Improving Process Profitability...Continuously℠

APV DRYER HANDBOOK

Process to Boardroom Automation℠

CONTENTS

INTRODUCTION

The drying of materials – whether solids, liquids or slurries – to improve storage life or reduce transportation costs is one of the oldest and most commonly used unit operations. Drying of fruit, meat and various building and craft materials date back before the discovery of fire. The physical laws governing drying remain the same, even though the machinery to accomplish it has improved considerably! Today, dryers are in operation in most manufacturing industries including chemical, pharmaceutical, process and food. Products that are dried range from organic pigments to proteins, as well as minerals to dairy products. Because of the spectrum of duties required, there is a great variety of dryers available. The correct choice depends on the properties of the feed material and the desired characteristics of the final product. This handbook reviews many types of dryers and provides guidelines for their selection. Certain types of commonly used dryers are reviewed in detail.

Since drying is an energy intensive operation, this handbook also provides information on techniques to improve efficiency.

DRYER TERMS

FEED DEFINITIONS

Solution: Solids fully dissolved

Slurry: Suspended or dispersed

Thixotropic: Thins with shear

Dilatent: Thickens with shear

Cohesive Paste: Just plain sticky

Friable Cake: Dry to touch, breaks up

Granules: Very coarse powder

DRIED PRODUCT CHARACTERISTICS

Fine: Typically pigment powders, fillers, talcum powder

Free Flowing: Usually over 50 microns, press filling applications

Dustless: Dyes, bulk handling, Kaolin – still free flowing

Granular: Coarser and less free flowing

Wettable: For easy mixing into water – agro chemicals, dyes

Agglomertated: Easiest mixing and dissolving – infant formula, creamer

Coated: Time release, lecithinated, flavored

Lump: Rabbit food, cattle feed, Kaolin

POWDER PROPERTIES

Hygroscopic: Flavors, salts, sugars, HVP

Hydrophobic: Fats, polymers, coated inorganics

Thermoplastic: Lignin, PVA resins, sugars, fats

Heat Sensitive: Protein, pigments, iron oxide, crystals

Inert: Mineral, oxides, Kaolin, waste

DRYERS

Dryer Selection Chart

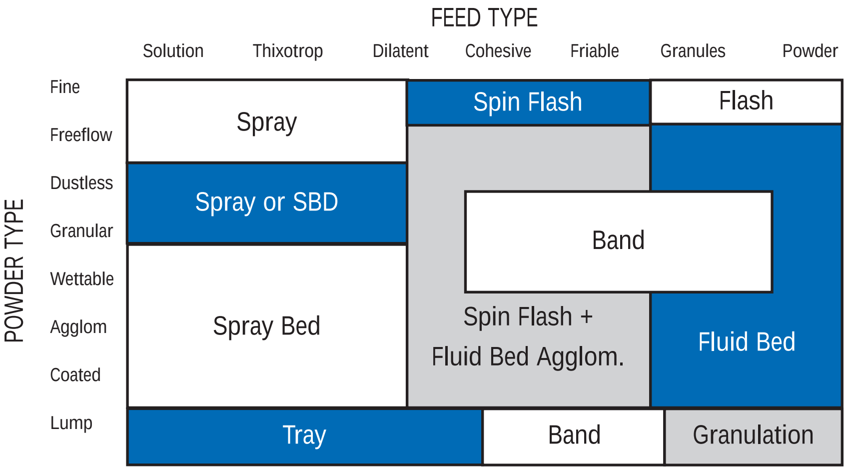

Figure 1. A guide to dryer selection

SELECTION, SIZING, COSTS

Throughout the food, dairy, chemical and process industries, there are various requirements for thermal drying. Some involve the removal of water or other volatiles from pasty materials such as pigments, clays, synthetic rubbers and fine chemicals. Others involve the drying of solutions or liquid suspensions such as whey, milk and coffee. To assist manufacturers in arriving at a reasonably accurate first assessment of the type, size and cost of equipment for a particular duty, this article describes the most widely used types of both batch and continuous dryers.

Three basic methods of heat transfer are used in industrial dryers in various combinations. These are convection, conduction and radiation.

In the processing industries the majority of dryers employ forced convection and continuous operation. With the exception of the indirectly heated rotary dryer and the film drum dryer, units in which heat is transferred by conduction are suitable only for batch use. This limitation effectively restricts them to applications involving somewhat modest production runs.

Radiant or so called “infra-red” heating is rarely used in drying materials such as fine chemicals, pigments, clays or synthetic rubbers. Its main application is in operations such as the drying of surface coatings on large plane surfaces, since efficient utilization generally requires a line of sight between the material being irradiated and the heat source or emitter. In all the dryers considered here, however, there is a radiant component in the heat transfer mechanism.

E_{av} = Evaporation (average)

	Evaporation rate (lb/ft^2hr) Mean rate = Eav	Evaporation rate (kg/m^2h) Mean rate =Eav	Fluids, liquid suspension	Pastes, dewatered cake	Powders	Granules, pellets, extrudates	Operation
FORCED CONVECTION (cross-airflow)	0.15 - 0.25 $E_{av} = 0.2$	.7 – 1.2 $E_{av} = 1$	poor	fair	fair	good	batch
FORCED CONVECTION (throughflow)	1.0 – 2.0 $E_{av} = 1.5$	5 – 10 $E_{av} = 7.5$	-	-	-	good	batch
AGITATED PAN (sub-atmospheric)	1.0 – 5.0 $E_{av} = 3.0$	5 – 25 $E_{av} = 15$	fair	fair	fair	poor	batch
AGITATED PAN (atmospheric)	1.0 – 5.0 $E_{av} = 3.0$	5 – 25 $E_{av} = 15$	fair	fair	fair	poor	batch
DOUBLE CONE TUMBLER (sub-atmospheric)	1.0 - 3.0 $E_{av} = 2.0$	5 – 15 $E_{av} = 10$	-	poor	fair	poor	batch
FLUIDIZED BED (throughflow)	2 – 50 $E_{av} = 26$	10 – 250 $E_{av} = 130$	-	-	good	good	continuous
CONVEYOR BAND (throughflow)	2.0 – 10.0 $E_{av} = 6.0$	10 – 50 $E_{av} = 30$	-	fair	-	good	continuous
FILM DRUM (atmospheric)	3.0 – 6.0 $E_{av} = 4.5$	15 – 30 $E_{av} = 22$	good	fair	-	-	continuous
PNEUMATIC or FLASH	50 – 250 $E_{av} = 150$	250 – 1250 $E_{av} = 750$	-	fair	good	fair	continuous
ROTARY (indirect)	1.0 – 3.0* $E_{av} = 2.0$	15 – 50 $E_{av} = 33$	-	poor	good	fair	continuous
ROTARY (direct)	2.0 – 6.0* $E_{av} = 4.0$	30 – 100 $E_{av} = 65$	-	fair	fair	good	continuous
SPIN FLASH	4.0 – 18* $E_{av} = 11$	70 – 300 $E_{av} = 185$	-	good	good	fair	continuous
SPRAY	0.3 – 1.6* $E_{av} = 1.0$	5 – 25 $E_{av} = 15$	good	-	-	-	continuous

**Note: Evaporation rates for rotary, Spin Flash, and spray dryers are expressed in lb/ft^3hr.*

Table 1. Product classification and dryer types as an aid to selection

Direct heating is used extensively in industrial drying equipment where much higher thermal efficiencies are exhibited than with indirectly heated dryers. This is due to the fact that there are no heat exchanger losses and the maximum heat release from the fuel is available for the process. However, this method is not always acceptable, especially where product contamination cannot be tolerated. In such cases, indirect heating must be used.

With forced convection equipment, indirect heating frequently employs a condensing vapor such as steam in an extended surface tubular heat exchanger or in a steam jacket where conduction is the method of heat transfer. Alternatively, systems which employ proprietary heat transfer fluids can also be used. These enjoy the advantage of obtaining elevated temperatures without the need for high pressure operation, as may be required with conventional steam heating. This may be reflected in the design and manufacturing costs of the dryer. Furthermore, in addition to the methods listed above, oil- or gas-fired indirect heat exchangers can also be used.

In general, dryers are either suitable for batch or continuous operation. A number of the more common types are listed in **Table 1**, where an application rating based on practical considerations is given. In the following review, some of the factors likely to influence selection of the various types are discussed for particular applications.

BATCH DRYERS

It will be apparent that batch operated equipment is usually related to small production runs or to operations requiring great flexibility. As a result, the batch type forced-convection unit certainly finds the widest possible application of any dryer used today.

The majority of designs employ recirculatory air systems incorporating large volume, low pressure fans which with the use of properly insulated enclosures, usually provide thermal efficiencies in the region of 50 to 60%. However, in special applications of this type of dryer that call for total air rejection, this figure is somewhat lower and is largely related to the volume and temperature of the exhaust air. Capital investment and installation cost are relatively low. The use of fan systems minimizes both power requirements and operating costs. In contrast, labor costs can be high.

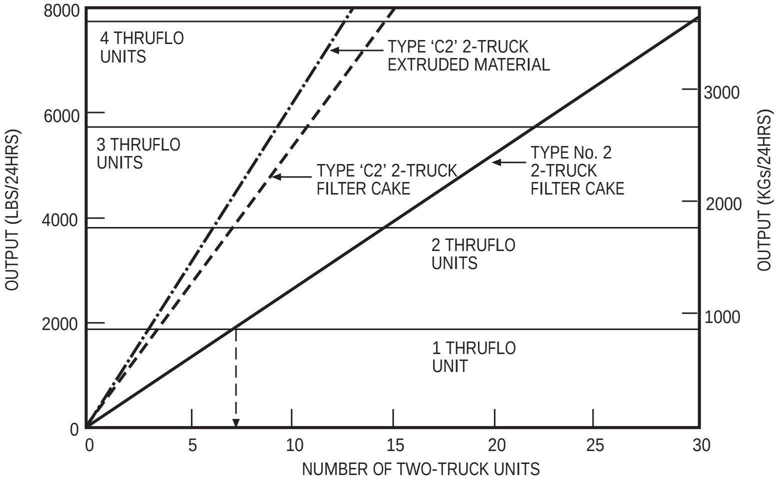

Figure 2. Comparative performance curves for Thruflo and conventional units

In such a plant, the drying cycles are extended, with 24 to 45 hours being quite common in certain cases. This is a direct result of the low evaporative rate, which normally is in the region of 0.15 to 0.25 lb / ft2hr. (0.7 to 1.2 kg / m^2h).

Following the recent trend and interest shown in preforming feedstock with regard to the design of extruding and tray-filling equipment for de-watered cakes – it is now possible to obtain the maximum benefit of enhanced evaporative rates by using through-air circulation dryers when handling preformed materials.

Figure 3. Thruflo dryer

Figure 2, shows how a high-performance dryer can produce 1950 lbs (890 kg) of dried material in a 24 hour period, at a terminal figure of 0.5% moisture (when handling a preformed filter cake having an initial moisture content of 58%). The significant improvement in performance can be seen from the curve, where the corresponding number of conventional two-truck recirculatory units would be between seven and eight for the same duty. The advantage is more apparent when it is seen that respective floor areas occupied are 55 ft^2 (5 m^2) for the Thruflo dryer pictured in **Figure 3**, and 245 ft^2 (22 m^2) in the case of conventional units using transverse air flow.

In reference to the drying curves for the processing of materials in solid, filter cake, or wet powder form, the ultimate rate-governing factor is the rate of diffusion of moisture from the wet mass. This becomes increasingly so during the falling rate period of drying. This situation, however, can be improved by preforming the product to increase the effective surface area presented to heat and mass transfer. The logical extension of this technique is total dispersion drying, i.e., flash or pneumatic dryers, fluid beds, etc. where discrete particles can be brought into contact with the hot gas. This produces rapid heat transfer with correspondingly short drying times.

Batch type fluidized bed dryers have, therefore, superseded forced convection units in many cases – notably in the drying of pharmaceuticals and for the processing of certain thermoplastics. These machines generally are available in a range of standard sizes with batch capacities from 50 to 200 lbs/h (23 to 90 kg/h), although much larger units are made for special applications.

When considering a fluid bed dryer, it is important to ensure that the feed material can be fluidized, both in its initial and final condition. It also should be remembered that standard fan arrangements are not equally suitable for a variety of materials of different densities. Therefore, it is necessary to accurately determine the minimum fluidizing velocity for each product.

If the feedstock is at an acceptable level of moisture content for fluidization, the fluid bed type of dryer provides many advantages over a batch type tray dryer. Simplified loading and unloading results in lower labor costs – high thermal efficiencies are common and the drying time is reduced to minutes, as opposed to hours in conventional units. Current developments of this type of equipment include techniques for the simultaneous evaporation of water and the granulation of solids. This makes these units ideal for use in the pharmaceutical field.

The various batch dryers operate by means of forced convection. The transfer

Figure 4. ***Double cone vacuum dryer***
Photo courtesy of Mitchell Dryers Limited, Carlisle, England

of thermal energy increases the vapor pressure of the absorbed moisture, while the circulated air scavenges the overlying vapor. Good conditions are maintained for continued effective drying.

Alternatively, and where the material is thermosensitive, implying low temperatures with consequently low evaporative rates, some improvement can be effected by the use of sub-atmospheric dryers, i.e., by reducing the vapor pressure. Several different configurations are in use and all fall into the category of conduction-type dryers. The most usual type of heating is by steam, although hot water or one of the proprietary heat transfer fluids can be used.

Figure 5. ***Conical section of a large spray dryer with secondary fluid bed dryer***

Two particular types are the double-cone dryer shown in **Figure 4** with capacities up to 400 ft^3 (11 m^3) and the agitated-pan dryer not normally larger than 8 ft (2.4 m) in diameter, where average evaporative rates per unit wetted area usually are in the region of 4 lb / ft^2hr (25 kg / m^2h). These units are comparatively simple to operate and when adequately insulated are thermally efficient, although drying times can be extended. They are especially suitable for applications involving solvent recovery and will handle powders and granules moderately well. However, with some materials, the tumbling action in double-cone dryers and the action of the agitator in agitated-pan machines can produce a degree of attrition in the dried product which may prove unacceptable.

Similarly, large rotary vacuum dryers are used for pigment pastes and other such materials, especially where organic solvents present in the feedstock need to be recovered. These units are normally jacketed and equipped with an internal agitator, which constantly lifts and turns the material. Here, heat transfer is entirely by conduction from the wall of the dryer and from the agitator. Due to the nature of their construction, initial cost is high relative to capacity. Installation costs also are considerable. In general, there are limited applications for these dryers.

CONTINUOUS DRYERS

For the drying of liquids or liquid suspensions, the evaporator of choice is usually either a drum dryer or a spray dryer.

A typical film drum dryer with a 4 ft (1.2 m) by 10 ft (3 m) long drum will evaporate about 600 lb / h (270 kg / h) of water. A typical spray dryer as shown in **Figure 5** will evaporate 22,000 lb / h (10,000 kg / h).

Where tonnage production is required, the drum dryer is at a disadvantage. However, the thermal efficiency of the drum dryer is high in the region of 1.3 to 1.5 mass units of steam per mass unit of water evaporated (65 to 75% efficiency) and for small to medium production runs, it does have many applications.

Drum dryers are usually steam heated, although work has been done to develope units for direct gas or oil heating. Completely packaged and capable of independent operation, these dryers can be divided into two broad classifications: single drum and double drum.

As seen in **Figure 6,** there are a number of different feeding arrangements for drum dryers, all of which have a particular use. In practice, these variants are necessary because of the differing characteristics of the materials to be dried and due to the fact that no universally satisfactory feeding device has yet been developed. This again illustrates the need for testing, not only in support of theoretical calculations for the determination of the best dryer size, but also to establish whether a satisfactory film can be formed.

