makes larger, heavier particles, this tendency is minimized.

SIZE OF UNIT

Drying units may vary a great deal in size, although there seems to be a certain minimum below which it is not satisfactory to operate. The unit with which the writer is most familiar requires a floor space of about 54 ft. $\times$ 15 ft. $\times$ 14 ft. This allows for working space. With two units there would be some saving on this. Such a unit would evaporate 200 lbs. of water per hour from a material which is fairly sensitive to heat, and give a product containing less than 3 per cent moisture. The dryness, however, will depend on the character of the material, especially on whether it has a tendency to retain water of crystallization.

RECOVERY OF PRODUCT

The recovery of product will depend on various factors, but mainly the concentration before drying and the efficiency of the dust collector. When operating under favorable conditions in these respects, it is quite possible to recover from 95 to 98 per cent of the total solids.

TEMPERATURE OF DRYING

The temperature of drying is affected by three things: steam pressure in the heater, amount of air passed through the drying chamber, and the amount of liquid sprayed. In practice, the amount of air is constant and the steam pressure is usually also constant. When such is the case, a sufficient amount of the liquid is sprayed in to reduce the temperature to the desired degree. There seems to be a limit to the temperature which it is permissible to use, both in the entering flue and in the drying chamber.

APPLICATIONS OF THE SPRAY PROCESS

The spray process may be used for the desiccation of a wide variety of substances. Whether it is the best method to use in any particular case will depend on the value of the material and on the properties required in the dried product. It is sometimes difficult to predict with certainty whether a material will dry satisfactorily by the spray process. Some materials have a tendency to form a gummy mass on the floors and walls of the drying chamber. It is not always a question of hygroscopicity. Consider two substances like refined cane sugar and commercial glucose. The glucose will dry quite readily to a fine white powder, but the cane sugar has a marked tendency to give a gummy product. Normally, dried glucose is hygroscopic; cane sugar is not. It appears to be a question of the rate at which the material solidifies. Substances which solidify slowly are likely to give trouble.

In general, it may be said that substances dried by the spray process are likely to retain their natural properties. In the case of milk, for instance, when the dried product is restored by the addition of water, it again becomes normal milk. It has the milk flavor. There is no sediment. The albumin is not coagulated. The casein has its colloidal character. The butter fat is in natural emulsion. The enzymes and vitamins are active.

Commercially, this process gives the greatest advantages in drying substances which are injured by temperatures and methods ordinarily used in desiccation. On these substances the slightly greater cost of drying will be much more than made up for by the quality of the resulting product.

Direct Heat Rotary Drying Apparatus

By Robert G. Merz

AMERICAN PROCESS COMPANY, NEW YORK, N. Y.

The removal of moisture by vaporization from the various materials employed in the different industrial processes is a subject of great commercial and technical importance, especially for chemical engineers, and hence a more or less intimate knowledge of the types and characteristics of mechanical drying apparatus, available for such work, is very desirable. In many cases the utilization of waste products is made possible only by the cheap and rapid elimination of the large quantities of water which such materials usually contain, and hence the mechanical dryer is a major factor in most by-product recovery processes.

For those not thoroughly acquainted with the necessity for drying many of the materials employed in manufacture, it may be well to review briefly the reasons for such treatment. Thus drying may be required:

- 1—To permit pulverizing or fine grinding.
- 2—To permit screening or grading.
- 3—To permit uniform mixing.
- 4—To permit magnetic and electrostatic separation or dry table concentration.

- 5—To increase capacity in later operations.
- 6—To reduce weight in shipment.
- 7—To prevent decomposition of organic material due to high moisture content.
- 8—To permit improved conditions of combustion when burned in a furnace, etc.

THE DIRECT HEAT ROTARY DRYER

Although there are many kinds of mechanical dryers in use, the present paper will be confined largely to the discussion of a type which has a wider field of application than any other single type, and which at the same time possesses certain advantages which make its use practically universal in many industries.

The direct heat rotary dryer is undoubtedly one of the oldest forms of mechanical drying apparatus and probably originated in satisfying a demand for a rapid and economical method of eliminating the natural moisture which occurs in minerals when taken from the earth or when exposed to the elements. For many years the use of the direct heat rotary dryer was limited to the drying of such natural inorganic materials.

With the advent, however, of the more complex in-

dustrial processes in manufacture, the increasing cost of fuel, and a better understanding of the principles involved, the employment of this type of dryer has been rapidly extended to the handling of many other inorganic, as well as numerous organic, substances, particularly by-products, which were formerly not considered capable of treatment by direct heat because of injury to the material.

