SCF) is a substance at a temperature and pressure above its critical point. It can effuse through solids like a gas, and dissolve materials like a liquid. Supercritical fluids possess unique properties that enable them to extract components selectively from a mixture. This ability has been investigated as an alternative to currently used separation processes such as distillation or liquid extractions. In addition, close to the critical point, small changes in pressure or

temperature result in large changes in density, allowing many properties of a supercritical fluid to be "fine-tuned". Above the critical point, this increased density produces enhanced solvency, approaching that of a liquid. It is this solvency that makes SCF extraction a feasible alternative. Mass transfer properties resembling that of gases are also a significant factor in SCF extraction. An application of SCF extraction that has seemingly gone unexplored is to the drying of food products. Since moisture content influences texture, chemical reactions, and susceptibility to microbial spoilage, drying is a way to retain quality and prolong shelf life. A complication associated with drying of food products is that they may undergo changes that alter the physical or chemical structure, thus changing the integrity of the product. SCF extraction avoids this problem because it allows the food product to be dehydrated without undergoing a phase change from liquid water to water vapour. Also, if a solvent such as supercritical carbon dioxide is used, it will not be necessary to heat the product above ambient temperatures.

7. SELECTION OF DRYING EQUIPMENT

In view of the enormous choice of dryer types one could possibly deploy for most products, selection of the best type is a challenging task that should not be taken lightly. The first consideration in selecting a dryer is its operability. Above all else, the equipment must produce the desired product in the desired form at the desired rate. The quality required in a finished product, and its necessary physical characteristics, are determined by its end use. A wrong dryer for a given application is still a poor dryer, regardless of how well it is designed. Although variety of commercial dryers are available in the market, the different types mare largely complementary, not competitive, and the nature of the drying problem dictates the type of dryer that must be used, or at least limits the choice to perhaps two or three possibilities. The final choice is then made on the basis of capital and operating costs. Attention must be paid, however, to the costs of the entire drying system, not just the drying unit alone.

There are some general guidelines which need to be followed to select a dryer, but it should be recognized that the rules are far from rigid and exceptions not uncommon. Often batch dryers are used when the production rate of dried product is less than 150 to 200 kg/h, while continuous dryers are suitable for production rates greater than 1 or 2 tons/h. To handle intermediate production rates other factors must be considered.

The dryer must also operate reliably, safely, and economically. Operation and maintenance costs must not be excessive; pollution must be controlled; energy consumption must be minimized. As with other equipment these requirements may be conflict with one another and a compromise needs to be reached in finding the optimum dryer for a given service. As far as the drying operation itself is concerned, adiabatic dryers are generally less expensive than non-adiabatic dryers, in spite of the lower thermal efficiency of adiabatic units. Unfortunately there is usually a lot of dust carry over from adiabatic dryers, and these entrained particles must be removed from the drying gas. Elaborate particle-removal equipment may be needed, equipment that may cost as much as the dryer itself. This often makes adiabatic dryers less commercially attractive than a "buttoned-up" non-adiabatic system in which little or no gas is used.

Lecture 3: DESIGN CONSIDERATION OF DRIERS

8. DESIGN OF DRYER

Design of a rotary dryer only on the basis of fundamental principle is very difficult. Few of correlations that are available for design may not prove to be satisfactory for many systems. The design of a rotary dryer is better done by using pilot plant test data and the full scale operating data of dryer of similar type if available, together with the available design equations. A fairly large number of variables are involved such as solid to be dried per hour, the inlet and exit moisture contents of the solid, the critical and equilibrium moisture contents, temperature and humidity of the drying gas. The design procedure based on the basic principles and available correlations is discussed below. In this case we assume that the solid has only unbound moisture and as shown in fig 2.7 in stage II the solid is at the wet bulb temperature of the gas.
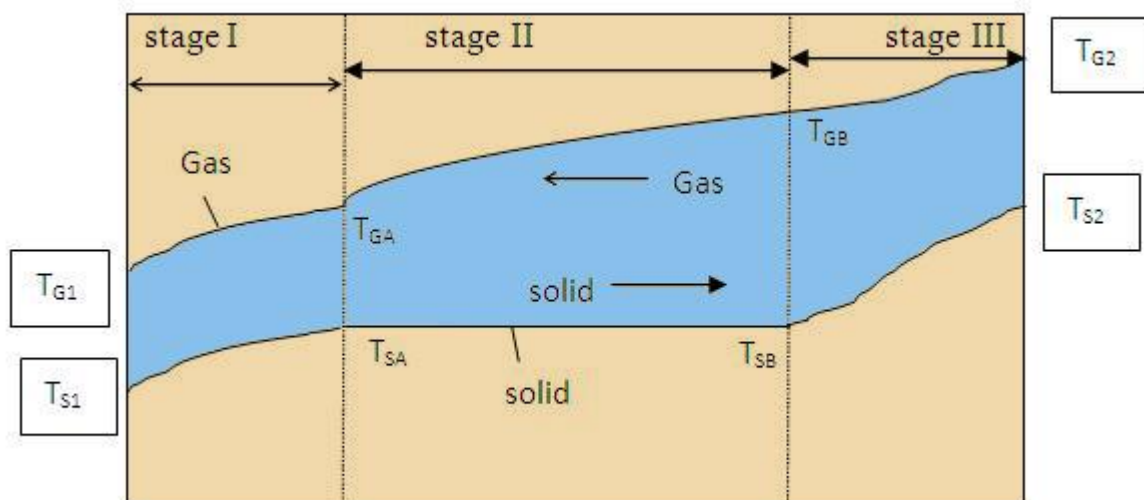