Double drum machines normally employ a “nip” feed device, with the space between the drums capable of being adjusted to provide a means of controlling the film thickness. Alternately, and in the case of the single drum types, a variety of feeding methods can be used to apply material to the drum. The most common is the simple “dip” feed. With this arrangement, good liquor circulation in the trough is desirable in order to avoid increasing the concentration of the feed by evaporation. Again, for special applications, single drum dryers use top roller feed. While the number of rolls is related to the

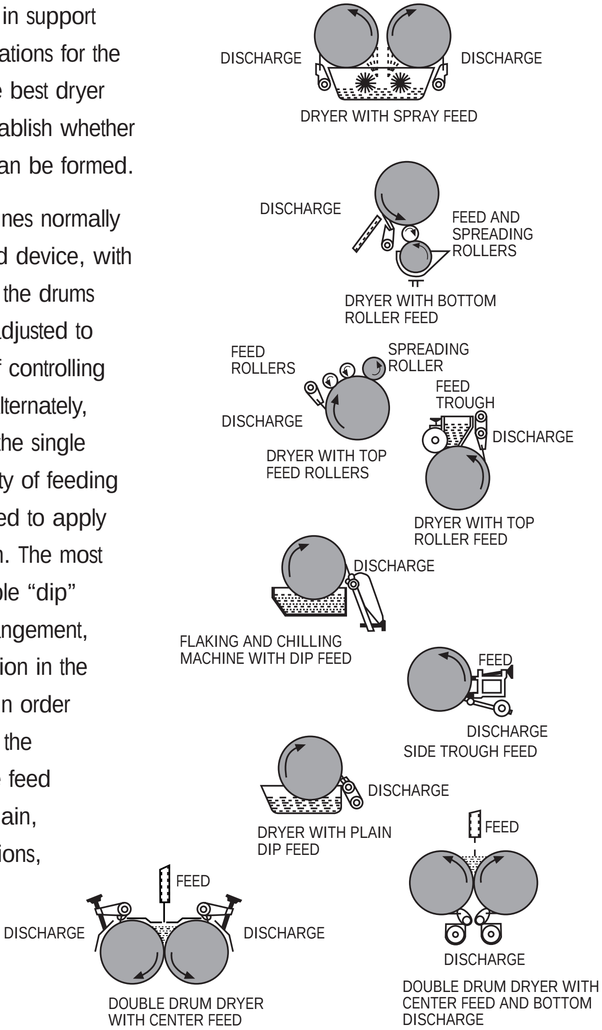

Figure 6. Feeding arrangements for drum dryers

particular application and the material being handled, generally this method of feeding is used for pasty materials such as starches. Where the feed is very mobile, rotating devices such as spray feeds are used.

It must be emphasized that the method of feeding the product to the dryer is of paramount importance to selection or design. There are, of course, certain materials which are temperature-sensitive to such a degree that their handling would preclude the use of an atmospheric drum dryer. In such cases, special sub-atmospheric equipment may provide the answer, although the capital cost in relation to output generally would restrict its use to premium grade products.

As an alternate, the spray dryer offers an excellent solution to a host of drying problems. Many materials, such as dairy and other food products, which would suffer from thermal degradation if dried by other methods, can often be handled by spray drying (due to the rapid flash evaporation and its accompanying cooling effect). The continuous method of operation also lends itself to large outputs and with the correct application of control equipment, to low labor costs.

SPRAY DRYERS

Fundamentally, the spray drying process is a simple one. However, the design of an efficient spray drying plant requires considerable expertise along with access to large scale test facilities, particularly where particle size and bulk density requirements in the dried product are critical. The sizing of spray dryers on a purely thermal basis is a comparatively simple matter since the evaporation is entirely a function of the Δt across the dryer. Tests on small pilot scale equipment are not sufficient in the face of such imponderables as: possible wall build-up, bulk density and particle size predictions. Atomization of the feed is of prime importance to efficient drying and three basic feed devices are used extensively: (1) single fluid nozzle or pressure type, (2) two-fluid nozzle or pneumatic type, and (3) centrifugal (spinning disc).

The single fluid nozzle produces a narrow spray of fine particles. While a multiplicity of nozzles of this type are used in tonnage plants to obtain the desired feed rate, due to the high pressure employed [up to 7000 PSIG (475 BARG)] excessive wear can result, particularly with abrasive products.

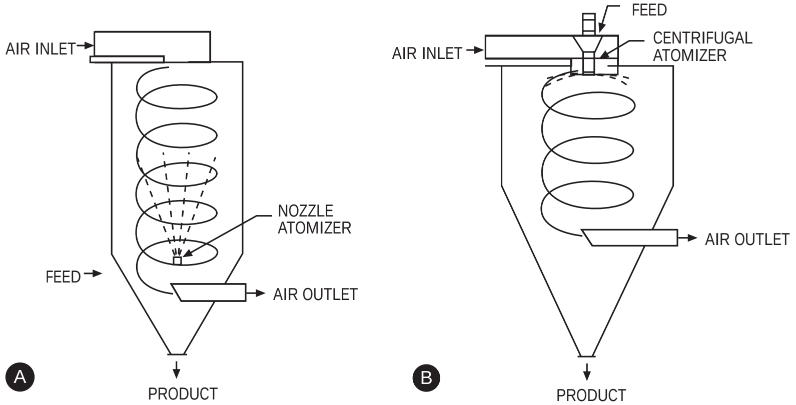

Figure 7. Alternative configurations of spray dryers showing (A) tall form type and (B) conical

As an alternative, the two-fluid nozzle with external mixing is used for a variety of abrasive materials. This system generally is limited to small capacity installations. Normally, the feed is pumped at about 25 PSIG (1.7 BARG) merely to induce mobility, while the secondary fluid is introduced at 50 to100 PSIG (3.5 to 6.8 BARG), producing the required atomization.

Centrifugal atomization achieves dispersion by centrifugal force, with the feed liquor being pumped to a spinning disc. This system is suitable for, and generally used on, larger productions. When stacked or multiple discs are employed, feed rates of 60,000 lb / hr (27,000 kg / h) are not uncommon.

Many different spray dryer configurations, along with a variety of air flow patterns, are in current use. The nature of the chamber geometry selected is strictly related to the system of atomization used. An example of this is the tower configuration designed to accommodate the inverted jet of the two-fluid nozzle, whereas the cylinder and cone of the more usual configuration is designed for the spray pattern produced by a disc type atomizer, shown in **Figure 7**. The product collection systems incorporated in spray drying installations are many and varied, and can constitute a substantial proportion of the total capital investment. In some cases, this can be as high as 20 to 25% of the installed plant cost. It also must be remembered that to be suitable for spray drying, the feed must be in pumpable condition. Therefore, consideration must be given to the up-stream process, i.e., whether there is any need to re-slurry or dilute, in order to make the feed suitable for spray drying. As a rule of thumb, the limiting viscosity for good atomization is 250 – 300 Centipoise.

The economic viability of a drying process ultimately depends on the cost per pound of the dried product. The spray dryer usually has a greater amount of water to remove by thermal methods than other types. For example, to dry 20,000 lbs/hr (9,000 kg/h) of a 30% solids/water slurry to 0.5% moisture, the spray dryer would have an approximate diameter of 30 ft for the evaporation of 14,000 lbs/hr (6,360 Kg/h). If, however, the feed solids were increased to 50% by evaporation, the hourly evaporation rate would decrease to 6,000 lbs/h (2,700 Kg/h) and the chamber diameter would be about 20 ft (6 m), with a corresponding decrease in thermal input and air volume. The former system would, as a result, also require larger fans and product collection systems. The overall thermal efficiency would remain substantially constant at 76% with increasing feed solids. However, the cost per pound of dry product is significantly lower when drying from the higher feed solids.

Spray drying does have many advantages, particularly with regard to the final product form. This is especially so where pressing grade materials are required, i.e., in the production of ceramics and dust-free products such as dyestuffs. With the introduction of new geometries and techniques, there has been further development into areas such as foods, and in the production of powders which may be easily reconstituted. These spray dryers usually incorporate one or two fluid beds – static and vibrating – for the final drying and cooling of the agglomerated powder.

ROTARY DRYERS

Another type of dryer, popular in the chemical and process industries, is the continuous rotary dryer. This machine is generally associated with tonnage product, and as a result of its ability to handle products having a considerable size variation, can be used to dry a wide range of materials. The principle sources of thermal energy are oil, gas and coal. While typical inlet temperatures for direct-fired dryers using these fuels is in the order of 1200°F (650°C), they

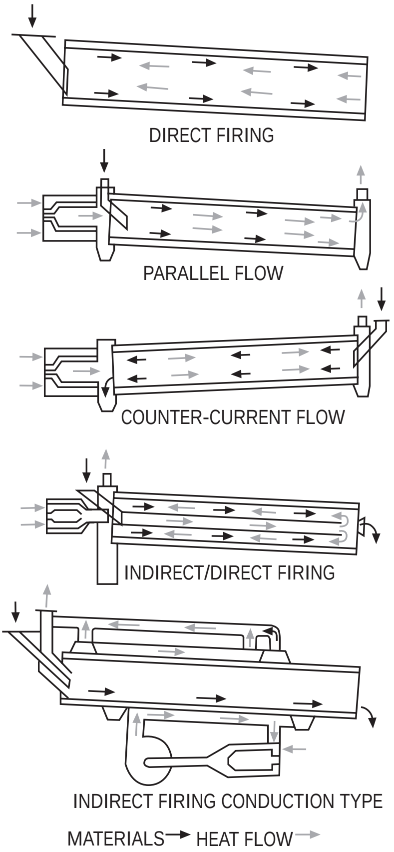

Figure 8. Typical rotary dryer arrangements

may be as high as 1600°F (850°C), depending largely on the nature of the product handled. Where feed materials are thermo-sensitive, steam heating from an indirect heat exchanger is also used extensively. These dryers are available in a variety of designs, but in general, can be divided into two main types: those arranged for direct heating and those designed for indirect heating. As seen in **Figure 8**, certain variants do exist. For example, the direct / indirect dryer simultaneously uses both systems.

Where direct heating is used, the products of combustion are in intimate contact with the material to be dried.
In the case of indirect systems, the hot gases are arranged to circulate around the dryer shell. Heat transfer is then conducted and radiated through the shell.

With the indirect-direct system, hot gases first pass down a central tube, coaxial with the dryer shell, and return through the annular space between the tube and shell. The material being cascaded in the annulus picks up heat from the gases, as well as by conduction from direct contact with the central tube. This design is thermally, highly efficient. While there are a number of proprietary designs employing different systems of air flow, the two main types most commonly used are parallel and counter-current flow. With parallel flow, only high moisture content

Figure 9. Fixed tube rotary dryer
Photo courtesy of Mitchell Dryers Limited, Carlisle, England

material comes into contact with the hot gases and, as a result, higher evaporative rates can be achieved than when using counter-current flow.

In addition, many thermo-sensitive materials can be dried successfully by this method. Such an arrangement lends itself to the handling of pasty materials, since the rapid flashing off of moisture and consequent surface drying limits the possibility of wall build-up or agglomeration within the dryer. On the other hand, counter-current operation normally is used where a low terminal moisture content is required. In this arrangement, the high temperature gases are brought into contact with the product immediately prior to discharge, where the final traces of moisture in the product must be driven off.

In both these processes, however, gas velocities can be sufficiently high to produce product entrainment. Therefore, they would be unsuitable for low density or fine particle materials such as carbon black. In such cases, the indirect-fired conduction type dryer is more suitable, since the dryer shell is usually enclosed in a brick housing or outer steel jacket into which the hot gases are introduced. Since heat transfer is entirely by conduction, conventional flighting and cascading of the material is not used. Rather, the inside of the shell is fitted with small lifters designed to gently turn the product, while maintaining maximum contact with the heated shell.

The steam tube unit is another type of indirectly heated dryer, which is particularly useful for fine-particle or heat-sensitive materials. This dryer can be of either the fixed tube variety – equipped with conventional lifting flights designed to cascade the product through a nest of square section tubes; or alternately, a central rotating tube nest. **Figure 9** shows a fixed-tube rotary dryer which normally has an electrical vibrator fitted to the tube nest to eliminate the possibility of bridging of the product, with consequent loss of heat transfer surface. Since the heat exchanger is positioned within the insulated shell in this type of dryer, the air rejection rate is extremely low and thermal efficiencies are high. In general, this design is suitable only for free flowing materials.

A considerable amount of work has been done on the development of various types of lifting flights, all designed to produce a continuous curtain of material over the cross section of the dryer shell. Other special configurations involve cruciform arrangements to produce a labyrinth path. The object is to give longer residence times where this is necessary. When the diffusion characteristics of the material or other process considerations call for extended residence times, these machines, no doubt, will continue to find application.

PNEUMATIC DRYERS

Where total dispersion of the product in a heated gas stream can be achieved with a significant increase in evaporative rates, pneumatic or continuous fluid bed dryers are preferred. The capital cost of these alternatives is generally lower and maintenance is limited to such components as circulating fans and rotary valves. When considering these two types of dryers, it is convenient to examine them

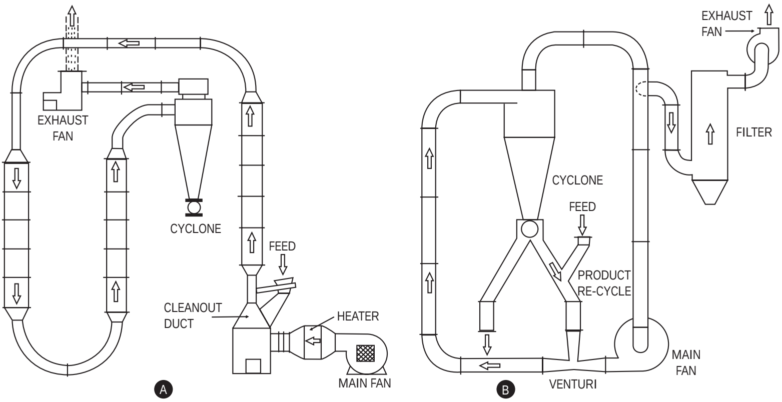

Figure 10. (A) Multipass and (B) air recycle arrangements in flash dryers

together since both share similar characteristics. Both employ forced convection with dispersion of the feedstock, and as a result of the intimate contact between the drying medium and the wet solids, both exhibit much higher drying rates than any of the other dryers previously mentioned.

In a fluidized bed dryer, the degree of dispersion and agitation of the wet solids is limited, whereas in a pneumatic dryer, the degree of dispersion is total and the material is completely entrained in the gas stream. This is often an advantage because the drying medium is used as a vehicle for the partially dried product. Other operations such as product classification can also be carried out where required. Another feature of fluid bed and flash dryers is that the method of operation allows many temperature-sensitive materials to be dried without thermal degradation, due to the rapid absorption of the latent heat of vaporization. This generally permits high-rate drying, whereas in other types of dryers, lower temperatures would be necessary and correspondingly larger and more costly equipment would be required.

A good degree of temperature control can be achieved in fluid bed dryers and the residence time of the material can be varied either by the adjustment of the discharge weir or by the use of multi-stage units. Similarly, the residence time in the flash dryer can be adjusted by the use of variable cross-sectional area and therefore, variable velocity. In addition, multiple effect columns can be incorporated to give an extended path length or continuous recirculatory systems employing both air and product recycle can be used as illustrated in **Figure 10**.