As might be expected, different substances require different methods of treatment on account of their form, size, composition, physical and chemical characteristics, initial and final moisture content, etc. Hence it has been found desirable to develop several classes of the direct heat rotary dryer the better to suit the various materials to be handled. In many cases, however, the same form of dryer, with slight modifications, can be satisfactorily employed to dry substances which possess entirely different physical and chemical characteristics.

In general, the direct heat rotary dryer consists essentially of three more or less distinct parts:

1—A furnace in which the required heat energy is liberated from the fuel by its thorough combustion.

2—A suitably mounted cylindrical steel shell, revolving on a horizontal axis or one slightly inclined to that axis.

3—A chamber into which the spent furnace gases and water vapor (and sometimes the dried product itself) are discharged for eventual escape into the atmosphere.

The arrangement of these three parts is such that the hot gases from the furnace are forced to pass *through* the rotating steel drum, giving up a major part of their heat content to the wet material, which likewise passes *through* this drum.

TYPES OF DRYER

When the drying material and the hot furnace gases move in the same direction through the revolving drum, we obtain what is technically termed a "parallel current" dryer, and when they move in opposite directions, a "countercurrent" dryer.

Again, the dryer may consist of one simple cylinder, in which case it is designated as a "single shell type." If the interior of such a single shell drum is divided longitudinally by partitions, it is known as a "compartment type," and when the cross section is broken up into cells or pockets, it is called a "cellular type."

If the main cylinder is fitted with a large concentric internal cylinder, we obtain the "double shell type," and when the interior is fitted with a multitude of smaller longitudinal flues or pipes, we have the "tubular type." Sometimes the concentric internal cylinder is employed in connection with several smaller longitudinal flues, located between the outer and inner shells, in which case a combination or "tubular, double shell type" is secured.

Whenever the hot furnace gases, *i. e.*, the products of combustion, during their movement through the dryer, mingle immediately and directly with the material to be dried and remain with the same during the entire drying operation, the dryer is designated as a "direct heat, direct contact type;" but when the

furnace gases mingle with the material only after their temperature has been partially reduced by the transference of some of their heat to the drying substance by conduction through and radiation from a surrounding shell plate, then a "semidirect heat, direct contact type" results.

Again, the hot gases may pass through numerous longitudinal flues in the rotating cylinder itself and never come in contact with the drying material at all. Properly speaking, this is an "indirect heat type," although it is often included with the direct heat dryers.

When the drying drum itself rotates within an enclosing chamber or housing in which the hot furnace gases circulate and surround the drum, we obtain what is commonly known as an "indirect heat dryer." Here the products of combustion and the material to be dried do not mingle. On the other hand, it is sometimes desirable to draw the combustion gases from the enclosing chamber, after their temperature has been materially reduced, through the dryer drum in direct contact with the drying material. In this case a so-called "direct, indirect heat" type of dryer is secured.

GENERAL MECHANISM OF THESE DRYERS

It is beyond the scope of the present paper to enter into details as to the interior construction of the drying cylinders themselves. Suffice it to say that provision is made for thoroughly agitating the wet material in intimate contact with the furnace gases so as to extract their heat rapidly and to advance the material through the revolving drum at the same time. A system of internal lifters and shelves usually accomplishes the former, while the inclination of the axis of the drying cylinder or a series of internal spiral-formed plates serve to move the drying material through the drum.

Obviously the countercurrent principle cannot be employed in a direct heat, direct contact type of dryer, except for inorganic materials which are not affected by very high temperatures or by the products of combustion. Moreover, unless it is necessary to eliminate practically all traces of moisture or to discharge the dry product at a high temperature, there is little to justify the use of the countercurrent type of dryer, and in many cases it is a positive disadvantage to dry material by this method.

Under certain conditions, even with organic substances, however, it is possible to use the countercurrent principle in connection with the semidirect heat, direct contact type, because of the fact that the temperature of the gases has been greatly reduced before coming in actual contact with the drying product.

In the majority of cases, where wet organic products are to be dried, the direct heat, direct contact type of dryer, using the parallel-current principle, is by far the most satisfactory and, in fact, the only logical method of drying such products. Even the inorganic materials are most successfully dried in this same parallel-current type of rotary dryer.

The selection of the type of direct heat dryer, most

suitable for the material to be handled and the work to be accomplished, should be left to those with extensive experience in direct heat drying processes, since an improper type may be the cause of serious difficulties and often considerable financial loss.