Figure 2.7: Temperature profile for solid and gas in a counter current rotary dryer

1. Heat losses from dryer surfaces are neglected.

2. Once the capacity of the dryer is known, the drying gas flow rate, its temperature and humidity are decided considering a number of factors. And the following moisture & enthalpy balances need to be satisfied.

$$Gs\ (Y_1 - Y_2) = Ms\ (X_1 - X_2)$$

$$Gs\ (Hg_2 - Hg_1) = Ms\ (H_{S2} - H_{S1})$$

Here, G_s = flow rate of air (dry basis, kg/h), Ms = flow rate of solid (kg/h, dry basis), H_s = humidity of air (kg/H_2O/kg dry air)

3. The gas and solid temperatures at the stage boundaries are obtained by moisture and energy (enthalpy) balances. The number of heat transfer unit for each zone is calculated. for the stage II. The number of heat transfer units is given by

$$(N_{tG})_{h,II} \times \Delta T_m = (T_{GB} - T_{GA})$$

4. The total length of dryer is given by

$$L = (L_T)_1 (N_{tG})_1 + (L_T)_{II} (N_{tG})_{II} + (L_T)_{III} (N_{tG})_{III}$$

5. The shell diameter is calculated from the dry gas flow rate (from step I) and suitable gas flow velocity or gas mass flow rate

Some useful correlations for the design of a rotary dryer are given below.

Volumetric gas-solid heat transfer coefficient.

$$\bar{U}_a = (W/m^3.K) = 237 (G')^{0.67}/d$$

Here, G' = gas mass flow rate (kg/m^2.h) and d, dryer diameter

Length of transfer unit $L_T = G'_{CH} / \bar{U}_a$

$$L_T = 0.0063 \ _{CH} . d. \ G_S^{0.84}$$

Here, c_H = average humid heat, and d = dryer diameter

Solid retention time:

$$\theta = \frac{0.23 \ L}{S \ N^{0.9} \ d} \pm 1.97 \frac{B \ L \ G'}{F}$$ (+ve sign is for counter flow; −ve sign is for parallel flow of the gas and solid)

Where,

θ = retention time (min); L = dryer length (m)

S = slope of the dryer (m/m); N = speed (rpm)

G' = gas mass flow rate (Kg/m^2.h)

F = feed rate (Kg/m^2. h) dry basis

$B = 5 (d_p)^{-0.5}$

d_p = weight average particle diameter (micron)

d = dryer diameter (m)

Example 2.1: Size of the rotary dryer can be estimated for the following case. A moist non hygroscopic granular solid at 26^0C is to be dried from 20% initial moisture to 0.3% final moisture in a rotary dryer at a rate of 1500 kg/h. The hot air enters the dryer at 135^0C with a humidity of 0.015. With condition that the temperature of the solid leaving the dryer must not exceed 110^0C and the air velocity must not exceed 1.5 m/s in order to avoid dust carry over. $C_{ps} = 0.85$ kJ/kg.K. Recommend the diameter, length and other parameters of the dryer.

Solution:

Basis of calculation is 1 hr operation

Solid contains 20% initial moisture

Mass of dry solid $\quad = M_S \quad = 1500 (1-0.2) \quad\quad = 1200$ kg/hr

Moisture in the wet solid $= X_1 = 20/80 = 0.25$

Moisture in the dry solid $= X_2 = 0.3/99.7 = 0.00301$

Water evaporated, $m_{S, \text{evaporated}} = M_S (X_1 - X_2)$

$$= 1200 (0.25 - 0.00301) = 296.4 \text{ Kg}$$

Given data:

$T_{S1} = 26^0C; \quad T_{G2} = 135^0C; \quad Y_2 = 0.015$

Let us assume that the exit temperature of the gas is $T_{G1 =} 60^oC$ and for solid $T_{S2} = 100^oC$

Now enthalpy of different streams (suppose ref temp $= 0^oC$)

$H_{S1} \quad = [C_{PS} + (4.187) X_1] [T_{S1} - 0]$

$\quad\quad = [0.85 + (4.187) 0.25] [26 - 0] = 49.31$ KJ/kg dry air

$H_{S2} \quad = [C_{PS} + (4.187) X_1] [T_{S1} - 0]$

$\quad\quad = [0.85 + (4.187) 0.0.00301] [100 - 0] = 86.2$ KJ/kg dry solid

$H_{g2} \quad = [1.005 + (1.88) 0.015] [135 - 0] + (0.015) (2500) = 177$ KJ/kg

$H_{g1} \quad = [1.005 + (1.88) Y_1] [60 - 0] + Y_1 (2500) = 60.3 + 2613 Y_1$

Overall mass balance

$G_S (Y_1 - Y_2) = M_S (X_1 - X_2) \quad \Longrightarrow G_S (Y_1 - 0.015) = 296.4$