Generally speaking, the residence time in fluidized bed dryers is measured in minutes and in the pneumatic dryer in seconds. Both dryers feature high thermal efficiencies, particularly where the moisture content of the wet feed is sufficiently high to produce a significant drop between inlet and outlet temperatures. While the condition of the feed in the pneumatic dryer is somewhat less critical than that in the fluid bed dryer – owing to the fact that it is completely entrained – it is still necessary to use backmixing techniques, on occasion, to produce a suitable feed. A variety of feeding devices is used with these machines.

In fluid bed dryers, special attention must be paid to the nature of the proposed feed since one condition can militate against another. To some extent, this is reflected in the range of variation in the figures given in **Table 1** for evaporative rates. If a large or heavy particle is to be dried, the fluidizing velocities required may be considerable and involve high power usage. In such circumstances, if the moisture content is low and the surface / mass ratio is also low, the thermal efficiency and evaporation would be low. This would make selection of a fluid bed dryer completely unrealistic and probably would suggest a conventional rotary dryer for the application.

Another case is when the minimum fluidizing velocity is so low that a dryer of very large surface dimensions is necessary to obtain the required thermal input. This also occurs in problems of fluid bed cooling and is usually overcome by the introduction or removal of thermal energy, or by additional heating or cooling media through extended-surface heat exchangers immersed in the bed.

With both types of dispersion dryer, many configurations are available. While the power requirements of each is usually well in excess of other dryers – due to the use of high efficiency product recovery systems – the small size of the fluid bed dryer compared with conventional rotaries, and the fact that the flash dryer can be arranged to fit in limited floor space, makes them attractive.

BAND DRYERS

When selecting a dryer, it is always necessary to consider the final product form. When the degree of product attrition common to pneumatic and fluidized bed dryer operation is unacceptable, continuous band or apron dryers can provide an effective solution. These are widely used where moderately high rates of throughput on a continuous basis are called for. The most commonly used continuous band dryer is the single pass machine employing through-air

Figure 11. Continuous conveyer band dryer arrangement for direct gas firing
Photo courtesy of Mitchell Dryers Limited, Carlisle, England

circulation. Alternatively, and where there is limited floor space or a possible need for long residence time, multi-pass units are used with the conveyors mounted one above the other. In similar circumstances, another special type of multi-deck dryer can be used which employs a system of tilting trays so that the product is supported on both the normal working and the inside of the return run of the conveyor band. This arrangement considerably increases the residence time within the dryer and is particularly useful where the product has poor diffusion characteristics.

The method of airflow employed on these dryers is either vertically downward through the material and the supporting band or alternatively upward. Sometimes a combination of the two may be dictated by the nature of the wet feed. It occasionally happens that extruded materials have a tendency to coalesce when deposited on the band, in which case one or more sections at the wet end of the dryer may be arranged for upward air flow to reduce the effect. Wherever possible, through-air circulation is used as opposed to transverse air flow. This results in greatly increased evaporative rates as, may be seen from **Table 1**.

An illustration of the relatively high performance of a band dryer operating on this system, as compared with a unit having transverse air flow, can be cited in a case involving the processing of a 70% moisture content filter cake. When this material is dried in a conventional unit, the cycle time is in the region of 28 hours. This is reduced to 55 minutes in the through-circulation band dryer, largely as a result of using an extruder / preformer designed to produce a dimensionally stable bed of sufficient porosity to permit air circulation through the feed.

In view of this, transverse air flow is usually used only where the type

Figure 12. Two-stage band dryer
Photo courtesy of Mitchell Dryers Limited, Carlisle, England

of conveyor necessary to support the product does not allow through-flow or where the product form is not suitable for this method of airflow. The most usual method of heating is by steam through heat exchangers mounted in the side plenums or above the band, although direct oil and gas firing are sometimes used. In such cases, the products of combustion are normally introduced to a hot well or duct at an elevated temperature from where they are drawn off, and mixed with circulating air in each zone or section of the dryer.

Another alternative with direct firing is to use a series of small individual burners positioned so that each serves one or more zones of the dryer. Typical single pass dryers of modular construction are illustrated in **Figures 11 and 12**.

With this type and size of dryer, the average product throughput is about 5600 lbs / hr (2550 kg / h) and involves an evaporation of 1600 lbs / h (730 kg / h) moisture. It is not unusual, however, to find equipment with evaporative capacities of 3000 lbs / h (1350 kg / h). Such outputs involve a large band area with correspondingly large floor area requirements. Various types of feeding arrangements are available to spread or distribute the wet product over the width of the band. Here again, the nature of the feed is an important prerequisite for efficient drying. Steam heated, finned drums have been used as a means of producing a partially dried, preformed feed. While the amount of pre-drying achieved is reflected in increased output for a given dryer size or, alternatively, enables a smaller dryer to be used, these items are usually much more costly than many of the mechanical extruders which are available.

Generally, these extruders operate with rubber covered rollers moving over a perforated die plate with feed in the form of pressed cakes, or more usually, as the discharge from a rotary vacuum filter. The pressure type employ a gear pump arrangement with extrusion taking place through a series of individual nozzles, while some use screw feeds which are usually set up to oscillate to obtain effective coverage of the band. Alternate designs include rotating cam blade or conventional bar-type granulators, although the latter often produce a high proportion of fines because of the pronounced shearing effect. This makes the product rather unsuitable due to the entrainment problems which can occur.

Each of the types available are designed to produce continuous / discontinuous extrudates or granules, the grid perforations being spaced to meet product characteristics. In selecting the proper type of extruder, it is essential to carry out tests on semi-scale equipment, as no other valid assessment of suitability can be made.

As a further illustration of the desirability of using a preforming technique, testing of a designated material exhibited a mean evaporative rate of 1.9 lbs / ft^2hr (10 kg / m^2h) when processed in filter cake form without preforming. When extruded, however, the same material being dried under identical conditions gave a mean evaporative rate of 3.8 lb / ft^2hr (20 kg / m^2h). This indicates, of course, that the effective band area required when working on extruded material would be only 50% of that required in the initial test. Unfortunately, the capital cost is not halved as might be expected, since the feed and delivery ends of the machine housing the drive and terminals remain the same and form an increased proportion of the cost of the smaller dryer. While the cost of the extruder also must be taken into account in the comparison, cost reduction still would be about 15%. Of course, there are other advantages which result from the installation of the smaller dryer. These include reduced radiation and convection losses and a saving of approximately 40% in the floor area occupied.

This type of plant does not involve high installation costs, and both maintenance and operating labor requirements are minimal. Since they are generally built on a zonal principle with each zone having an integral heater and fan, a good measure of process control can be achieved. Furthermore, they provide a high degree of flexibility due to the provision of variable speed control on the conveyor.

PULSE DRYING

Pulse drying is a relatively new technique for drying high moisture / low solids feed streams into a powder form. The basis for the technology is the use of a pulse combustion burner. The burner, which is similar to the pulse burner used in the Lennox furnace, is aerodynamically designed to produce a pulsating air flow within the burner system, along with the heat release which is used for evaporation. This fossil fueled, pulse burner produces both pressure waves and heat from one fuel source.

The pulsation rate is determined by the geometry of the combustor and has a natural frequency of approximately 45 to 50 cycles per second in a 3.5 to 4.0 mBTU burner. A single detonation cycle causes the pressure to rise in the burner, shutting off the fuel flow and air supply momentarily, while exiting the burner through the exhaust system. As the pressure wave falls after the first cycle, it is followed by a negative pressure wave, which draws in more air and fuel. The next cycle is initiated either by an igniter, or residual heat in the combustion chamber. In a continuously operating pulse burner, the divergent exhaust nozzle amplifies these discreet detonations into a 250 Hz wave form in the downstream hot exhaust gasses. This combination of pressure waves and heat is used for drying free-flowing, high moisture and low solids liquid feed streams.

The wave form atomizes the raw feed liquid into many finely divided slurry and water particles, apparently acting to shear the bond that the water has to the solids. Since this is simultaneously done in a 2,300°F (1260°C) heat zone, flash evaporation takes place. The residence in the drying section is only a few milliseconds and the continuing evaporation keeps the product particle temperature very low, typically 125° to 135°F (52° to 57°C). The process is continuous.

From a cold start, production drying can take place within 3 to 5 minutes. Pulse drying has been used for organic, inorganic, process and waste streams. It can handle a wide range of feeds, from sub-micron to 5/16 in (8 mm) particle size, and can be fed with any positive displacement pump, diaphragm pump or screw auger. The smallest system can evaporate one ton/hour of water and the largest single system module evaporates four tons/hour.

Production Pulse Dryers have been in use since 1985 to dry organic fish meal, hazardous plating wastes and radioactive depleted uranium oxides. It also is specified to dry a food grade, cold water, swelling starch product.

Energy consumption ranges from 1,475 to 1,675 BTU/s (370 to 420 Kcal/s) to remove one pound of water, depending on whether the feed is organic or inorganic. The evaporation rate is improved by the pulse combustion burner, which increases the heat and mass transfer rates so that there is less time required for drying.

At this time Pulse Drying technology is best suited to waste industrial sludge feed streams where only water elimination is needed. It is also suitable in other applications where the powder form is not specific, where the feed stream is free flowing, and where the solids are not hygroscopic. Reliability is extremely high, maintenance is very low, and operator attention is usually limited to periodically changing the powder container.

The Pulse Dryer can also dry up to 80 to 99% granular solids, depending on the requirement. The system is horizontally designed, can be fully shop pre-fabricated, and is transportable.

SELECTION

The application ratings in **Table 1** list the approximate mean evaporative rates for products under a generic classification and are based on the writer's experience over a number of years in the design and selection of drying equipment. It should be appreciated, however, that drying rates considerably vary in view of the variety of materials and widely differing chemical and physical characteristics. Furthermore, drying conditions such as temperature and the moisture range over which the material is to be dried, have a definite effect on the actual evaporative rate. It is important, therefore, when using the figures quoted that an attempt is made to carefully assess the nature of the product to be handled and the conditions to which it may be subjected to achieve greater accuracy. With these factors in mind, it is hoped that the foregoing observations on drying techniques, along with the appropriate tables and curves, will provide a basis for making an assessment of the type, size and cost of drying equipment.

In making a preliminary assessment of dryer selection, there are a number of further points to consider:

- What is the nature of the up-stream process? Is it feasible to modify the physical properties of the feed, e.g., mechanical dewatering to reduce the evaporative load?
- Does the quantity to be handled per unit time suggest batch or continuous operation?

- From a knowledge of the product, select the type(s) of dryer which it appears would satisfactorily handle both the wet feedstock and the dried product. Relate this to the equipment having the highest application rating in **Table 1**.
- From a knowledge of the required evaporative duty, i.e., the total mass of water to be evaporated per unit time and by the application of the approximate Eav figure given in **Table 1**, estimate the size of the dryer.

Although a great deal of fundamental work has been carried out into the mechanics of drying which enables recommendations to be made, it is most desirable for pilot plant testing to be done. This is not only necessary to support theoretical calculations but also to establish whether a particular dryer will satisfactorily handle the product. In the final analysis, it is essential to discuss the drying application with the equipment manufacturer who has the necessary test facilities to examine the alternatives objectively, and has the correlated data and experience from field trials to make the best recommendation.

EFFICIENT ENERGY UTILIZATION IN DRYING

It is generally necessary to employ thermal methods in order to achieve a product that is termed commercially dry. Thermal dryers, therefore, are an important unit operation in many industries. Products such as pigments, baby formula, kaolin and instant coffee usually have to be processed in dryers to obtain the final product.

The commercial drying process can take place in a number of different types of dryers as described in the previous section. However, the thermodynamics of drying is the same regardless of the actual device. Water or another liquid such as a solvent has to be evaporated from a solid by the application of heat. Generally, the drying takes place in an air atmosphere, although some specialized dryers may use nitrogen or even superheated steam as the atmosphere.

The most important parameter that governs the pretreatment and the dryer design is the "cost per unit weight of dried product."

While drying is an extremely energy intensive operation, there are techniques that can be used to minimize the energy costs per unit output of product, including:

- Minimizing the water content of the feed prior to feeding to the dryer.
- Maximizing the temperature drop of the drying gas. This implies maximum inlet and minimum outlet temperature.
- Employing the maximum possible recirculation of the drying gas.
- Considering the possibility of two stage counter flow drying.
- Utilizing the heat in the discharge air to preheat incoming air.

- Utilizing direct heat wherever possible.
- Reducing radiation and convection heat loss by means of efficient thermal insulation.

The most important of the above is to minimize the water content of the feed by pretreatment with other techniques. Mechanical separation processes such as settling, centrifuging, filtration, reverse osmosis, etc., are far more energy efficient than thermal processes. When mechanical separation is not possible, evaporation should be considered. Although evaporation is a thermal process, the thermal efficiency of water removal is many times that of a dryer. In a large system, it is possible to evaporate 7 or 8 mass units of water for 1 mass unit of steam supply. Mechanical recompression evaporation can be even more energy efficient. A typical dryer does not even evaporate 1 mass unit per 1 mass unit of steam.

MINIMIZE WATER CONTENT OF THE FEED

An example of this technique would be the case of a kaolin dryer with a duty to produce 50,000 lb/h (12,727kg/h) of solids with 1% moisture from a feed of 99,000 lb/h (45,454kg/h) of material at 50% moisture. Typically, this duty would be performed in a large spray dryer. However, if the solids content of the feed

PARAMETER	PNEUMATIC DRYER	SPRAY DRYER
Feed rate	88,200 lb/h (40,090 Kg/h)	88,200 lb/h (40,090 Kg/h)
Filtrate rate	21,500 lb/h (9,770 Kg/h)	–
Evaporative rate	9,200 lb/h (4,180 Kg/h)	30,700 lb/h (13,950 Kg/h)
Production rate	57,500 lb/h (26,100 Kg/h)	57,500 lb/h (26,100 Kg/h)
Initial moisture content	14%	35%
Final moisture content	0.1%	0.1%
Air inlet temperature	752°F (400°C)	752°F (400°C)
Air outlet temperature	230°F (100°C)	230°F (100°C)
Total thermal input	21.43×10^6 BTU/h (5.6×10^6 Kcal/h)	66.2×10^6 BTU/h (16.7×10^6 Kcal/h)
Basic air volume (BAV) at NTP	28,100 ft^3/min	86,700 ft^3/min
Fuel consumption	1,080 lb/h (490 Kg/h)	3,290 lb/h (1495 Kg/h)
Total dryer horsepower	187 kW	530 kW
Total filter horsepower	295 kW	–
Total system horsepower	482 kW	530 kW
Total thermal input expressed as kilowatts	6,280 kW	19,400 kW
Total energy input to system	6,762 kW	19,930 kW

Table 2. ***Comparison of the operating conditions and energy utilization of pneumatic and spray dryers processing concentrates***

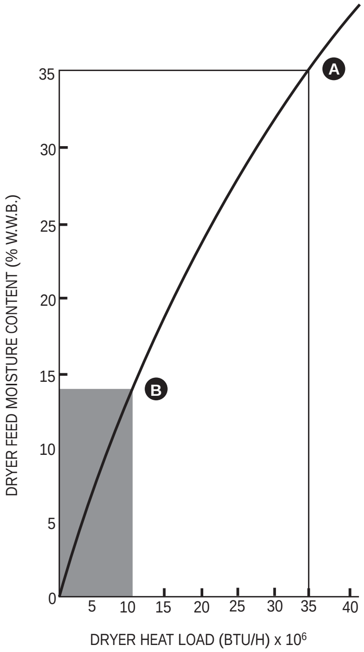

Figure 13. Thermal energy required for drying vs. feed moisture content (duty as in Table 2)

material can be increased from 50% to 60% by evaporation, the amount of water to be evaporated in the spray dryer is reduced by 33%. A similar example is shown in **Table 2**. In this case the surplus water is being removed by filtration, and the resulting cake flash dried. This results in a smaller and less expensive dryer because evaporation is far more thermally efficient than drying. For example, a double effect evaporator for kaolin will require only 1 / 3 the energy per unit of evaporation than the dryer. The pre-concentration will save approximately 15 million BTU / h (3.8 million Kcal / h).