APPLICATIONS OF DIRECT HEAT ROTARY DRYERS

Only a brief survey of the numerous fields of application of the direct heat rotary dryer is permissible here. Each year, in fact, sees this type of drying apparatus introduced into new industries for the handling of new and varied products.

For many years the clay, cement, sand, and plaster industries have employed the direct heat rotary dryer, and its use is practically universal for this work.

The mining and metallurgical industries very frequently find it necessary to dry ores, either to reduce their weight for shipment, to increase the capacity of furnace processes, to permit of pulverizing for separation or concentration, or to eliminate the moisture from flotation concentrates, etc., and the same type of rotary dryer is used for the purpose.

The fertilizer, by-product, and allied industries invariably have occasion to dry the materials which they handle. The removal of water from animal tankage, fish and fish offal, after cooking and grease extraction, from manure, guano, garbage, peat and other fillers, as well as from digested leather scrap, steamed bone, sewage sludge, natural phosphates, potash salts, etc., all of which eventually enter into the manufacture of complete fertilizers, is generally carried out by direct heat rotary processes because of the economy possible with this class of dryer.

The chemical industries have for many years found this type of dryer a most essential part of their mechanical equipment, not only for the raw material and the by-products, but in many cases for the finished product itself. The chemical industry is undoubtedly one of the largest and most extensive fields for the application of the direct heat rotary dryer, and with the growing importance of chemical manufacture in this country, this economic type of mechanical drying apparatus is certain to become a very essential factor in the manufacturing process and the treatment of the by-products of the industry.

Aside from those mentioned above, many industries find it necessary to dry the materials which enter into the manufacture of their various products or to eliminate the water from waste or refuse resulting from such manufacture. Sugar refineries, paper mills, paint and pigment mills, petroleum works, tanning extract plants, alcohol recovery mills, briquetting plants, etc., often employ the direct heat dryer. It must be understood, of course, that the direct heat rotary cannot be employed successfully for all materials because of the possible injury caused by excessive temperature, discoloration or contamination by the products of combustion, physical or chemical peculiarities, etc.

ADVANTAGES OF THIS TYPE OF DRYER

As might be expected from the fact that the heat is applied in the most direct manner to the material from

which the water is to be vaporized, the direct heat rotary dryer, when properly designed and operated, is capable of large capacity and great economy. Because of the high temperatures employed, and the constant exposure of new surfaces of the drying material to the hot furnace gases with which they are intimately mingled, the removal of the contained moisture is very rapid.

The comparative simplicity of the apparatus, the absence of high pressure joints, the ease of inspection of all parts while in operation, the small number of wearing surfaces and their ready replacement, also the freedom from frequent and extended shutdowns, entirely aside from the high efficiency and great capacity obtainable, together with the possible application to such a large number of materials, give the direct heat rotary dryer a most important and prominent place among the mechanical devices employed in modern industry.

Chemical engineers and all those concerned with the drying of materials will do well, therefore, to investigate very carefully the application of the direct heat rotary to any problems involving the vaporization of water from solid or semisolid substances.

It should be remembered that, in all cases, a uniform feed of wet material, as well as a steady and constant supply of hot furnace gases, are absolutely essential for satisfactory results.

DISADVANTAGES

The disadvantages of the direct heat rotary dryer are comparatively few, and encountered mainly in the drying of organic materials:

- 1—Dust losses.
- 2—Overheating or burning of the material.
- 3—Production of unpleasant odors.
- 4—Explosions due to gas or dust.

The three latter occur, as a rule, only in the handling of organic materials or a combination of organic and inorganic products.

By intelligent selection of the type of dryer, care in its design, and proper operation of the machine, all of the above difficulties can be overcome, or at least reduced to such an extent that they are no longer an important factor.

EFFICIENCY

In a general way, the efficiency of a direct heat rotary dryer corresponds to the efficiency of a steam boiler, *i. e.*, it represents the ratio of the heat usefully employed in vaporizing the moisture in the material to the available heat in the fuel employed in the drying process. And, as in the case of the boiler, the efficiency is a variable quantity, but depending upon a much larger number of factors.

As a general rule, the higher the initial and final moisture contents of the material, the greater the efficiency. When the final moisture must be reduced to a very low point, the efficiency decreases very rapidly, and when the specific heat of such material is also high, the efficiency may fall to a comparatively low value.