$$\Longrightarrow \quad\quad G_S = 296.4/(Y_1 - 0.015)$$

$$M_S [H_{S2} - H_{S1}] = G_S [H_{g2} - H_{g1}]$$

$\Longrightarrow \quad 1200 [86.2 - 49.31] = 296.4/(Y_1 - 0.015) \times (177 - 60.3 - 2613Y_1)$

$$Y_1 = 0.04306 \text{ and } G_s = 296.4/(Y_1 - 0.015) = 10560 \text{ Kg/h}$$

Shell Diameter

Volume of humid inlet gas (135^0C and $Y_2 = 0.015$)

$$V_{H2} = 1.183 \text{ m}^3/\text{Kg dry air}$$

Volume of humid exit gas (60^0C and $Y_1 = 0.04306$)

$$V_{H1} = 1.008 \text{ m}^3/\text{Kg dry air}$$

The max. volumetric gas flow rate $= G_s.V_{H2}$

$$= 10560 \times 1.183 = 12490 \text{ m}^3/\text{h}$$

The working velocity i.e. superficial velocity $\quad = 1.5 - 0.2 \times 1.5$

$$= 1.2 \text{ m/s}$$

$$\therefore \ \pi / 4 \times d^2 \ (1.2) = d = 1.98 \text{ m}, \ say \ 2.0 \ m$$

Heat Transfer Unit

Dryer is divided into three zones and therefore, the stage wise calculation of temperature and humidity of the stream can be obtained by material and energy balance.

Stage III

Very less water left for vaporization in stage III. Consider solid is at T_{SB}, the wet bulb temperature of the air at location between III & II.

$$\text{assume } T_{SB} = T_{SA} = 41^0\text{C}$$

Enthalpy of solid at the inlet to stage III

$$H_{SB} \quad = \quad [0.85 + (0.00301) (4.187)] (41\text{-}0)$$
$$= \quad 35.37 \text{ KJ/kg dry solid}$$

Humid heat of gas entering stage III

$$C_{HB} \quad = \quad [1.005 + (1.88) (0.015)]$$
$$= \quad 1.003 \text{ KJ/kg.K}$$

Heat balance over stage III

$$M_S [H_{S2} - H_{SB}] = G_S (C_{HB})_{III} (135 - T_{GB})$$
$$T_{GB} = 129^0\text{C}$$

Adiabatic saturation temperature of air entering stage II (129^0C & humidity of 0.015) is 41.3^0C.

At the boundary B, $\quad\quad\quad \Delta T_B = 129 - 41 = 88^0\text{C}$

At end 2, $\quad\quad\quad\quad\quad \Delta T_2 = 135 - 100 = 35^0\text{C}$

$$LMTD_{III} = (\Delta T)_m = 88-35/\ln(88/35) = 57.5^0C$$

$$(N_{tG})_{III} = T_2 - T_{GB}/(\Delta T)_m = 135 - 129/57.5 = 0.104$$

Stage II

$\Rightarrow$ Use heat balance equation over stage II to calculate the value of T_{GA}. The calculated T_{GA} value can be use to estimate the number of transfer units.

Since $Y_B = 0.015$

$H_{GB} = [1.005 + 1.88\ Y_B]\ (129-0) + 2500\ (Y_B) = 170.8\ KJ/Kg$

$H_{AS} = [0.85 + C_{PS}\ X_1]\ (T_{SA} - 0)\qquad = [0.85 + (4.187)\ (0.25)]\ (41)$

$\qquad\qquad\qquad\qquad\qquad\qquad\qquad = 77.77\ KJ/(Kg\ dry\ solid)$

Enthalpy balance:

$$M_S\ (H_{SB} - H_{SA}) = G_S\ (H_{GB} - H_{GA})$$

$$1200\ (35.37 - 77.77) = 10560\ (170.8 - H_{GA})$$

$$\therefore\ H_{GA} = 175.6\ KJ/Kg$$

Once H_{GA} value is known then T_{GA} can be calculated using the following equation

$$H_{GA} = 175.6 = [1.005 + 0.04306\ (1.88)]\ [T_{GA} - 0] + 0.04306\ (2500)$$

$$\Rightarrow T_{GA} = 63^0C$$

At section A temp diff. $\Delta T_A = 63 - 41 = 22^0C$ and $\Delta T_B = 88^0C$

$$(\Delta T)_M = (88-22)/\ln(88/22) = 47.6^0C$$

Number of transfer unit $\qquad = (N_{tG})_{II} = T_{GB} - T_{GA}/(\Delta T)_M$

$$= (129 - 63)/47.6 = 1.386$$

To validate the assumed value of exit gas temperature i.e. $T_{G1} = 60^0C$, first do an energy balance over stage I.

$$G_S\ (H_{g2} - H_{g1}) = M_S\ (H_{S2} - H_{S2})$$

$$10560\ (175.6 - H_{g1}) = 1200\ (77.77 - 49.31)$$

$$\Rightarrow H_{g1} = T_{G1} = 59.6^0C$$

Stage I

$(\Delta T)_1 = 60\text{-}26 = 34^0C$

$(\Delta T)_A = 22^0C$

$(\Delta T)_M = 34\text{-}22/\ln (34/22) = 27.5$

Number of transfer unit, $N_{tG} = 0.104 + 1.386 + 0.109 = 1.53$

Length of Transfer Unit:

Avg. mass flow rate $\quad = [10560\ (1.015) + 10560\ (1.04306)]/2$

$$= 10867\ Kg/h$$

The gas mass flow rate, G' $\quad = (10867/3600)/\ \pi\ /\ 4 \times (2)^2$

$$= 0.961\ Kg/m^2.S$$

Volumetric heat transfer coeff. $= \overline{U}_a = (237\ (G')^{0.67})/d$

$$\therefore\ \overline{U}_a = (237 \times (0.961)^{0.67})/2 = 115\ W/m^3.K$$

Humid heat at the ends

$$C_{H2} = 1.005 + 1.88\ (0.015) = 1.033$$

$$C_{H1} = 1.005 + 1.88\ (0.04306) = 1.083$$

Avg. humid heat,

$$C_H = (1.033 + 1.083)/2 = 1.058\ KJ/Kg.\ K$$

Length of transfer unit, $L_T = G'.\ C_H/\overline{U}_a\ = (0.961 \times 1058)/115 = 8.84\ m$

Length of dryer, L $\quad = N_{tG}.\ L_T$

$$= 1.56 \times 8.84 = 13.8\ m$$

d = 2 m and L = 14 m

Lecture 4: SOLVED PROBLEMS

Example 2.2: (Process design)

A rotary drier using counter current flow is to be used to dry 25000 lb/hr of wet solid (PTA) containing 5 weight percent water to a water content of 0.10 weight per cent. The wet solid enters at 30°C (86°F). Ambient air at 30°C (86°F) will be heated to 156°C (313°F). Specific heat of solid is 0.2871. Estimate the length and diameter of the drier.

Feed to the drier:	Condition of inlet air:
Water content in the feed = 25000 × 0.05 = 1250 lb/Hr Dry solid in feed = 25000 − 1250 = 23,750 lb/Hr Water content in Product = 24 lb/Hr Water removed by the drier = 1226 lb/Hr Steam pressure = 150 psig	Ambient temp. of air (dry bulb) = 30°C = 86°F Wet bulb temp. (wet bulb)= 22°C = 71°F Heated Inlet temp. of air = 156°C = 313°F Humidity H_{mW} = 0.002 lb water/lb dry air.

$$\varphi = H_{mG} - H_{mw} = h_G(T_G - T_W)/(m\lambda_w Pk_G)$$

H_{mG} Humidity of air at temperature T_G °F

H_{mW} Humidity of air at temperature T_W °F

T_G Temperature of inlet air °F; T_W Wet bulb temperature °F

M Molecular weight of air; λ_W Latent heat of vaporization at T_W °F

$h_G/(mPk_G) = 0.26$ for air at T_W and here m = 29.

First Trial: assume wet bulb temperature is 90°C = 194°F

Hence at T_W = 194 °F, H_{mW} = 0.046 ∴ H_{mW} - H_{mG} = 0.046- 0.002 = 0.044; λ_w = 547.3

$\varphi = (0.26(313-194)/547.3) = 0.056$

$$\boxed{\varphi > H_{mW} - H_{mG}}$$

Since Φ> H_{mW} – H_{mG} therefore the temperature assumed is high

Second Trial: Assume a wet bulb temperature of 180^0 F

$H_{mW} = 0.065$ $\therefore$ $H_{mW} - H_{mG} = 0.065 - 0.002 = 0.063$; $\lambda_w = 532$

$\varphi = (0.26 (313-180)/532) = 0.063$

Therefore wet bulb temperature assumed is true i.e. $T_W = \textbf{180}^\textbf{0}$ **F**

The temperature of the outlet air should be selected on the basis of an economic balance between dryer and the fuel costs. Empirically it is found that drier operates economically when total number of transfer units (NTU) is between 1.5 to 2. (Badger and Banchero, Pg 508)

$NTU = \ln(T_{G1} - T_W)/(T_{G2} - T_W)$

Take $NTU = 1.5 = \ln (313 - 180)/(T_{G2} - 180)$ $\therefore$ $\textbf{T}_\textbf{G2} = \textbf{209}~^\textbf{0}\textbf{F}$

Energy balance:

C_P (PTA) $= 0.2871 Btu/lb^0F$; C_P (Water) $= 1~Btu/lb^0F$

Product discharge temperature $= (313 + 209)/2 = 261^0F$

Temperature of feed $= 176^0F$

Heat required to raise the product to discharged temp.