A further example is illustrated in **Figure 13**. At 35% moisture content as shown at point “A” , a spray dryer could be used to dry the material to 0.1%. However, if a rotary vacuum filter can be used to reduce the water content to 14%, the energy requirements are reduced to less than 1 / 3. The final drying can then be performed by a spin flash or pneumatic dryer.

It is important to re-emphasize that, in almost all drying applications, the best energy saving technique is to pre-concentrate the product as far as possible prior to drying. In addition to energy, there are also large savings on the capital cost of the dryer – which in most cases, far exceed the cost of the preliminary dewatering equipment.

MAXIMIZE THE TEMPERATURE DROP OF THE DRYING GAS

Unlike evaporators where the latent heat of the evaporated water can usually be reused in effects operating at lower pressure, the steam from a dryer is not easily reused apart from some preheating applications. The steam is usually carried in a gas stream, which reduces the thermal potential. Hence, the dryers are usually a once-through system. Therefore, it is important to minimize the volume of inlet gas used to input the heat and carry over the steam that is generated. If large quantities of gas exit the dryer, an equally large quantity of heat is lost. The higher the inlet gas temperature, the lower the quantity of gas required, and the higher the efficiency of the dryer. Unfortunately, there are usually temperature limitations associated with the product which limit both the inlet and outlet gas temperature. For example, with dairy products, the inlet gas temperature limit is approximately 480°F (250°C). For ceramics, the gas inlet temperature can exceed 1200°F (650°C). The outlet temperature is controlled by the type of product and the dryness required.

GAS RECIRCULATION

Any gas that leaves the system carries heat and reduces the thermal efficiency of the dryer. It appears logical to recirculate as much gas as possible. However, this system is limited by the relationship between the required dryness of the product and the humidity of the outlet gas. A condenser can be used in the recirculation loop to condense some water vapor, but the heat can only be recovered at low temperatures.

A pneumatic dryer with recirculation is shown in **Figure 14**. In this example, the hot gases are recycled with only a relatively small quantity rejected at the exhaust and a correspondingly small amount of fresh air admitted at the burner. An additional benefit is that this system reduces the oxygen content in the gas stream. In some cases, this permits the use of higher temperatures for products which can oxidize. This results in higher thermal efficiency. A comparison between a partially closed pneumatic dryer and a total rejection dryer is detailed in **Table 3**.

TWO STAGE DRYING

To reduce the outlet gas temperature, it may be appropriate to use two stages of drying. The first stage of drying would remove the bulk of the water, but since the product would not need to be low in dryness, the outlet air temperature could be lower. A second and much smaller dryer would be used as the final stage. This

PARAMETER	CLOSED CIRCUIT	TOTAL REJECTION
Evaporation	1,250 lb/h (568 Kg/h)	1,250 lb/h (568 Kg/h)
IMC % wwb	85	85
FMC % wwb	10	10
Feed	1,500 lb/h (682 Kg/h)	1,500 lb/h (682 Kg/h)
Air inlet temperature	932°F (500°C)	662°F (350°C)
Air outlet temperature	302°F (150°C)	248°F (120°C)
Exhaust dry airflow	1,368 lb/h (622 Kg/h)	16,400 lb/h (7550 Kg/h)
Heat losses	79,700 BTU/h (20,000 Kcal/h)	744,000 BTU/h (188,000 Kcal/h)
Total heat input	1,680,400 BTU/h (423,000 Kcal/h)	2,375,700 BTU/h (600,000 Kcal/h)
Efficiency %	87.9	62.4

Table 3. Comparison of self-inertizing t.v. dryer versus total rejection t.v. dryer

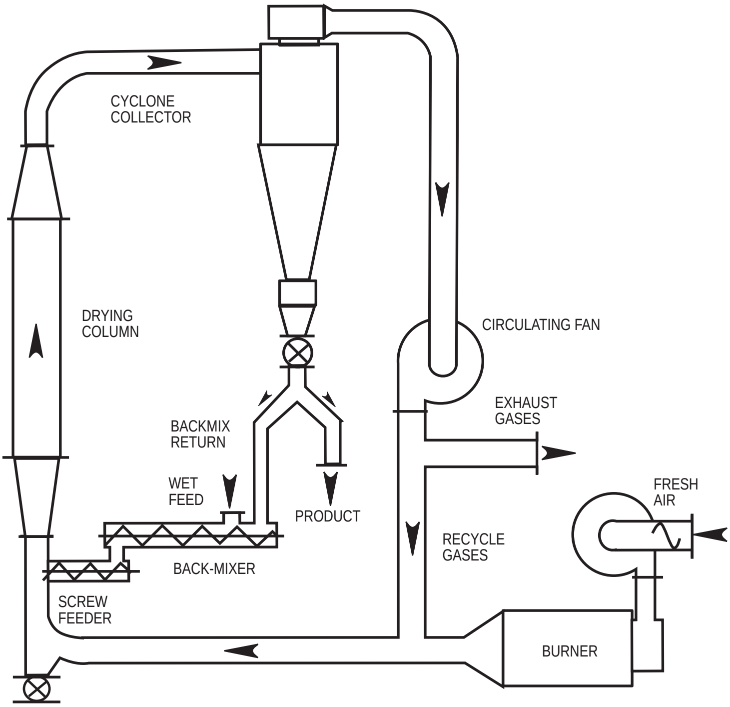

Figure 14. Self-inertizing pneumatic dryer with backmix facility

would produce the product at the final required dryness. There are a number of applications for this technique since second stage dryers are needed for other functions such as dust removal and agglomeration.

RECUPERATIVE HEATING OF INCOMING AIR

Heat can be saved by using the discharge gas (air) / steam mixture to preheat the incoming air. This technique is most beneficial when product properties restrict the gas (air) inlet temperatures, requiring large volumes of gas (air).

UTILIZE DIRECT HEAT

There is less heat loss when the inlet gas (air) is heated directly by the combustion gases from the gas or oil burner. Clearly, this is not possible for many products. However, an indirect heating system using a flue gas / air heat exchanger will typically have an efficiency of 85%. This can be improved to 93 to 95% with air preheating and flue gas recuperation.

THERMAL INSULATION

Drying equipment tends to be large. Also the equipment operates at quite high temperatures. As a result, there is a large potential for high heat loss from both convection and radiation. Insulation of the equipment is vital to ensure energy efficiency.

CHANGING CAPACITY

One overlooked parameter that can have a significant bearing on efficiency is changing capacity. With spray dryers and rotary dryers, the mass airflow can be varied, facilitating modulation of the dryer when operated at lower throughputs. In the case of pneumatic, fluidized and spin flash dryers, however, the drying gas medium performs a dual function of providing the heat input for the drying and also acts as the conveying medium for the transportation of the product. Since the mass flow of the gas has to remain relatively constant, the only way a dryer can be turned down is to reduce the inlet gas temperature. This has an adverse effect on efficiency.

Figure 15 illustrates the effects on thermal efficiency – of either increasing or decreasing the evaporator capacity for an application – where it is necessary to maintain a constant air outlet temperature to maintain acceptable dry product. Since the gas flow has to be constantly maintained, the only parameter that can be changed is the inlet gas temperature. The figure refers to total rejection and demonstrates that an efficiency of 62.4% can be achieved at design rate (this is reduced to 50% when the dryer is operated at 60% of design capacity). This illustrates the need to establish realistic production requirements and also avoid excessive safety factors on the design.

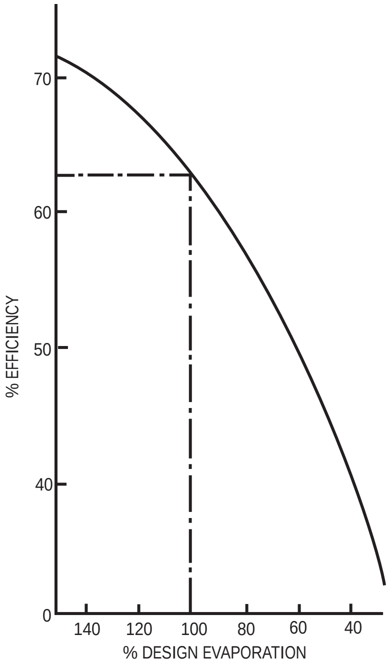

Figure 15. ***Variation of efficiency with dryer turndown***

FLUID BED

Most powder-like products produced by spray drying or grinding are dusty, exhibit poor flow characteristics and are difficult to rehydrate.

It is well known, however, that agglomeration in most instances will improve the redispersion characteristics of a powder. Added benefits of agglomerated powders are that they exhibit improved flowability and are non-dusting. All of these characteristics account for their increased demand in recent years.

Depending on the application or industry where the process is being used, agglomeration is sometimes referred to as granulation or instantizing.

INSTANT POWDERS

Powders with particle size less than about 100 micron typically tend to form lumps when mixed with water and require strong mechanical stirring to become homogeneously dispersed or dissolved in the liquid. What happens is that water, aided by capillary forces, penetrates into the narrow spaces between the particles and the powder starts to dissolve. As it does so, it forms a thick, gel-like mass which resists further penetration of water. Thus, lumps containing dry powder in the middle will be formed and, if enough air is locked into these lumps, they will float on the surface of the liquid, resisting further dispersion.

To produce a more readily dispersible product, the specific surface of the powder has to be reduced and the liquid needs to penetrate more evenly around the particles. In an agglomerated powder with an open structure, the large passages between the individual powder particles assist in quickly displacing the air – and allow liquid to penetrate before an impenetrable gel layer is formed. The powder can disperse into the bulk of the liquid, followed by final dissolution.

Although there is always some degree of overlap between them, the reconstitution of an agglomerated product can consist of the following steps:

1. Granular particles are wetted as they touch the water surface.
2. Water penetrates into the pores of the granule structure.

3. The wetted particles sink into the water.
4. The granules disintegrate into their original smallest particles, which disperse in the water.
5. The small, dispersed particles dissolve in the water.

It is important to realize that the total time required for all these steps should be the criteria used to evaluate a product's instant properties. It is not unusual to see products characterized only on their wettability and sinkability. This neglects the importance of the dispersion and dissolution steps, the time for which may vary considerably with different agglomeration methods.

For powders produced by spray drying, there are a number of ways in which the agglomeration can be accomplished in the spray dryer itself. This often is referred to as the "straight-through" process and is illustrated in **Figure 16**. Note that fine powder from the cyclone is conveyed up to the atomizer where it is introduced into the wet zone surrounding the spray cloud. Cluster formation will occur between the semi-moist, freshly produced particles and the recycled fines. The agglomerated product is then removed from the bottom of the drying chamber, cooled and packaged. This method produces a degree of agglomeration that is sufficient for many applications.

An alternative approach to agglomeration is referred to as the re-wet method. This is characterized by processing an already existing fine dry powder into an agglomerate, using fluidized bed technology.

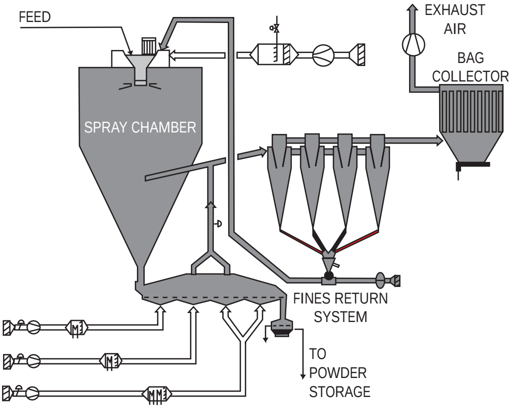

Figure 16. Straight-through agglomeration

THE AGGLOMERATION MECHANISM

Two particles can be made to agglomerate if they are brought into contact and at least one of them has a sticky surface. This condition can be obtained by one or a combination of the following:

1. Droplet humidification whereby the surface of the particles is uniformly wetted by the application of a finely dispersed liquid.
2. Steam humidification whereby saturated steam injected into the powder causes condensation on the particles.
3. Heating – for thermoplastic materials.
4. Addition of binder media, i.e., a solution that can serve as an adhesive between the particles.

The steam condensation method usually cannot provide enough wetting without adversely heating the material and is used less frequently on newer systems.

After having been brought into a sticky state, the particles are contacted under such conditions that a suitable, stable, agglomerate structure can be formed. The success of this formation will depend on such physical properties as product solubility and surface tension, as well as on the conditions that can be generated in the process equipment.

For most products, possible combinations of moisture and temperature can be established as shown in **Figure 17**. Usually, the window for operation is further narrowed down by the specifications for product characteristics. Once the agglomerate structure is created, the added moisture is dried off and the powder cooled below its thermoplastic point.

AGGLOMERATION EQUIPMENT

While slightly different in equipment design and operation, most commercially available agglomeration processes are fundamentally the same. Each relies on the formation of agglomerates by the mechanism already described. This is followed by final drying, cooling and size classification to eliminate the particle

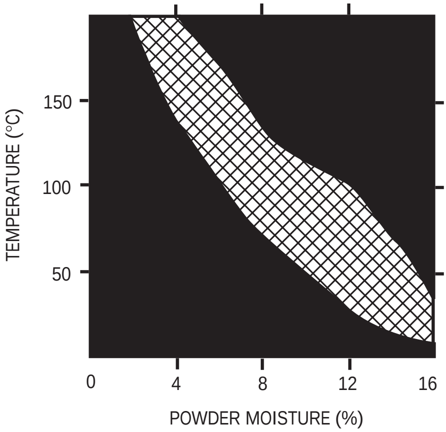

Figure 17. Typical combinations of conditions for agglomeration

agglomerates that are either too small or too large. Generally, designs involve a re-wet chamber followed by a belt or a fluid bed for moisture removal. Such a system is shown in **Figure 18**.

It is obvious that this system is quite sensitive to even minor variations in powder or liquid rates. A very brief reduction in powder feed rate will result in overwetting of the material with consequent deposit formation in the chamber. Conversely, a temporary

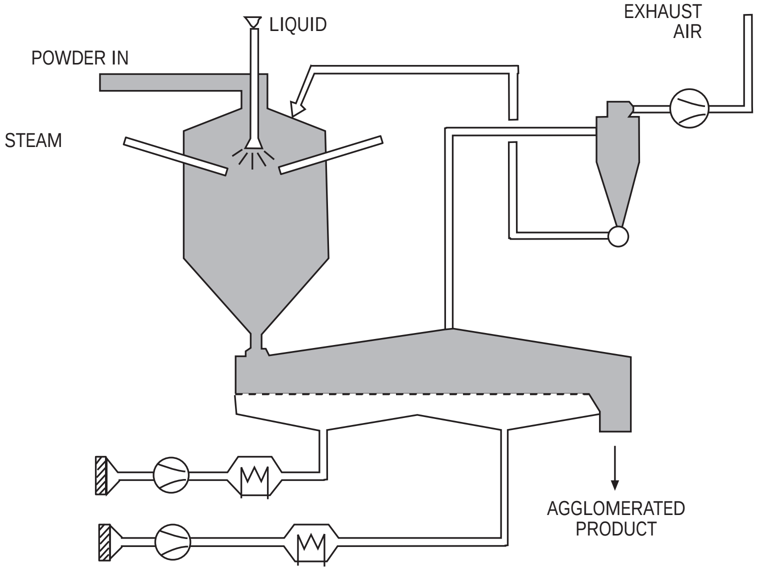

Figure 18. Typical agglomeration system

reduction in liquid rate will result in insufficiently wetted powder and therefore, weak agglomerates. Many designs rely on the product impacting the walls of the agglomeration chamber to build up agglomerate strength. Other designs include equipment for breaking large lumps into suitably sized agglomerates before the final drying. Obviously, deposit formation will always be a concern in agglomeration equipment as the process depends upon the creation of conditions where the material becomes sticky.