Hence the same dryer may have various efficiencies when handling different materials, owing to the characteristics of the material when fed to the machine and the requirements of the discharged product. Variations in the size of the pieces may likewise cause a reduction in the efficiency compared to that of uniform-sized material, because of the necessity of overheating the smaller pieces in order to dry the larger lumps properly. This is particularly true of porous substances where the moisture permeates the entire mass, as distinguished from hard dense materials where the moisture exists on the surface only.

Naturally, the kind of fuel employed for the drying process has a considerable influence on the efficiency, just as in the case of the boiler. This is due to the fact that the heat losses, caused by excess air required for the combustion of the fuel, become greater in proportion to the increase in the weight of air used per pound of fuel consumed and per unit of heat liberated. Moreover, fuels which contain considerable quantities of water when burned, such as is usually the case with wood, lignite, and similar materials, or where the constituents of the fuel itself burn to form superheated water vapor, as with certain gases of high hydrogen content, likewise result in reduced efficiency.

Again, the necessity of reducing the extremely high temperatures produced by the combustion of fuels of high calorific intensity, in order to prevent injury when handling certain materials, by the introduction of additional cool air, also materially affects the efficiency obtainable.

Although there are other factors which have a direct or indirect influence upon the efficiency of the direct heat rotary dryer, enough has been said to show that such efficiency may be a very changeable quantity, entirely aside from that due to carelessness or improper operation.

UTILIZATION OF WASTE HEAT FROM OTHER PROCESSES

The question frequently arises as to the advisability of employing the waste heat from other processes, such as from steam boilers, reverberatory or smelting furnaces, roasting or calcining operations, etc., as a drying medium. A satisfactory answer to this cannot be given without a thorough knowledge of all the local conditions involved in the problem. Although the proposition of the utilization of such waste heat is a very attractive one, there are a great many factors to be considered.

For instance, when only low temperature gases are available, such as from steam boilers, a very large volume of such gas must be handled and passed through the drying drum to recover a comparatively small quantity of heat. The moving of this large volume of gas against considerable resistance requires much power, which, together with the probable reduction of temperature, before entering the drying drum itself, especially if located at some distance from the boiler plant, and the relatively large size of the apparatus required for a small evaporation, is usually not an economic proposition. In other words, the installation is very likely to become quite extensive and costly in order to save a small amount of heat. As a general

rule, it is more profitable to recover as much heat as possible by means of a suitable economizer and to employ a separately fired dryer to vaporize the water in the material to be dried.

When gases of high temperature are available from other furnace processes, especially where the drying outfit can be located close to the source of these hot gases, there is better chance of success. It must be remembered that, for all such cases, these very hot gases must flow under the influence of gravity, since they cannot be handled by means of a fan except after cooling.

Another important point to be considered is the effect of the drying unit upon the installation which serves as the source of the hot gas supply. And in many cases the regulation of the initial outfit so seriously affects the drying process as to make its use unprofitable, unsuccessful, and at times entirely impossible.

APPLICATIONS OF THE MODIFIED ROTARY DRYERS

For some materials, particularly when injury results by direct contact with the products of combustion, the indirect heat type of dryer, previously described, is frequently employed. Its efficiency, however, is quite low, the capacity is small for the space occupied and the capital invested, and the cost of repairs is generally a very considerable item. There are certain cases, nevertheless, where its use is advisable because of the nature or peculiarities of the material to be dried.

There are also a large number of substances, both organic and inorganic, which cannot be subjected to high temperatures or to the products of combustion without injury or complete destruction of their form, composition, purity, or commercial requirements. For such materials the "steam-heated air, rotary dryer" is particularly well adapted. The essential difference between the direct heat and the steam-heated air type is in the source of the drying medium. Instead of the high temperature furnace gases, a volume of heated air from a pipe coil heater, using either exhaust or live steam, is forced or drawn through some form of a rotating drying cylinder, very similar to those described under direct heat dryers, where the material to be dried is constantly showered in direct contact with the heated air.

Naturally the efficiency of such a form of dryer is comparatively low, based on the heat units in the fuel from which the steam itself is derived, except where use is made of exhaust steam from other processes and for which there is no special use.

CONCLUSION

In conclusion it may be said that the subject of mechanical drying involves an intimate knowledge of thermodynamics, including the laws of combustion, heat generation and heat transmission, heat capacities of various gases, effect of partial pressures upon rate of evaporation, etc. In addition a proper knowledge of the physical and chemical properties of the various materials handled, as well as of the principles of mechanical construction, is essential for a satisfactory and economic installation.