$= 23705 \times 0.2871(261-176) + 24 (261-176) = 5.8143 \times 10^5 Btu/Hr$

Heat required to remove the water $= 1226 [(180-176) + 0.45 (209-180) + 550]$

$$= 6.952 \times 10^5~Btu/Hr$$

Total Heat $= 1.27 \times 10^6$ Btu/Hr

Air Required:

S_H-Humid Heat of inlet air $= 0.24 + 0.45 \times 0.002 = 0.2409$

Use average humid heat $= 0.242$

$G_G^{'}S \times$ Humid heat of air $\times$ Temperature$=$ Total Heat, here S = cross sectional area, sq ft

$G_G^{'} . S \times (0.242) \times (313-209) = 1.27 \times 10^6$

$G_G^{'} . S = 50723.27$ **lb/Hr**

Humid heat of outlet air $= \dfrac{1226}{50723.27} + 0.002 = 0.02617$ lb water/lb dry air

Humid heat $= 0.24 + 0.45 \times 0.02617 = 0.2517$ and $S_{Havg} = (0.2409 + 0.2517)/2 = 0.2463$

Therefore the average humidity taken above is valid

Mean temperature difference across the rotary drier can be calculated by using following formulae

Let q_p = heat required to preheat the feed from inlet to wet bulb temperature.

q_s= heat required to heat product from wet bulb temperature to discharge temperature.

q_v= heat required to evaporate water at wet bulb temperature.

Preheating period:

q_p= 23705 x 0.2871(180-176) + 1250 (180-176) $= \mathbf{3.2274 \times 10^4}$ **Btu/hr**

Change in air temp. is $= [(3.2274 \times 10^4)/(1.27 \times 10^6)] \times (313 - 176) = 2.67\ ^0$F

Air temperature at the end of preheat $= 209 + 2.67 = 212\ ^0$F

$$\Delta T)_P = \frac{(209-158)-(212-180)}{\ln\left[\dfrac{209-158}{212-180}\right]} = 40.76^{\circ}\text{F}$$

Heating period:

$q_s = 23705 \times 0.2871\ (261-180) + 24\ (261-180) = 5.542 \text{ x } 10^5$ Btu/hr

Change in temperature $= \dfrac{5.542 \text{ x } 10^5}{1.27 \textbf{ x } 10^6} \text{ x } (313-209) = 45.38^{\circ}\text{F}$

Air temperature at the start of heating $= 313 - 45.38 = 267\ ^0$F

$$(\Delta T)_s = \frac{(267-180)-(313-261)}{\ln\left[\dfrac{267-180}{313-261}\right]} = 68\,^{\circ}\text{F}$$

Evaporating period:

q_p= 1.27 x 10^6 – 5.542 x 10^5 – 3.2274 x 10^4 = **6.83 x 10^5 Btu/hr**

$$(\Delta T)_v = \frac{(267-180)-(212-180)}{\ln\left[\dfrac{267-180}{212-180}\right]} = 55\,^{\circ}\text{F}$$

The mean temperature difference given as

$$\frac{1}{(\Delta T)_M} = \frac{1}{q_t}\left[\frac{q_p}{(\Delta T)_p} + \frac{q_s}{(\Delta T)_s} + \frac{q_v}{(\Delta T)_v}\right]$$

$$\frac{1}{(\Delta T)_M} = \frac{1}{2.49 \times 10^6}\left[\frac{8.52 \times 10^4}{45.29} + \frac{1.499 \times 10^6}{54.54} + \frac{5.658 \times 10^5}{54.7}\right] = 0.0168$$

$(\Delta T)_M$ = **60^0F**

NTU Check:

$$\text{NTU} = \frac{(T_1-T_2)}{(\Delta T)_m} = \frac{(313\text{-}209)}{60} = 1.73$$

According to the condition NTU should be between 1.5 to 2. Therefore the above mean temperature value can be accepted.

TRIAL 1: To Calculate the Diameter of the Drier

Air entering the drier is 50723.27 lbs/h. But for designing purpose air is taken in excess so that the loss of heat from the drier is compensated.

Air entering the drier can be taken as ~ 51000 lb/hr.

Assume that the maximum superficial air mass velocity to be = 1000 lb/ (hr ft^2)

$$G_G S = 51000\left[1+0.0165 \times \frac{50723.27}{51000}\right] = 51836.93 \text{ lb/Hr}$$

$$S = \frac{51836.93}{1000} = 51.837 \text{ ft}^2$$

$$D = (4*51.837/\pi)^{0.5} = 8.07 \text{ ft} = 2.46 \text{ m}$$

Similarly length of the dryer can be calculated by using following equation

$$Q = U_a \times S \times Z \times (\Delta T)_M$$

Where,

Q = Total heat, Btu/Hr

Z = Length of drier, ft

S = cross sectional area, ft^2

Before that we need to calculate the overall heat transfer coefficient from:

$$Ua = \frac{15(G_G)^{0.16}}{D}$$

G_G = Maximum superficial air mass velocity, lb/ft^2 Hr

U_a = Overall heat transfer coefficient (volumetric), Btu/Hr ft^3 ^{0}F

D = Diameter of the drier in ft.

$$Ua = \frac{15(1000)^{0.16}}{8.07} = 5.57 \text{ Btu/hr ft}^3 \text{ }^o\text{F}$$

$\therefore$ Length of the drier

$$Z = \frac{1.27 \times 10^6}{5.57 \times 51.837 \times 60} = 73.30 \text{ ft} = 22.34 \text{ m}$$

Z/D ratio check:

$$Z/D = \frac{22.34}{2.46} = 9$$

Which checks the condition that the Z/D ratio is between 3- 10. Therefore the above diameter and length can be accepted.