Typically, equipment designs are complicated, probably reflecting the fact that agglomeration actually is a complicated process. Despite the complexity of the process, however, it is possible to carry out agglomeration by means of comparatively simple equipment, which involves the use of a fluidized bed for the re-wetting and particle contact phase. This approach provides the following advantages:

1. There is sufficient agitation in the bed to obtain a satisfactory distribution of the binder liquid on the particle surfaces and to prevent lump formation.
2. Agglomerate characteristics can be influenced by varying operating parameters such as the fluidizing velocity, re-wet binder rate and temperature levels.
3. The system can accept some degree of variation of the feed rate of powder and liquid as the product level in the fluid bed is always constant, controlled by an overflow weir. Thus, the re-wetting section will not be emptied of powder. Even during a complete interruption of powder flow, the fluidized material will remain in the re-wet section as a stabilizing factor in the process.
4. By using fluid bed drying and cooling of the formed agglomerates, it is possible to combine the entire agglomeration process into one continuously operating unit.
5. Start-up, shut-down and operation of the fluid bed agglomerator are greatly simplified due to the stabilizing effect of the powder volume in the re-wet zone.

Proper implementation of a fluid bed agglomeration system requires detailed knowledge of the fluidization technology. Fluidization velocities, bed heights, air flow patterns, residence time distribution and the mechanical design of vibrating equipment must be known.

FEATURES OF FLUID BED AGGLOMERATION

Figure 19 shows a typical agglomerator system where the process is implemented through the use of a vibrated, continuous fluid bed.

The powder is fed into the agglomerator by a volumetric screw feeder. Due to the previously mentioned stabilizing effect of the material already in the fluid bed, the reproducibility of a volumetric feeder is satisfactory and there is no need for a complicated feed system such as a loss-in-weight or similar type.

The fluid bed unit is constructed of several processing zones, each having a separate air supply system. The first section is the re-wet and agglomeration section where agglomerates are formed. Here, the powder is fluidized with heated air to utilize any thermoplastic characteristics. The binder liquid – usually water or a water based solution – is sprayed over the fluidized layer using two fluid nozzles driven by compressed air. For large systems, numerous nozzles are used. Powder deposits are minimized by accurate selection of spray nozzle

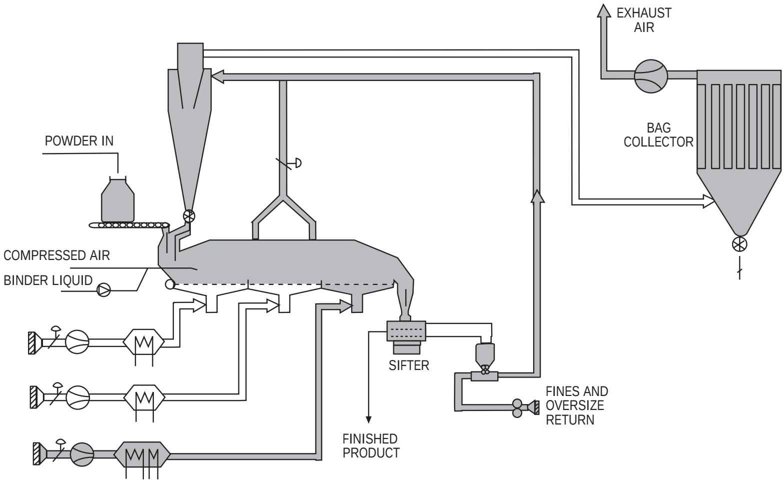

Figure 19. Fluid bed re-wet agglomeration system

angles and nozzle position patterns. Powder movement is enhanced by the vibration of the fluid bed unit and by the use of a special perforated air distribution plate with directional air slots. A proper detailed design is vital for trouble-free operation.

From the agglomeration zone, the powder flows into the drying area where added moisture is removed by fluidization using heated air. In some instances, more than one drying section is required, and in such cases, these sections are operated at successively lower drying temperatures to reduce thermal exposure of heat sensitive dry powders.

The final zone is for cooling, where either ambient or cooled air is used to cool the agglomerates to a suitable packaging temperature.

During processing, air velocities are adjusted so that fine, unagglomerated powder is blown off the fluidized layer. The exhaust air is passed through a cyclone separator for removal and return of entrained powder to the inlet of the agglomerator. When there are high demands for a narrow particle size distribution, the agglomerated powder is passed through a sifter where the desired fraction is removed and oversized and undersized material is recycled into the process.

As with all re-wet agglomeration equipment, the operation must be performed within certain operating parameters. Overwetting will lead to poor product quality, while underwetted powder will produce fragile agglomerates and an excessive amount of fines. However, fluid bed agglomeration does offer a great degree of flexibility in controlling the final result of the process. The characteristics of the formed agglomerate can be influenced by operating conditions such as binder liquid rate, fluidizing velocity and temperature. Typically, the fluid bed re-wet method will produce agglomerated products with superior redispersion characteristics.

As indicated by this partial list, this method has been used successfully with a number of products.

Dairy products
Baby formula
Calf milk replacer
Flavor compounds
Fruit extracts
Maltodextrines
Corn syrup solids
Natural gums
Sweeteners
Detergents
Enzymes
Herbicides
Egg albumin
Starch
Cocoa mixes
Insecticides

In most cases, the agglomeration can be accomplished using only water as a re-wet media. This applies to most dairy products and to maltodextrine-based flavor formulations. For some products, increased agglomerate size and strength has been obtained by using a solution of the material itself as the binder liquid. In the case of relatively water insoluble materials, a separate binder material has been used, but it must be one that does not compromise the integrity of the final product. The addition of the binder material may have a beneficial effect on the end product at times. This is seen, for example, in flavor compounds when a pure solution of maltodextrine or Gum Arabic may further encapsulate the volatile flavor essences and create better shelf life. In other instances, the added binder can become part of the final formulation as is the case with some detergents.

For some materials, the addition of a binder compound is an unavoidable inconvenience. At such times, the selected binder must be as neutral as possible and must be added in small quantities so that the main product is not unnecessarily diluted. An example is herbicide formulations, which often have a well defined level of active ingredients.

FOR FOOD PRODUCTS	FOR CHEMICAL PRODUCTS
Maltodextrines	Lignosulfonates
Gum arabic	Poly-vinyl alcohol (PVA)
Starch	Any of the food product binders
Gelatin	
Molasses	
Sugar	

Table 4. Frequently used binders

For products containing fat, the normal process is often combined with a step by which the agglomerates are coated with a thin layer of surface active material, usually lechithin. This is accomplished by mounting an extra set of spray nozzles near the end of the drying section where the surfactant is applied.

Variations of the fluid bed re-wet technology have been developed whereby the system serves as a mixer for several dry and wet products. An example of this may be seen in the APV fluid mix process for the continuous production of detergent formulations from metered inputs of the dry and wet ingredients. This provides an agglomerated end product with minimum energy input when compared to traditional approaches.

SPRAY BED DRYER AGGLOMERATION

While the fluid bed re-wet agglomeration method produces an excellent product which is, in most respects, superior to that made directly by the straight-through process, a new generation of spray dryers has evolved that combines fluid bed agglomeration with spray drying. These are referred to as “Spray Bed” dryers. The concept was developed from spray dryers having a fluid bed integrated into the spray chamber itself and is depicted in **Figure 20**. What distinguishes the Spray Bed dryer is that it has the drying air both entering and leaving at the top of the chamber. Atomization can be with nozzles or by a centrifugal atomizer.

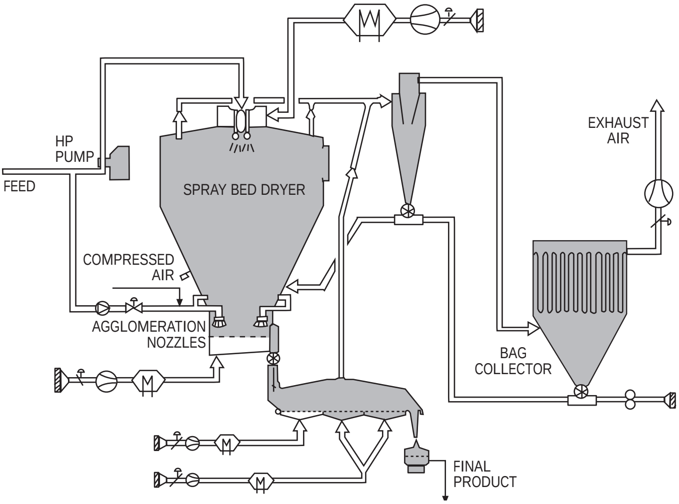

Figure 20. Spray Bed type agglomerating spray dryer

During operation, the chamber fluid bed is vigorously agitated by a high fluidization velocity. As the particles from the spray-drying zone enter the fluid bed with a very high moisture content, they agglomerate with the powder in the bed. Fines carried upwards in the dryer by the high fluidizing velocity have to pass through the spray cloud, thus forming agglomerates at this point, as well. Material from the integrated fluid bed is taken to an external fluid bed for final drying and cooling.

	ORDINARY SPRAY DRIED POWDER	INTEGRATED FLUID BED AGGLOMERATION	RE-WET AGGLOMERATED POWDER
Wettability, sec.	>1000	<20	<10
Dispersibility: %	60-80	92-98	92-98
Insolubility index	<0.10	<0.10	<0.20
Average particle size, micron	<100	>250	>400
Density, lbs/ft^3	40-43	28-34	29-31
Density, kg/m^3	640-690	450-545	465-500

Table 5. Reconstitutability and physical structure of different types of skim milk powder

The Spray Bed dryer is a highly specialized unit that can only produce agglomerated powder, although the degree of agglomeration can be controlled. Agglomerates from the Spray Bed dryer exhibit excellent characteristics. They are very compact and show high agglomerate strength and good flowability.

CONSIDERATIONS AND CONCLUSIONS

While the agglomeration process improves the redispersion, flowability and non-dustiness of most fine powders, it invariably decreases the bulk density. The comparisons in **Table 5** clearly show that agglomeration improves the powder wettability and dispersibility. Individual powder particles with a mean diameter of less than 100 micron are converted into agglomerates ranging in size from 250 to 400 micron with the re-wet method being able to produce the coarser agglomerate. The powder bulk density will decrease from about 43 lb / ft^3 (670 Kg / m^3) to approximately 28 lbs / ft^3 (450 Kg / m^3). Use of the re-wet method will expose the product to one additional processing step which can somewhat affect the proteins, occasionally resulting in a slightly poorer solubility.

Since fluid bed agglomeration can be operated as an independent process, it can be used in conjunction with existing powder producing equipment. It offers great flexibility and ease of operation – and provides a convenient way to add functionality, non-dustiness and value to a number of products.

SPIN FLASH DRYERS

for continuous powder production from pastes and filter cakes

While mechanical dewatering of a feed slurry is significantly less expensive than thermal drying, this process results in a paste or filter cake that cannot be spray dried and can be difficult to handle in other types of dryers. This article describes the Spin Flash dryer, shown in **Figure 21***, as one option available for continuous powder production from pastes and filter cakes without the need for grinding.*

Powder production generally involves some form of drying operation. There are several generic types of dryers but all must involve the evaporation of water, which can take anywhere from 1000 to 2500 BTU/lb (555 to 1390 Kcals/kg), depending on dryer type. Due to its ability to produce a uniform powder at relatively low temperatures, the spray dryer is probably the most common of these dryers. However, by its definition, a spray dryer requires a fluid feed material to allow its atomization device to be employed. Generally, there is a maximum viscosity limitation in the range of 250 to 300 Centipoise.

Figure 22 (on page 49) illustrates the amount of water which must be evaporated to produce one pound of bone dry powder from a range of different feed solids. It can be clearly seen that even a 5% increase in total solids will reduce the water evaporation and hence, the dryer operating costs by about 20%. If this water removal can be done mechanically by, for example, filtration or centrifuging, the cost will be significantly lower than that required to heat and evaporate the same water. The direct energy cost can be calculated as equivalent to 3-8 BTU/lb (1.7-4.5 Kcals/kg) compared to an average 1500 BTU/lb (830 Kcals/kg) for evaporation. This increase in solids, however, inevitably will result in an

Figure 21. Spin Flash dryer

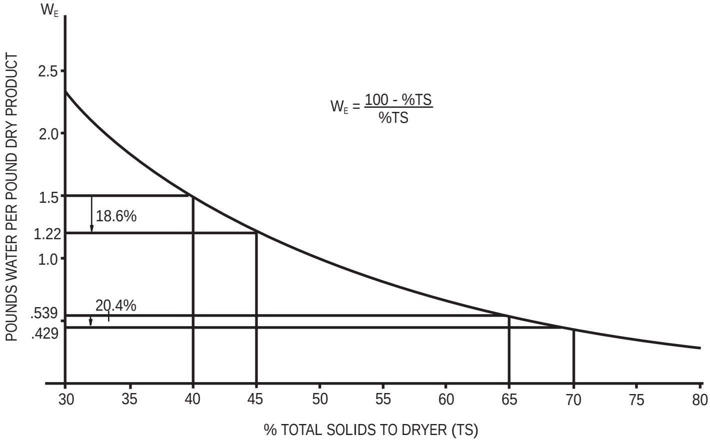

Figure 22. Water evaporation vs. total solids ratio

increase in viscosity, which may exceed the limitations of a spray dryer.

Available options for drying these higher viscosity feed materials are listed in **Table 6**. The subject of this paper is the Spin Flash dryer, which is among the newest of the dryer options and has the capability of drying most materials ranging from a dilatent fluid to a cohesive paste.

SPIN FLASH DRYER

The Spin Flash dryer was developed and introduced in 1970 in response to a demand by the chemical industry to produce a uniform powder on a continuous basis from high viscosity fluids, cohesive pastes and sludges.

DRYER OPTIONS FOR
HIGH VISCOSITY MATERIALS

DIRECT SUSPENSION DRYERS
- Pneumatic or flash dryers
- Spin Flash dryers
- Fluid bed dryers

DIRECT NON-SUSPENSION DRYERS
- Tray dryers
- Tunnel dryers
- Belt dryers
- Rotary dryers

INDIRECT DRYERS
- Screw conveyor dryers
- Vacuum pan dryers
- Steam tube rotary dryers

Table 6.

PROCESS DESCRIPTION

The Spin Flash dryer can be described as an agitated fluid bed. As shown in **Figure 23**, the unit consists primarily of a drying chamber (9) which is a vertical cylinder. At the base is an inverted conical bottom, an annular air inlet (7) and an axially mounted rotor (8). The drying air enters the air heater (4), is typically heated by a direct fired gas burner (5) and enters the hot air inlet plenum (6) tangentially. This tangential inlet, together with the action of the rotor, causes a turbulent whirling gas flow in the drying chamber.

The wet feed material, typically filter cake, is dropped into the feed vat (1) where the low speed agitator (2) breaks up the cake to a uniform consistency and gently presses it down into the feed screw (3). Both agitator and feed screw are provided with variable speed drives.

In the case of a dilatent fluid feed, the agitated vat and screw would be replaced with a positive displacement pump and several liquid injection ports.

As the feed material is extruded off the end of the screw into the drying chamber, it becomes coated in dried powder. The powder coated lumps then fall into the

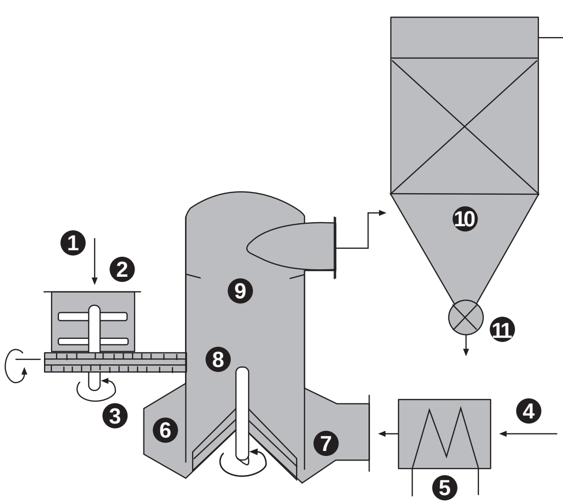

*Figure 23. **Standard Spin Flash dryer configuration***

DRYER CHARACTERISTICS	
Drying medium	Air Inert Gas Low humidity waste gas
Drying method	Direct gas contact
Inlet temperature	Up to 1800°F (980°C)
Flow	Co-current
Capacity	Up to 10 tons per hour of final product
Feed material	Dilatent fluids Cohesive paste Filter cake Moist granules
Product residence time	5-500 seconds

fluid bed and are kept in motion by the rotor. As they dry, the friable surface material is abraded by a combination of attrition in the bed and the mechanical action of the rotor. Thus, a balanced fluidized bed is formed which contains all intermediate phases between raw material and finished product.

The dryer and lighter particles become airborne in the drying air stream and rise up the walls of the drying chamber, passing the end of the feed screw and providing, in effect, a continuous back mixing action within the heart of the dryer. At the top of the chamber, they must pass through the classification orifice, which can be sized to prevent the larger particles from passing on to the bag collector. These larger lumps tend to fall back into the fluid bed to continue drying.

Air exiting from the bag collector (10) passes through the exhaust fan (12) and is clean enough for use in a heat recovery system. Dried powder is discharged continuously from the bottom of the bag collector through the discharge valve (11).

Two important features make the Spin Flash dryer suitable for products which tend to be heat sensitive. First, the dry powder is carried away as soon as it becomes light enough and therefore is not re-introduced into the hot air zone. Second, the fluid bed consists mainly of moist powder which constantly sweeps the bottom and lower walls of the drying chamber and keeps them at a temperature lower than the dryer air outlet temperature. In addition to this self-cooling capacity, the lower edge of the drying chamber directly above the hot inlet can be provided with an auxiliary cooling ring.

Figure 24 illustrates the very rapid reduction in air temperature that occurs due to the high heat transfer rate obtained in the fluid bed.

OPERATING PARAMETERS

Inlet temperature of the drying air introduced into the chamber is dependent on the particular characteristics of the product being dried but generally would be similar to that used on a spray dryer for the same product.

Outlet temperature is selected by test work to provide the desired powder moisture and is controlled by the speed of the feed screw. Since the Spin Flash dryer produces a finer particle size than does a spray dryer, it has been found that a slightly lower outlet temperature may be used to obtain the same powder moisture. This provides an increase in thermal efficiency.

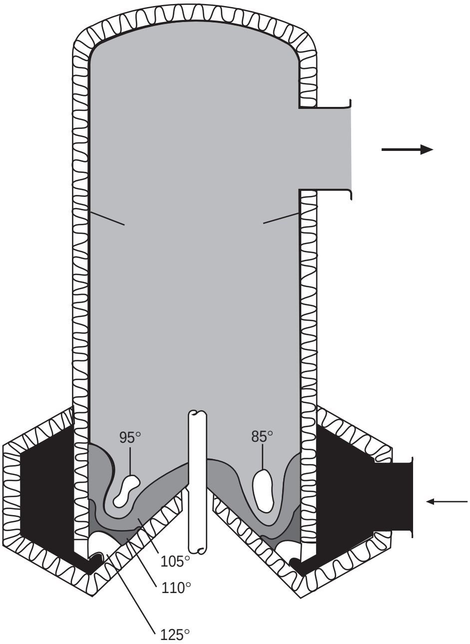

Figure 24. Fluid bed provides rapid air temperature reduction

Air velocity through the cross section of the drying chamber is an important design factor and is determined, in part, by the final particle size required. A lower velocity will tend to reduce the final dried particle size carried out of the chamber. The major factor, however, is the stability of the very complex bed which must neither settle back into the air distributor nor blow out of the top of chamber. Once the maximum velocity has been determined by test work for a given product, the diameter of a drying chamber can be selected to provide the desired water evaporation rate.

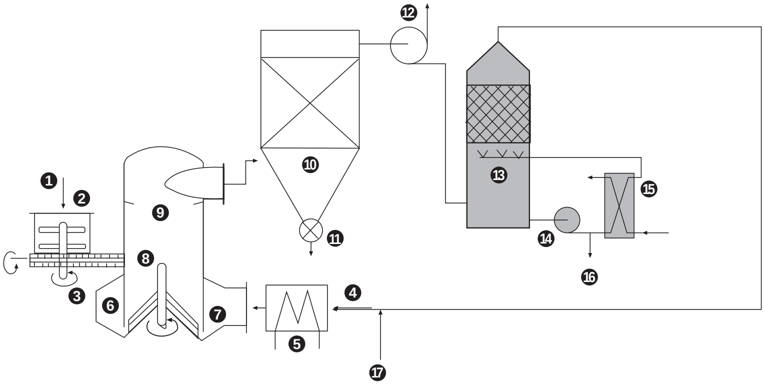

Figure 25. Spin flash dryer in closed cycle arrangement

Capacity can be adjusted to suit the output from the preceding process equipment which may be hard to control and slow in its response time. This is achieved by a cascade control from a feed vat level sensor to the inlet temperature controller set-point. The feed vat sometimes can be oversized to accept the batch discharge from a preceding filter press while allowing the dryer to operate continuously.

CLOSED CYCLE DRYING

Once a decision has been made to increase feed solids prior to drying, the small size and lower air flow requirements of the Spin Flash dryer make it practical to design the system as a closed cycle dryer, with nitrogen as the drying medium. This type of system can be used to dry a solvent based powder, allowing complete recovery of the solvent.

The simplified schematic shown in **Figure 25** illustrates a possible configuration of a closed cycle Spin Flash dryer. The operating process as described earlier, is extended, with exhaust gas from the baghouse being scrubbed and cooled in a condenser (13) using cooled solvent from an external plate heat exchanger (15) as the scrubbing medium. Recovered solvent is bled off at (16), downstream from the scrubber recirculation pump (14) at a controlled rate based on scrubber liquid level.

The drying chamber would be maintained at a pressure slightly higher than ambient using a pressurized nitrogen purge (17). The heater (5) would use either a steam coil or a thermal fluid system with an external heater.

A less expensive alternative to the closed cycle approach is a “Lo-Ox” system, where a low excess air burner is used in a direct fired heater. The products of combustion are recirculated through the condenser and the surplus gas is vented to atmosphere. The oxygen level in such a system can be controlled to less than 3%.

STEAM ATMOSPHERE SPIN FLASH DRYING

A recent development of the Spin Flash drying technology is it’s operation with an atmosphere consisting solely of superheated steam. The plant configuration is very similar to the closed circuit system described above, but the primary condenser is omitted, and replaced with a vent duct. The dryer system is operated at a positive pressure throughout the loop. Before start-up, the loop is purged with auxiliary steam, either from the factory supply, or from a packaged boiler adjacent to the dryer. The process heater is a two-pass fired tubular super-heater, which can heat the steam atmosphere up to 1100°F entering the inlet distributor of the dryer. Once the dryer loop has been thoroughly warmed up, and the feed system has been started, the moisture evaporated supplies the necessary vapor to maintain a positive pressure and the boiler is no longer required. Modulating the vent valve downstream from the baghouse, controls the actual system pressure. A dry superheated condition is maintained throughout by controlling the feed rate to hold a dryer outlet temperature of around 250°F.

Compared to other alternatives the APV Steam Spin Flash concept offers the following significant advantages:

Lower Operating Cost

Compared with conventional dryers operating at the same temperature span, there is a reduction of up to 30% on the actual fuel cost for the dryer itself. This results from only heating the drying gas from the dryer outlet temperature back up to the inlet temperature.

"Free" Steam

In addition, there is the fringe benefit of exhaust steam at a rate equal to the evaporation in the dryer. This will be low-grade steam, but of a suitable quality for heating of process air or water – either by using heat exchangers, or by direct sparging.

Environmentally Friendly

Apart from the fired super-heater, there are no gaseous emissions from the Steam Spin Flash dryer. The exhaust vapor stream is fully condensed. Any organic compounds evaporated from the feed are recovered in the liquid phase.
This simplifies environmental permitting issues, since any potential odor problems are eliminated.

Inert Atmosphere

In keeping with the other closed circuit configurations, the Steam Spin Flash dryer has no "Fire Risks" – a problem occasionally experienced with air drying of organic materials.

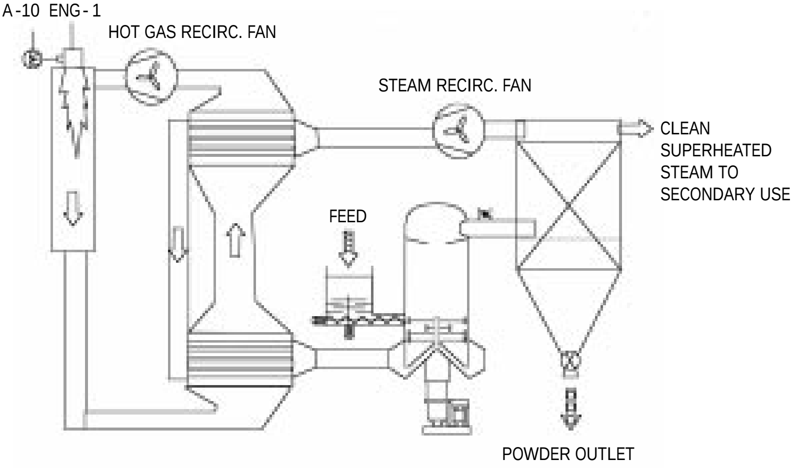

Figure 26. Steam Spin Flash drying process flow diagram

COST BENEFITS

In comparison to a spray dryer, the Spin Flash dryer has a much shorter residence time and consequently is considerably smaller and requires less building space. Its ability to dry to even higher solids than a spray dryer results in operating cost savings. **Table 8** (see page 57) shows a detailed size and cost comparison based on actual test drying of yellow iron oxide.

It can be seen that the investment in a Spin Flash dryer plant is some 31% lower than a spray dryer for the same powder capacity and that Spin Flash operating costs are approximately 28% lower. These figures, however, do not include the capital investment in filtration equipment.

CONCLUSION

Despite its obvious size and cost advantages, there are many instances when a Spin Flash dryer cannot replace a spray dryer. Typically, such cases occur when

	UNIT	SLUDGE OF VARIOUS METAL HYDROXIDES	DOLOMITE	YELLOW IRON OXIDE	ALUMINA	ALUMINUM SILICATE	CALCIUM CARBONATE WITH BINDER	CALCIUM CARBONATE (PURE)	FERRITE	TARTRAZINE (AZO DYE)	FOOD YELLOW (C.I. 15985)	CALCIUM STEARATE	POLYVANADATE	NICKEL CATALYST ON DIATOMACEOUS EARTH	BARIUMSULPHATE	TITANIUM DIOXIDE
INLET AIR TEMPERATURE	°F	482	590	617	482	842	536	968	932	410	437	212	914	662	1112	1292
	°C	250	310	325	250	450	280	520	500	210	225	100				
OUTLET AIR TEMPERATURE	°F	185	293	212	194	212	194	338	257	203	203	126	320	311	275	257
	°C	85	145	100	90	100	90	170	125	95	95	52				
TEMPERATURE OF THE FEED	°F	60	60	55	65	60	55	32	55	50	70	70	55	70	60	60
	°C	15	15	13	13	15	13	0	13	10	21	21				
TOTAL SOLIDS IN FEED	%	70	34	35	29	20	58	67	62	50	28	43	35	33	78	65
RESIDUAL MOISTURE	%	4.5	0.4	0.6	12.5	5.5	0.3	0	1.0	5.0	9	0.32	2.7	3	0.1	0.5
MEAN PARTICLE SIZE	µm	40	15	5	70	20	50	5	15	10	10	16	20	15	5	3
BULK DENSITY	gr/cm^3	0.8	0.45	0.3	0.4	0.2	0.45	0.8	0.9	0.7	0.3	0.14	0.76	0.32	1.6	0.6

Table 7. Selection of typical Spin Flash dried products and their main operating parameters

a free flowing spherical particle of a particular size range is required or when agglomeration is needed.

There are, however, many situations both in the food and chemical industries where the particular capabilities of the Spin Flash dryer to produce powders from paste warrant careful consideration of its use.

SIZE AND COST COMPARISON: spray dryer vs. Spin Flash dryer

SPACE REQUIREMENTS		SPRAY DRYER CSD 70/71		SPIN FLASH SFD 59
Heater type (gas)		direct fired		direct fire
Chamber diameter	14 ft	4.25 m	2.625 ft	0.8 m
Building floor area	650 ft^2	60 m^2	325 ft^2	30 m^2
Building height	46 ft	14 m	16.5 ft	5 m
Building volume	24,700 ft^3	700 m^3	5,300 ft^3	50 m^3
CAPACITY				
Powder	880 lb/h	400 kg/h	880 lb/h	400 kg/h
PERFORMANCE DATA				
Feed solids (%)		30		45
Feed rate	2,995 lb/h	1362 kg/h	1,951 lb/h	887 kg/h
Water evaporation	2,115 lb/h	961 kg/h	1,071 lb /h	486 kg/h
Powder moisture (%)		0.4		0.4
Gas consumption	4,416 SCF/h	125 sm^3/h	2,192 SCF/h	62 sm^3/h
1000 BTU/SCF 8,900 Kcals/m^3				
Power consumption (kWh)		40		30
INVESTMENT COSTS – Approx U.S. $				
Building		175,000		50,000
Dryer equipment		600,000		510,000
Baghouse		55,000		40,000
Installation		150,000		80,000
		$980,000		$680,000
ASSUMPTIONS				
Gas cost ($/M BTU)		$ 4.50		
Electricity cost ($/kWh)		$ 0.07		
Salaries per hour		$30.00		
Manpower required = 1/2 operator				
VARIABLE OPERATING COSTS/HOUR				
Wages		$15.00		$15.00
Gas		19.87		9.86
Electricity		2.80		2.10
TOTAL		$37.67		$26.96
Cost per lb of powder		$0.043		$0.031

Table 8. Size and cost comparison

SPRAY DRYERS

SPRAY DRYER OPTIMIZATION

Spray drying is a technique used to convert either solutions or free-flowing slurries, into powder particles having specific characteristics. There is a wide variety of spray dryer configurations, each suited to a particular type of powder or feed consistency.

The following notes are directed towards APV Anhydro Spray dryers, but will be generally applicable to many other spray dryers made by different manufacturers. Spray drying remains – to a great extent – an art, although there is a scientific basis to all of the many adjustments which must be made before a particular dryer is optimized to dry a particular feed stream and produce the desired powder characteristics.

ATOMIZATION

This is the process which turns a liquid feed into small droplets immediately prior to drying. The size of the droplet formed controls the size of the powder particles coming out of a single stage spray dryer. The two principle means of atomization are centrifugal and pressure nozzle – both have their advantages and disadvantages and the choice is dependent on both feed and powder properties of the specific application.