To calculate the speed of the rotation of the drier;

Assume the peripheral speed of rotation to be 30feet/min

Revolution per min = peripheral speed / diameter

RPM = 30/8.07 = 3.7

The revolution of the drier varies between 2 and 5. Therefore the above value can be accepted

Flight design:

Number of flights in the drier = 3 x D

Where D is the diameter of the drier in feet

Number of flights = 3 x 8.07 = 24.21, say 24

Radial height of the flight:

The radial height of the flight taken as $1/8^{th}$ of the diameter of the drier

The radial height of the flight = (1/8) x 8.07 = 12.18 inches, say 12.25"

DRIER DETAILS:

Drier Type: Counter Current Rotary Drier

Diameter of the drier = 8.07 ft = 2.46 m

Length of the Drier = 73.3 ft = 2.34 m

RPM of the drier = 3.7 rpm

Number of Flights = 24

Radial height of the flights = 12.25 inches

Temperature of the inlet air = $156^oC = 313^0F$

Temperature of the inlet wet solid = $90^oC = 194^0F$

Mean temperature Difference = 60^0F

Air mass flow rate = 51000 lb/hr

Moisture removed by the drier = 1226 lb/hr

The volumetric heat transfer coefficient of drier = 5.57 Btu/Hr ft^{3o}F

Lecture # 5: SOLVED PROBLEM

Example 2.3: (*Mechanical Design*) The drier has a uniform temperature of around 150 $^{\circ}$C at any point of time (working pressure in the drier is 0.1013 N/mm^2). So the material used for the construction of the dryer should withstand the high (operating) temperature. Since mild steel withstand high temperature of 200 $^{\circ}$C. The material used to construct the dryer is mild steel and permissible pressure of material used is 124 N/mm^2.

Length of drier = 22.34 m; Inner diameter of the drier = 2.46 m

$\therefore$ *Design pressure = 1.5 x W P = 1.5 x 0.1013 $\Rightarrow$ 0.152 N/ mm^2*

Thickness of the drier shell:

$$t_s = \frac{p\,D}{2\,f\,J + p}$$

P $\rightarrow$ Design pressure, N/ mm^2

D $\rightarrow$ Diameter of the drier, mm^2

F $\rightarrow$ Permissible stress, N/ mm^2

J $\rightarrow$ 0.85

$$t_s = \frac{0.152 \times 2460}{2 \times 0.85 \times 124 + 0.152} = 1.77 \text{ mm}$$

For the shell minimum thickness is given as 8 mm. Consider corrosion allowance of 2 mm therefore, including the C.A. the thickness can be taken as 10 mm.

Therefore the outer Diameter $= D_i + 2 \text{ x } 10 = 2460 + 2 \times 10$

$$D_0 = 2480 \text{ mm} = \textbf{2.480 m}$$

The thickness of the insulation:

From the heat balance it is clear that there is some heat lost into the atmosphere. To limit the heat loss to the same figure insulation is to be given to the drier. The insulation material can be chosen as asbestos.

Density of asbestos $= 577 \, Kg/ \, m^3$

Thermal conductivity of asbestos $= 681.4 \text{ x } 10^{-3} \, W/ \, m^2 K$

Thermal conductivity of mild steel $= 147.6 \, W/ \, m^2 K$

Convective heat transfer coefficient $= 56.78 \, W/ \, m^2 K$

From heat balance,

Heat loss from the drier $= 97.006\ KW$

Inner diameter of the drier shell, $D_1 = 2.46$ m

Outer diameter of the drier shell, $D_2 = 2.48$ m and $t_1 = 10$ mm

Let 'y' be the thickness of insulation.

$$D_3 = D_2 + 2y$$

$$T_1 = 122\,^oC \quad \text{and} \quad T_2 = 76\,^oC$$

We have from continuity equation,

$$Q = \frac{(T_1 - T_2)}{\left(\dfrac{t_1}{k_1 A_1}\right) + \left(\dfrac{t_2}{k_2 A_2}\right) + \left(\dfrac{1}{h\,A_3}\right)}$$

$$
\begin{aligned}
A_1 &= \pi\,(D_1 + D_2) \times L/2 \\
&= \pi\,(2.46 + 2.48) \times 22.34/2 \\
&= 174.24\ \mathrm{m}^2
\end{aligned}
$$

$$
\begin{aligned}
A_2 &= \pi\,(D_2 + D_3) \times L/2 \\
&= \pi\,(2.48 + 2.48 + 2y) \times 22.34/2 \\
&= (174.42 + 70.26y)\ \mathrm{m}^2
\end{aligned}
$$

$$
\begin{aligned}
A_3 &= \pi \times D_3 \times L \\
&= \pi\,(2.48 + 2y) \times 22.34 \\
&= (174.04 + 140.36\ y)\ \mathrm{m}^2
\end{aligned}
$$

$$97.006 \times 10^3 = \frac{122.0 - 76.0}{\dfrac{10 \times 10^{-3}}{147.6 \times 174.24} + \dfrac{y}{681.4 \times 10^{-3}\,(174 + 70.24\ y)} + \dfrac{1}{56.78\,(174.84 + 140.36\ y)}}$$

$$97.006 \times 10^3 = \frac{46}{\dfrac{10 \times 10^{-3}}{25717.82} + \dfrac{y}{(118.6 + 47.87y)} + \dfrac{1}{(9927.4 + 7969.6\ y)}}$$