VISCOSITY

The ability to atomize a liquid is largely dependent on the viscosity at the atomizing device. A general rule of thumb is to keep the viscosity below 250 centipoise at the atomizer. When the viscosity is too high, the liquid tends to form non-spherical “prolates” (potato shaped large particles), and ultimately strings or threads, like cotton candy. Poor atomization can also be indicated by a narrow ring around the dryer wall level with the atomizer wheel, or by speckled deposits on the lower walls and cone of a nozzle spray dryer. The simplest way to reduce viscosity is to add water, but this dramatically reduces the capacity of the spray

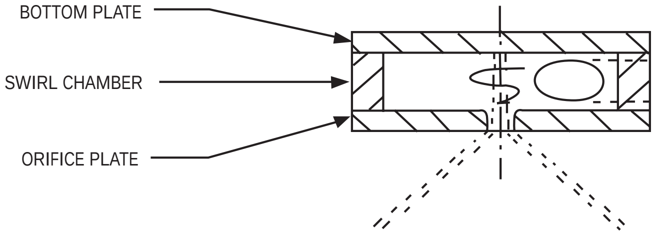

Figure 27. Simplex nozzle for spray drying

dryer to produce powder. A more efficient way to reduce viscosity is to increase the feed temperature. This has the added advantage of further increasing the spray dryer capacity, since less heat is required inside the dryer to raise the droplet temperature.

PRESSURE NOZZLE

A pressure nozzle atomizer requires the use of a high pressure pump to feed the liquid to the dryer. It typically produces a powder with a high bulk density, a narrow particle size distribution and, in the case of fat containing powders a low free-fat content.

The principle disadvantage in spray drying is that there is very little adjustment of possible flow rate without changing the powder properties or shutting down to change the nozzle set-up. In a nozzle atomizer, the liquid is pumped into a swirl chamber and passes out through an orifice plate.

CONE ANGLE

To get the best mixing between the liquid spray and the hot air coming into the dryer, it is important to use the widest spray angle possible. As the nozzle pressure increases, you will observe that the edge of the spray pattern tends to curve inwards towards the centerline of the spray. This is caused by the exchange of momentum between the liquid droplets and the air in the drying chamber – the pressure within the spray tends to become lower than the pressure outside the spray, causing it to contract **(Figure 28)**.

SWIRL CHAMBER

Feed liquid passes from the nozzle body, tangentially into the swirl chamber, where it is forced to rotate. The faster the rotational speed, the wider the spray angle becomes.

The volume of the swirl chamber controls the rotational speed for a given flow rate. The thinnest swirl chamber is designated by the letter “A” – subsequent letters denote thicker, and hence larger, swirl chambers. As a general rule, use a thinner swirl chamber to get a wider spray or a thicker swirl chamber for a narrower angle or longer spray.

ORIFICE SIZE

The choice of orifice size is dependent on the liquid flow rate and the powder particle size desired. The swirling liquid leaves the orifice plate as a hollow spinning tube formed on the inner edge of the orifice hole. To get finer particles, a higher nozzle pressure is required. For a given flow rate, this means that a smaller orifice is needed. For larger particles, use a bigger orifice to get a lower nozzle pressure.

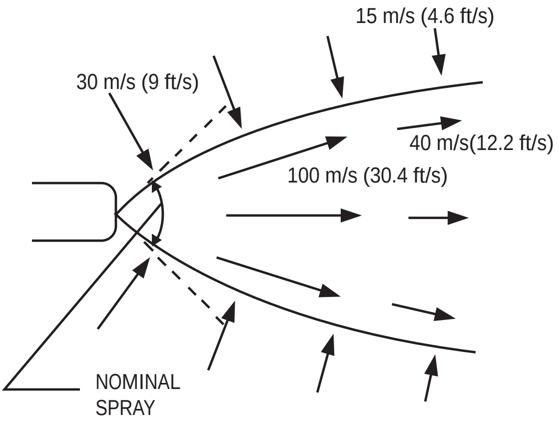

Figure 28. Nominal spray

FLOW RATE

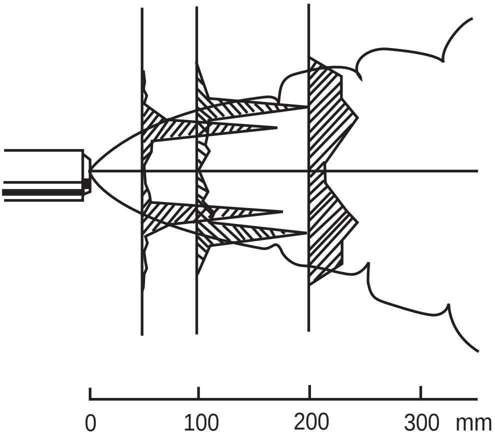

Figure 29. "Hollow Cone" spray actually fills further from the nozzle

The flow rate of liquid into the spray dryer is used to control the dryer outlet temperature and hold it at a given value to keep a controlled powder moisture.

If a certain product can be dried at a higher inlet temperature, then the flow rate will be higher to keep the outlet temperature down. This higher flow rate will require a larger orifice or you can expect an increase in nozzle pressure to get a finer powder particle. Feed solids content is another factor that impacts flow rate. The dryer is only evaporating water. Powder is just the "left-over" portion. Diluting the feed means less powder for each pound of water, or put another way, less powder will be produced from the dryer, even though it is running at the same operating temperatures.

NOZZLE PRESSURE

Nozzle pressure has a large influence on the final powder particle size. If you want larger particles or a coarser powder, you need to use a lower nozzle pressure. For finer particles, use a higher nozzle pressure. Nozzle pressure, for a given orifice size, varies as the square of the flow rate – a higher flow gives a much higher pressure.

CENTRIFUGAL ATOMIZER

In a centrifugal atomizer shown in **Figure 30**, the feed liquid is accelerated to a high speed by a spinning disc. The high relative speed between the liquid film and the surrounding air at the edge of the wheel causes the liquid to form small droplets. The liquid leaves the outer edge of the disc radially into the hot air stream as a flat cloud of droplets.

WHEEL SPEED

A centrifugal atomizer is a much simpler device to operate than a pressure nozzle, since the major factor affecting particle size is the wheel tip speed. The normal operating tip speed for an Anhydro centrifugal atomizer is 130 m/s (just over 290 miles/hr). This is achieved by spinning the wheel at a rotational speed of between 6000 rpm and 50,000 rpm, depending on wheel diameter. The CF-100 atomizer on a compact spray dryer has a normal speed of 25,000 rpm and a maximum speed of just over 30,000 rpm, whereas the larger CB-160 atomizer used on the 65 and 67 dryers has a normal operating speed of 15,000 rpm with a maximum speed of 20,000 rpm. To get a finer particle with a centrifugal atomizer, you need to run the wheel at a higher speed. For a coarser particle, use a lower wheel speed.

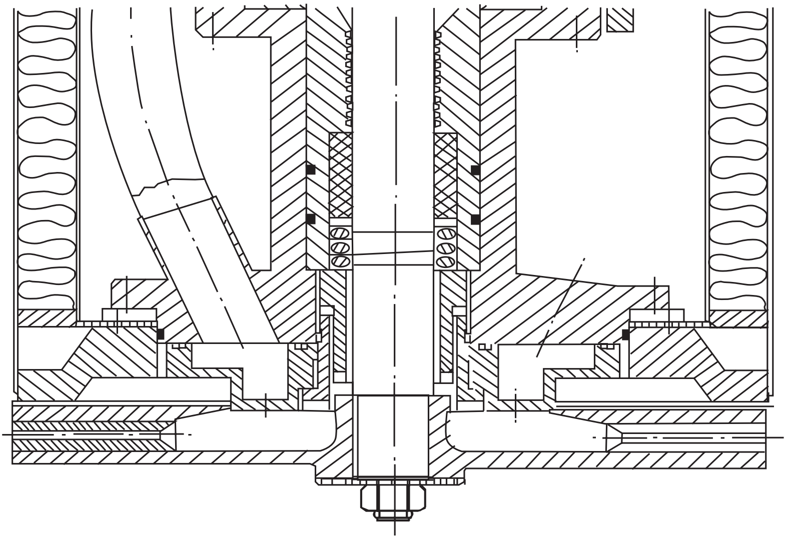

Figure 30. Centrifugal atomizer

HYDRAULIC CAPACITY

The wheel speed also affects the hydraulic capacity of the atomizer, although this is usually only seen at extremely high liquid rates or very low wheel speeds. A higher wheel speed causes a greater pumping action within the atomizer wheel and contributes to the hydraulic capacity of the atomizer. If the hydraulic capacity of a centrifugal atomizer is exceeded for any reason, feed liquid is forced to flow up the atomizer spindle and through the bearings, causing very rapid failure in most cases.

WHEEL TYPE

There are two types of atomizer wheels available for Anhydro atomizers: radial drilled or standard wheel and cup wheel.

Standard Wheel

The standard wheel has radial drilled holes and can be provided with abrasion resistant inserts, shown in **Figure 31a**, for handling crystalline or other abrasive feed materials. It has the higher hydraulic capacity due to its large acceleration chamber – and can withstand a certain amount of abuse during operation and cleaning.

Cup Wheel

The cup wheel shown in **Figure 31b** is used when the narrowest particle size distribution is required from a centrifugal atomizer. The cup wheel has a smaller

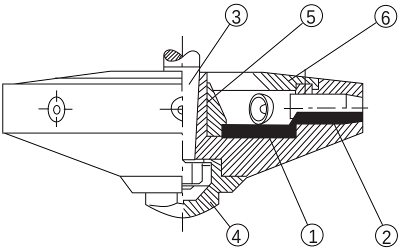

Figure 31a. Abrasion resistant radial drilled wheel

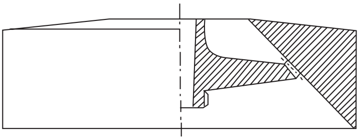

Figure 31b. Cup wheel

internal bowl diameter, radial drilled holes at one third of the wheel diameter and an outer cup surface against which the liquid is accelerated. The cup wheel must be run at a speed approximately 10% higher than the standard wheel to compensate for the slippage across the smooth surface of the cup, but since the fluid leaves the outer edge as a uniform thickness film, the resultant droplets are more uniform.

The outer edge of the wheel must remain smooth and uniform, hence the cup wheel must be handled carefully during cleaning to avoid damage.

INLET TEMPERATURE

The air inlet temperature to the spray dryer is controlled by the burner firing rate. The indirect fired air heater is designed to operate at a maximum process air outlet temperature of 572°F (300°C) but the burner is sized for each specific installation. Higher inlet temperatures improve the thermal efficiency of the spray drying operation as well as the production rate.

PRODUCTION RATE

The air inlet temperature to the spray dryer controls the production rate of the final powder. For higher production, you run with a higher inlet temperature. There are three other factors which can limit the inlet temperature:

POWDER IGNITION TEMPERATURE

Many powders will ignite and burn if they are exposed to temperatures above their ignition temperature. If this occurs in a spray dryer, it can result in a fire and possibly a deflagration. At the very least, you will have a substantial clean-up job to do!

Two ignition temperatures for flamable powders can be determined by laboratory testing. They include the “cloud ignition temperature” and the “minimum ignition layer temperature.” Generally, the MILT is the lower of the two and it is normally considered safe to operate the spray dryer at an inlet temperature of 90°F (50°C) lower than the MILT.

THERMAL DEGRADATION

Although the majority of the powder remains below the outlet air temperature of the spray dryer, a few powder particles become re-entrained into the hot inlet air stream at the top of the dryer and become scorched. This can result in reduced quality due to changes in color, taste or other functional properties.

POWDER HYGROSCOPICITY

Many flavor products are hygroscopic. If left out in the open air, they absorb water and become sticky. This can frequently be felt by rubbing some powder between the finger and thumb. The higher the ambient humidity, the stickier the powder becomes.

The spray dryer operates by evaporating water from the feed to produce a dry powder, but the evaporated water increases the humidity of the air inside the drying chamber. The higher the inlet temperature to the dryer, the more water evaporated, resulting in higher chamber humidity. Whenever deposits are all over the inside of the dryer, it is generally because the plant has been operated above the optimum inlet temperature. Next time, operate at 18°F (10°C) lower inlet temperature. If the dryer is then completely clean, increase the inlet temperature by a few degrees and try again.

AMBIENT HUMIDITY

When spray drying very hygroscopic powders, consider that ambient humidity variations due to changing seasons or even a passing thunderstorm, have a very large effect on the drying chamber deposits. If the ambient humidity is low, the chamber usually runs clean – but high humidity conditions can rapidly lead to chamber deposits and lumps which can frequently force a plant to be shut down for cleaning. If a spray dryer is operated correctly, the inlet temperature can be raised during dry weather to increase production, but the inlet temperature must be reduced during higher humidity conditions to avoid chamber deposits **(Figure 32)**. Only by making these seasonal variations in operating temperature can the production rate of the plant be maximized. To avoid these seasonal variations, some plants utilize an inlet air dehumidification system.

The ambient air is drawn into the plant through filters to remove dust and airborne contaminants which could foul the equipment, then across a chilling coil. This coil is cooled to around 33°F (0.5°C) by a recirculated stream of water and glycol. The cold coil surface, with the extended fins, cools the air and causes the ambient moisture to condense on the coil surface. This condensation runs down the surface of the coils and is collected in a trough at the base from which it runs to a building drain. The air velocity across the face of the coil is important. Too high a velocity will prevent the water droplets from clinging to the coil surface, producing a mist, that will pass downstream to the fan. To reduce the danger of this, most systems are followed by a demister, comprising either chevrons or a coarse polymer demisting pad.

OUTLET TEMPERATURE

The spray dryer outlet temperature is controlled by adjusting the feed rate to the atomizer. This, in turn, is accomplished by adjusting the speed of the feed pump through a variable frequency drive. As more feed is atomized into the dryer chamber, it cools the air in the chamber and the outlet temperature goes down. It is important to note that unless the feed is adequately atomized, the outlet

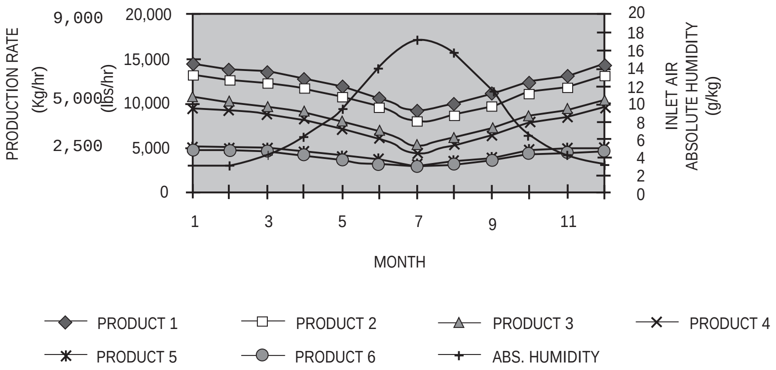

Figure 32. Seasonal capacity changes when spray drying hygroscopic products

temperature will NOT be reduced. This can be seen if the centrifugal atomizer speed is reduced to the point that a “Mud Ring” forms around the upper chamber wall. When this occurs, the outlet temperature will rise, more feed is automatically introduced to try to reduce the temperature and the system will soon trip on high outlet temperature, leaving a very messy chamber to be cleaned.

POWDER MOISTURE

The residual moisture content in the powder is largely controlled by the dryer outlet temperature. A lower outlet temperature causes the powder moisture to increase.

Inlet temperature also affects the powder moisture by changing the humidity in the outlet air. If the inlet temperature is increased to get a higher production rate, the outlet temperature will also need to be raised slightly to maintain the same powder moisture. As a rule of thumb, for every 100 degrees rise in inlet temperature, the outlet temperature should be raised by 12 degrees. This will retain the same relative humidity in the outlet air and hence, the same powder moisture.

CONDENSATION

When humid air is cooled, the moisture vapor condenses and forms water droplets on the nearest surfaces. The “dew” seen on the ground on some mornings is caused by this effect. The “dew point” of a humid air mass is dependent on the humidity or water content of the air, but is higher in temperature as the humidity increases.

If any parts of the inside surface of the dryer are at a temperature below the dew point, there will be a localized condensation at those points. Powder particles stick to the condensed water droplets, and in turn, become sticky and adhere to the hard surface.

When the spray dryer is started, the warm-up time is being used to heat the inner surfaces of the chamber to a temperature above the dew point.

Condensation deposits can frequently be seen as straight lines inside the dryer chamber, tracing the wall and roof stiffening steel. Due to the heavier mass of this steel, these points take longer to warm up than the adjacent sheet metal skin of the chamber.

If there is too much cooling air being drawn through the ring, condensation deposits can sometimes be seen on the inner surfaces of the cooling ring around the hot air inlet to the drying chamber.

Good, dry, insulation and careful design of the chamber stiffeners, combined with an adequate warm-up time, will generally eliminate condensation deposits.

THERMOPLASTICITY

This is the name given to a property of materials which become soft at higher temperatures, but harden again as the temperature is reduced. Many flavor products containing sugars or fats exhibit this property. As the powder temperature rises, the particles first soften then become sticky. This latter temperature is known as the "sticking temperature."

If the wall temperature is higher than the "sticking temperature" of the powder, the powder particles soften on contact with the wall and tend to stick. The sticking temperature of a powder is difficult to measure in the laboratory, as it is affected by the moisture content of the powder. The simplest method is to use a graduated hot bench, but this tends to dry the powder during the test. The powder is sprinkled along the surface of a polished metal plate, which is electrically heated so that one end is considerably higher in temperature than the other end. The powder is then swept off the surface using a soft brush. The point on the plate's surface where the powder ceases to be swept clean is noted – and the temperature at that point is measured using crystals of a known sharp melting point.

Figure 33. Air broom

If deposits of powder on the cone of the dryer can be easily swept clean after the dryer has cooled down, there is a good chance they have formed due to thermoplasticity – i.e., the dryer outlet temperature was above the sticking point. The simple correction would be to try operation at a lower outlet temperature on a subsequent run, but this will also give higher powder moisture. The problem is best solved by the use of an “air broom” inside the drying chamber.

MAIN AIR FLOW

Airflow through the main air distributor, in combination with inlet air temperature, directly affects the production rate of a spray dryer. If the air flow is reduced, either by choice or due to a problem, the production rate of the dryer will also be reduced.

CYCLONE PRESSURE DROP

The airflow through the heater, spray dryer, ductwork and cyclone causes a pressure drop across each, which increases as the square of the flow. In the case of a cyclone, the pressure drop is used to swirl the powder and air around the inside surface, causing the powder to be thrown to the outside and fall to the bottom discharge point.

The higher the pressure drop, the faster the material swirls around the inside. This may – or may NOT – be a good thing. The pressure drop is significantly affected by the diameter of the cone insert at the top center of the cyclone. For a lower pressure drop with the same air flow through the dryer, a larger diameter cone insert can be installed.

LOW FAT PRODUCTS

In the case of fine powders without fat, a higher pressure drop is good, since it improves cyclone collection efficiency. For these powders, the optimum cyclone pressure drop is around 8 inches w.c. If two cone inserts are available, install the smaller diameter insert for these powders.

HIGH FAT PRODUCTS

If the powder contains fat, however, the higher pressure drop has an overall dis-advantage. The higher velocity causes the fatty powder to smear around the lower part of the conical cyclone body. This smearing results in a firm layer building up on the inside surface, which can ultimately cause the cyclone to block and cease to discharge any powder. With this type of powder, it is necessary to reduce the cyclone pressure drop to also reduce the swirl velocity as well as the chance of bridging the cyclone.

If two inner cone inserts are available, install the larger diameter cone insert for high fat powders. It may also be necessary to adjust the main airflow to trim the cyclone pressure drop, understanding that this will reduce the instantaneous production rate. The actual pressure drop that will allow the system to operate successfully may depend on the fat content, but could be as low as 4 inches (100 mm) w.c. This low pressure drop is not really detrimental to collection efficiency, since higher fat products tend to be easier to collect than low fat powders.

LEAKING SEALS

One frequent cause of reduced airflow is leaking seals around access doors and clean-out ports. These seals should be checked visually when the plant is being washed, but they can also be checked by ear while the plant is in operation. If a whistling noise can be heard coming from a flange or door seal, it probably indicates a leak. The source of the noise should be found and the area marked for checking at the next opportunity.

Powder deposits can be another indication of a leak, which should be corrected. Leaking seals in the chamber or powder carrying ducts usually cause a localized deposit to occur. These deposits are due to condensation on the cold surfaces adjacent to the leak and can be seen immediately prior to cleaning the plant after a production run.

DETECTION AND CORRECTION

The simplest method of accurately locating the leaking part of a door seal is to coat the metallic part of the seal face with “prussian blue” or similar marking compound, then close the door. When the door is closed, the blue will transfer to the seal face wherever the seal is mating correctly, but will leave the white silicone uncolored at the places where a seal is not made. To correct the seal, the metal face must be bent towards the silicone seal. Around the main chamber door, this can be accomplished using a large wrench and an extension pipe. On the smaller inspection doors, a special tool can be procured from APV. If the rubber seal has been damaged, replacement tubular seal material is also available from APV.

POWDER COOLING SYSTEM

Hygroscopic or thermoplastic powders need to be cooled prior to final packaging to avoid the formation of lumps in the box. This cooling is accomplished by transferring the powder from the main cyclone into a secondary air stream, which is dehumidified and re-heated to reduce the relative humidity.

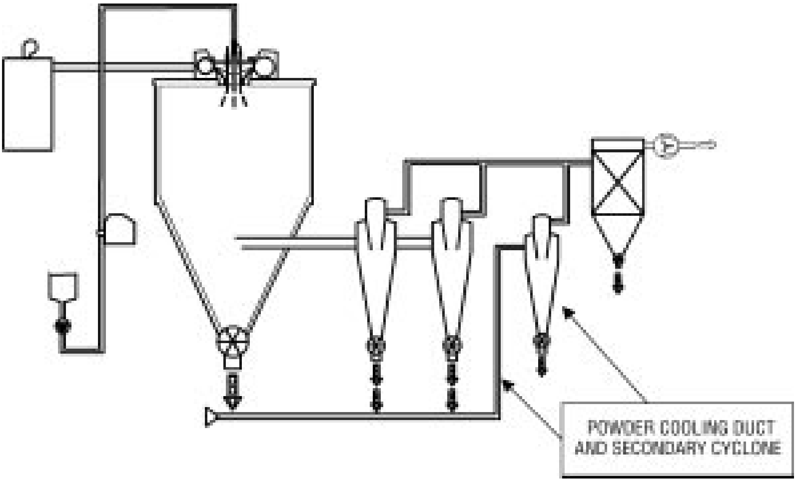

Figure 34. Powder cooling system

INLET TEMPERATURE

The powder cooling air must be both cool AND low in humidity. To accomplish this, the air is first passed across a chilling coil to condense and remove the majority of the water from the ambient air. At this point, the cooling air is saturated at its dewpoint and must be re-heated to reduce the relative humidity to around 50%. The cooling air temperature is controlled automatically by mixing some air from the main air heater, with cold air taken from the upstream of the same heater. To raise the blend temperature, an automatic valve in the hot air mixing duct is opened by the controller. There is a manual valve in the cold air mix duct which must be set to allow correct operation of the temperature control system. If the automatic hot air valve is fully open, this indicates that the manual cold air butterfly valve is open too far, drawing an excessive amount of cold air and insufficient hot air to achieve the correct air temperature. The cold air butterfly valve should be closed – but only by one "notch" at a time – until the hot air actuated valve is steady at some mid position.

AIR FLOW RATE

The powder cooling airflow rate should be adjusted to give the maximum acceptable powder temperature in the final powder box. By using only the minimum amount of cooling air, more air can be drawn through the main cyclone maximizing the overall capacity of the spray dryer. The airflow rate is controlled mainly by the powder cooling exhaust fan speed, but also by the position of the manual cold air butterfly valve. The intention is to set the powder cooling exhaust fan speed and the manual valve so that the air flow is minimized – and the pressure in the powder cooling duct at the venturi throat is slightly lower than the pressure in the cyclone.

VERTICAL WHIRL TRAP

The vertical whirl trap at the base of the main cyclone is designed to remove very difficult powders from the system before they can harden and block the cyclone. It comprises an adjustable throat, a secondary cold air inlet and an inspection port with sight glass.

THROAT ADJUSTMENT

The width of the venturi throat should be adjusted to allow all of the powder, plus a small amount of cyclone air, to pass out into the powder cooling air stream. The correct combination of throat gap and cooling duct pressure can be judged easily by feel. The lower part of the whirl trap should always be as hot as further up the cyclone's side. If the bottom of the whirl trap feels cool, the cyclone pressure is lower than the powder cooling duct pressure and cold air is entering the cyclone from the venturi. This will ruin the cyclone collection efficiency and quickly cause a cyclone blockage.

If the powder cooling duct just after the venturi is hot all around, this indicates that too much hot cyclone air is being drawn into the cooling duct. The venturi throat should be closed slowly until the cooling duct feels hot on the side closest to the cyclone axis and cold on the opposite side, for a distance of about two to three feet downstream from the venturi. Further down the cooling duct, the two streams will have mixed and the duct surface temperature should feel warm to the touch.

If the venturi throat cannot be adjusted for any reason, the correct air flow balance can be achieved by adjusting the pressure in the cooling duct by either changing the powder cooling exhaust fan speed or by making a small adjustment to the manual cold air butterfly valve.

SECONDARY AIR ADJUSTMENT

Some very difficult powders can settle in the bottom of the cylindrical cyclone base and immediately harden to a firm lump. This settling can be avoided by opening the secondary air inlet valve adjacent to the cyclone base. This will allow the low cyclone pressure to draw in some cool room air, providing an additional air sweep of the base of the cyclone. The amount of secondary air should be kept to a minimum – and must be totally removed into the powder cooling duct to prevent excessive cyclone losses.

POWDER DENSITY

The density of spray dried powder is greatly affected by the included air or vacuoles formed as the liquid droplets dry. The rate of drying can affect the density, since the surface of the particle can either retain its initial shape (case hardening) or shrink as the internal water evaporates. Faster drying can lead to case hardening. Slower drying allows the inner moisture to permeate through the surface, which then collapses as the inner volume reduces.

The powder density produced by a nozzle atomizer is generally slightly higher than that produced on a centrifugal atomizer. This is due to air, which can be entrained in the liquid as it is accelerated across the bottom of the standard radial drilled centrifugal atomizer wheel. If a cup wheel is used, the entrained air tends to be separated during passage across the cup surface, giving bulk densities much closer to those of a pressure nozzle system. Powder density is also affected by feed solids. Higher feed solids will generally give a higher powder density – this gets more powder into a box.

Entrained air in the feed is another factor affecting powder density. If the feed preparation involves high shear mixing, this can entrain air in the form of tiny bubbles into the liquid. This entrained air is compressed as the feed is pumped, but expands rapidly as the feed leaves the nozzle. This rapid expansion causes the atomized droplets to “explode” and produce more fines. These fines are likely to be lost past the cyclones, leading to poor yields. If air entrainment cannot be avoided, the air may be removed by using a vacuum de-aerator system.

NOZZLE PRESSURE FLUCTUATIONS

The feed pressure to the nozzle atomizer should be quite steady. Any fluctuations in pressure indicate a possible problem. Entrained air in the feed is a frequent cause of pressure fluctuations. An increased stuffing pump pressure ahead of the high pressure pump can help to reduce the effect of entrained air. But it is much better to eliminate entrained air or avoid its inclusion in the first place, by using ba homogenizer instead of a high shear mixer.

The frequency of the pulsations should be compared with the speed of the high pressure pump plungers. If the pulsation frequency matches a single plunger frequency, the problem is likely to be in a valve seat on one of the plungers. The pump should be stripped and cleaned – and any damaged seals or seats should be replaced.

A leaking valve seat will also cause a reduction in pump capacity, requiring higher pump speeds to get the same flow of liquid to the spray dryer.

SYSTEM LOSSES

Vane Insert Adjustment

The vane insert is mounted in the air distributor around the atomizer and is designed to swirl the inlet hot air around the chamber to obtain the correct use of the chamber volume. The vane angle is important and is usually set during commissioning of the plant by the factory engineers. In some cases, the vane angle may change over time – due to fretting at the pin hinges or simply to rough handling during cleaning.

The effects of incorrect vane angle will only be seen when a dryer is pushed to its limit, causing deposits to occur on the chamber wall. If deposits are seen on the lower walls or cone, the vane angle may be too close to vertical. If deposits are seen on the upper half of the chamber walls, the vane angle is too far away from vertical. GREAT CARE MUST BE USED when making adjustments to the vane angle, since the wrong angle can lead to turbulence below the vanes, causing powder to be deposited on the vanes themselves. Any such deposits will char in the hot inlet air stream, leading to scorched particles in the product, which can cause a fire or explosion.

Chamber Air Sweep

If loose powder deposits are seen in the chamber at the end of a run, they can sometimes be recovered by an “air sweep” of the chamber. During “cold run,” the exhaust fan can be put into “manual” to hold its speed, then the chamber door is opened and held partly open by resting it on the door clamp hand wheels. The resulting slot allows room air to be drawn into the chamber in a tangential way, causing a fast rotation inside the chamber. Dislodged powder rotates around the chamber wall, tending to scour additional powder from the walls. All the powder leaves the chamber and is collected in the cyclone. Before this procedure is carried out, it is advisable to change the powder box. Carefully check the “sweep down” box for quality, since this powder will have been exposed to the higher temperatures in the dryer for a considerable time and may have deteriorated.

MEASURING POWDER DEPOSITS

Optimizing the production rate from a spray dryer involves creating a balance between high inlet temperatures with their resultant chamber deposits, and lower inlet temperatures, resulting in a cleaner chamber, but lower powder production rate.

For a good evaluation of the results of any given test run, it is essential to determine the quantity of powder which remains inside the equipment after shut down. Although one may observe the deposits, any guess regarding the weight of powder remaining is vague at best. When the spray dried product is soluble in water, the deposits can be measured very accurately by using the CIP system. The first tank of water is heated to the maximum temperature consistent with safe operation of the equipment and the flash point of any volatile components in the feed. The CIP system valves are then routed to recirculate the hot water through all the system cleaning loops, returning to the water tank. This hot water will dissolve the deposits and take the majority of the material to the CIP water tank. Once the system has fully drained back to the tank, the volume of water in the tank can be measured and a liquid sample taken for solids content analysis. From these two results, the mass of solids which had remained on the system walls after the production run can be calculated. This mass, added to the powder produced and bagged, should be very close to the total solids used in the feed formulation. The difference can be assumed to have been lost either as solids passed the cyclone or volatilized.

CYCLONE LOSSES

When the cyclone is followed by a scrubber, the determination of cyclone losses can be further refined by taking a similar set of measurements on the scrubber liquids.

The scrubber is drained before the run and filled with clean fluids of known solids content. The bleed stream must be stopped before the run starts and the scrubber operation carefully monitored. At the end of the production run, the total volume of liquid in each stage of the scrubber can be measured. Samples from each of the stages should be taken for density and solids content determination.

From these results, the total solids collected in the scrubber can be calculated. These solids can be assumed to have bypassed the cyclones.

For efficient powder collection, a cyclone should have an airtight seal at the bottom. Any air leakage at the bottom of the cyclone will carry powder away and out of the top inner cone.

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