After solving the final equation obtained as follows

$$y^2 + 1.42\ y - 0.0654 = 0 \qquad \therefore\ y = 0.04\ \mathrm{m}$$

Therefore the thickness of the insulation should be **40 *mm***

To find the power to drive the Driver; Use equation (20- 44) from Perry,

$$\text{Power} = \frac{r\,(4.75\ d\ w + 0.1925\ D\ W + 0.33\ W)}{100000}$$

Where   r → rpm of the drier   d → shell diameter, ft

                  w → live load, Ib   W → total rotating load, Ib

                  D → riding ring diameter, ft (d + 2)

To calculate the live load and the rotating load;

Density of mild steel $= 480\ Ibs/ft^3$

We have,

D_2 = Outer diameter of the drier shell

D_1 = Inner diameter of the drier shell

Volume of shell material = $\dfrac{\pi\ L\ (D_2^2 - D_1^2)}{4}$

$$= \frac{\pi \times 73.30 \times (8.13^2 - 8.07^2)}{4}$$

$$= 56\ \text{ft}^3$$

Weight of the drier   = Volume of shell material × density

$$= 56 \times 480$$

$$= 26859.71\ \text{lbs}$$

Assume Hold up = 0.1

Volume of drier filled with material = $\dfrac{\pi\ L\ D_1^2}{4} \times 0.1$

$$= \frac{\pi\ (8.07)^2}{4} \times 73.30 \times 0.1$$

$$= 374.92\ \text{ft}^3$$

Weight of material in drier at any time, w = Volume x Density

$$= 628.41 \times 94.07$$

$$= 35.268 \times 10^3 \text{ lbs}$$

Volume of the insulating materials $\quad = \dfrac{\pi \, L \, (D_3^2 - D_2^2)}{4}$

$$= \dfrac{\pi \times 73.30 \times (8.26^2 - 8.13^2)}{4}$$

$$= 122.21 \text{ ft}^3$$

Weight of the insulating material $\quad$ = Volume x Density

$$= 122.21 \times 36$$

$$= 4399.62 \text{ lbs}$$

Total weight,

$$W = weight\ of\ the\ drier + weight\ of\ the\ insulation + weight\ of\ the\ material$$

$$= 26859.71 + 35.268 \times 10^3 + 4399.62 = \mathbf{6.652 \times 10^4 \text{ lbs}}$$

W = weight of the material

w = 35.268×10^3 lbs

Riding ring diameter, $D = d + 2$

$$= 8.07 + 2 = 10.07 \text{ ft}$$

The rpm of the drier, r = $3\ rpm$

$$\text{BHP} = \dfrac{3 \times (4.75 \times 8.07 \times 35.268 \times 10^3 + 0.1925 \times 10.07 \times 6.652 \times 10^4 + 0.33 \times 6.652 \times 10^4)}{100000}$$

$$= 45.08 \text{ BHP}$$

$$= 33.62 \text{ KW}$$

To calculate the power required by the Blower:

Temperature of the inlet air = 30 °C

Humidity of inlet air $= 0.002\ Kg\ of\ H_2O/Kg\ of\ air$

Total quantity of air handled = 23512.83 Kg/hr

$$\text{Volume of the inlet air} = \frac{23512.83 \times 22.4 \times 303}{29 \times 298}$$

$$= 18.466 \times 10^3\ \text{m}^3/\text{hr}$$

Use equation (6-34a) from Perry,

$$\text{Power} = 2.72 \times 10^{-5}\ Q\ p$$

Where

$Q \rightarrow$ Fan volume, m^3/hr

$p \rightarrow$ Fan operating pressure, cm water column

p = 20 cm water column

Power = $2.72 \times 10^{-5} \times 18.466 \times 10^3 \times 20 = 10$ KW

To calculate the power required by the Exhaust fan:

Temperature of outlet air = 87 °C

Humidity of the outlet air $= 0.065\ Kg\ of\ H_2O/Kg\ of\ air$

Total quantity of air handled =

Volume of the inlet air $= \dfrac{24628.7 \times 22.4 \times 363}{29 \times 298} = 42.64 \times 10^3\ \text{m}^3/hr$

Power = $2.72 \times 10^{-5} \times 42.64 \times 10^3 \times 20$

$= 23.19$ KW

To find the diameter of the feed pipe:

Feed Rate $\quad = \quad$ 25000 lb/hr

Volumetric feed rate $\quad = \quad 743 \; ft^3/hr$

$\quad = \quad 21 \; m^3/hr$

Assume the velocity of the feed to be 100 m/hr

Cross sectional area of the feed pipe $= (21/100)$

$$= 0.21 \; m^2$$

Diameter of the feed pipe $= \; 0.52 \; m = \mathbf{21''}$

To find the diameter of the air inlet and outlet pipe:

INLET:

Temperature of air $\quad = 156 \, ^oC$

Humidity of inlet air $\quad = 0.002 \; Kg \; of \; H_2O/Kg \; of \; air$

Volumetric flow rate of air $\quad = 7.14 \; m^3/s$

Assume the velocity of the air entering to be 20 m/s

Cross sectional area of the inlet air pipe $\quad = (7.14/20)$

$$= 0.357 \; m^2$$

Diameter of the inlet pipe $\quad = \; 0.674 \; m$

$$= 26.5''$$

With corrosion allowance diameter $= \mathbf{28''}$

OUTLET:

Temperature of air $\quad = 156 \, ^oC$

Humidity of outlet air $\quad = 0.065 \; Kg \; of \; H_2O/Kg \; of \; air$

Volumetric flow rate of air $\quad = 9.11 \; m^3/s$

Assume the velocity of the outlet air to be 20 m/s

Cross sectional area of the outlet air pipe $= (9.11/20)$

$$= 0.455 \text{ m}^2$$

Diameter of the outlet pipe $= 0.761 \text{ m}$

$$= 29.96''$$

With corrosion allowance diameter $= 32''$

DRIER DETAILS

Length of the Drier	$= 22.34 \text{ m}$
Inner diameter of the drier	$= 2.46 \text{ m}$
Outer diameter of the drier	$= 2.48 \text{ m}$
The thickness of the shell	$= 10 \text{ mm}$
The thickness of the insulation	$= 40 \text{ mm}$
Power required to drive the Drier	$= 33.62 \text{ KW}$
Power of the Blower	$= 10 \text{ KW}$
Power of the Exhaust fan	$= 23.19 \text{ KW}$
Diameter of the feed pipe	$= 21''$
Diameter of the inlet pipe	$= 28''$
Diameter of the outlet pipe	$= 32''$
Rotation of the Drier	$= 3 \text{ rpm}$

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Exercise problems:

Example 1: A double drum drier is to be designed for drying a paste with a capacity of 100 kg/hr. The drier is heated with indirect stream available at atmospheric pressure (100°C). The following data is available:

Temperature of the paste = 30°C.

Initial moisture content of paste = 60°C (wet basis).

Final moisture content of paste = 10°C (wet basis).

Heat transfer from the condensing steam to steam wall = 8500 W/m^{2}k.

Heat capacity of the paste material = 3400 J/kgk.

Thermal conductivity of the paste material = 0.8 W/mk.

The thickness of layer of material = 1.5mm.

The thickness of iron drum wall = 8mm.

Thermal conductivity of iron drum = W/mk.

Air is blown over the surface of material at a velocity of 1.5 m/sec.

Temperature of the air is 40°C.

Relative humidity of air is 40%.

Latent heat of vaporization of water at atmospheric pressure = 2240 kJ/kg.

Maximum temperature of the outer surface of the material being dried is 70°C.

Vapour pressure of water at 70°C = 350 mmHg.

Partial pressure of water vapour in air at 40°C and relative humidity 40% id = 22 mmHg.

Rate of flow of moisture being evaporated can be estimated by the correlation.

$$G = 1.14 \times 10^{-5} u^{0.8} (\Delta P)$$

u – velocity of air flow over the surface, m/sec.

*(**Ans**: U = 210W/m^{2}k; heating surface area A = 3.02 m^2; Actual surface area = 4.368m^2; Area of each drum =2.184m^2; drum diameter = 562mm)*

Example 2: Salicyclic acid crystals are to be dried in a pneumatic dryer at a rate of 200 kg/h of dry product. Initial moisture content of the crystals is 20% while the final moisture content should be 1%. Temperature of the crystals supplied to the drier is 10^oC while the temperature of the crystals discharged from the dryer is 50^oC.

Temperature of the air entering the heater = 10^oC

Temperature of the air leaving the heater and entering the drier.

Relative humidity of air entering the heater is 70%.

Temperature of the air leaving the dryer = 60^oC.

Specific heat of dry crystals = 1160 J/kgk.

Equivalent diameter of crystals = 0.001 m.

Density of material = 1480 kg/m^3.

Wet bulb temperature = 30^oC.

Estimate the diameter, and length of the pneumatic dryer and the time needed to dry salicyclicstals.

Moisture content of air initially = 0.0065 kg/kg dry air.

Moisture content of air finally = 0.020 kg/kg dry air.

Enthalpy of air at the inlet of air heater = 33.5 kJ/kg.

Enthalpy of air at the outlet of air heater h_1 = 111 kJ/kg.

Thermal conductivity of air = 0.0285 w/mk.

Density of air = 1.03 kg/m^3.

Kinematic viscosity of air = 2420 kj/kg.

(**Ans:** *flow rate of dry air required, M= 2787 kg/hr; Heat transferred to air, Q =59991Watts; number of particles passing through the dryer per second, n = 71691.4 / sec; velocity of deposition of the particles, V= 3.814 m/sec; Diameter of the pneumatic dryer, D = 0.45m)*

Example 3: (Sizing of a rotary dryer) A fine granular solid to be dried at a rate of 600 kg/h from 22% to 0.2% moisture (all wet basis) in a countercurrent rotary dryer using hot air at 110^oC of humidity 0.012 kg/(kg dry air). The moist solid fed to the dryer is at 25^oC and the dried solid leaves at 80-oC. The moisture in the solid is unbound. In order to avoid dusting, the gas velocity should not exceed 1.7 m/s. The specific heat of the dry solid is 0.9 kJ/kg. ^{o}C, Suggest a dryer size.

(**Ans:** *Diameter of dryer, D =1.8 m; Length of dryer = 25 m)*