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Conveyor Dryers

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1. INTRODUCTION

The conveyor dryer—also called an apron or band dryer—is in the class of machines along with tray, truck, and tunnel dryers within which the usually granular product is spread more or less evenly in a bed and dried by the passage of heated air across or through the bed.

With the exception of transfer operations (or occasionally deliberate stirring of the bed), the individual particles of product remain fixed in position with respect to each other. This is in contrast, for example, with a rotary dryer in which the product particles are continuously tumbling.

In general, the flow of heated air can be adjusted so that each area of the bed is exposed to the process conditions of air velocity, air temperature, and air humidity most suitable for that phase of the drying process. The bed depth, and in some instances particle size, can also be adjusted as appropriate.

Tray, truck, tunnel, and conveyor dryers therefore offer the two key features of (1) gentle physical handling of the product and (2) close control of process conditions.

The conveyor dryer, however, offers the additional advantages of a continuous process and the greatly increased drying efficiency obtained with positive through-the-bed air circulation. In contrast, the other types tend to be associated with labor-intensive batch operations and in general tend to operate with cross, or mixed cross and through circulation of air.

An important factor in the application of the through-circulation conveyor dryer is the preforming or other preparation of the product to permit forming a bed permeable to airflow. This is discussed further below.

2. MACHINE DESCRIPTION

Figure 1 is a cutaway view of a typical single-conveyor dryer (other types are discussed later). Product in granular form is here being distributed onto a perforated-plate conveyor by an oscillating feeder conveyor.

The dryer conveyor, described further below, can be from 1.0 to 4.5 m wide, with 2.5–3.0 m most typical.

The product is carried through an insulated housing within which heated air is forced through the material. Housing lengths can be from 3 m (in narrow widths) to 60 m or more.

In this illustration the product passes first into an "air-up" zone, where heated air is forced up through the moving bed of material by backward-blade turbine fans, chosen for their efficiency at high static pressures and their nonoverloading characteristics. The return air is reheated by steam heat exchangers (finned coils). Other possible heat sources are discussed later. Uniform delivery of the heated air to the bed is ensured by passing it first through perforated air distribution plates installed across the full width of the conveyor.

The conveyor in this illustration now moves into an "air-down" zone, where the flow direction is reversed. Air passing through a bed of drying material is giving up heat and picking up moisture as it goes. Thus the product particles on the leaving side of the bed are not subjected to as effective drying conditions as those on the entering side. Air direction reversals are often employed, therefore, to enhance moisture uniformity throughout the bed.

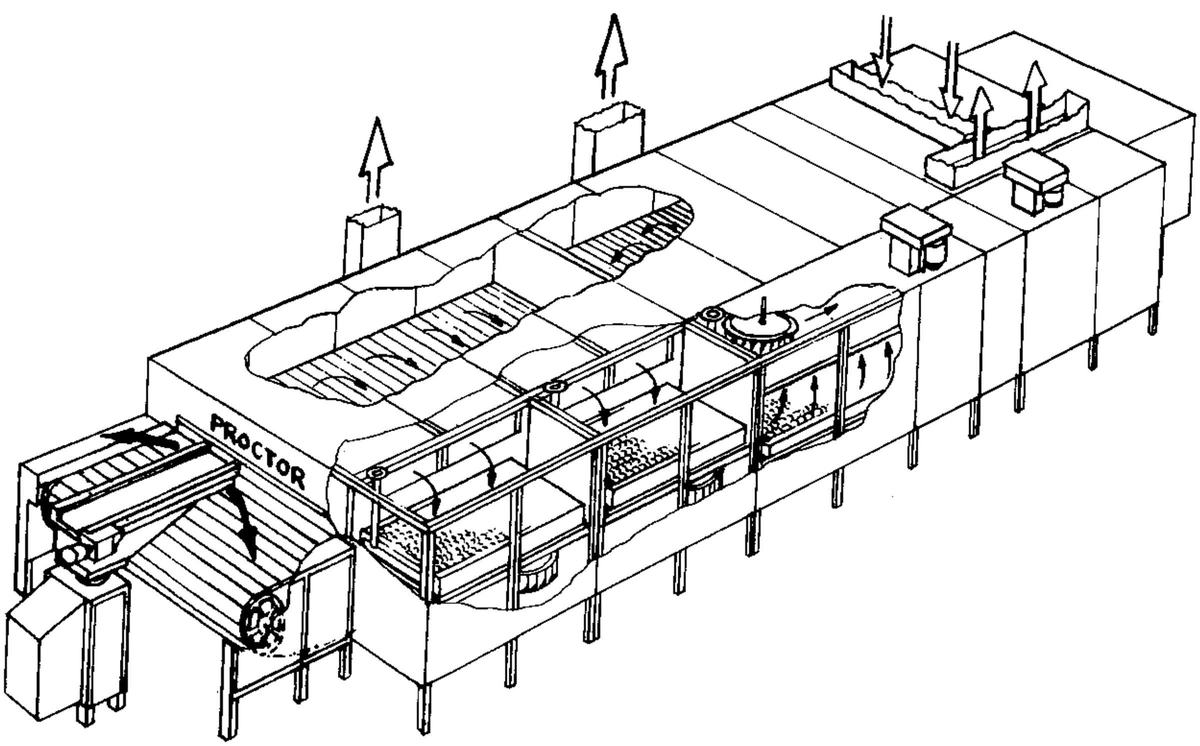


FIG. 1 Cutaway view of single-conveyor dryer (courtesy Proctor & Schwartz, Ltd.).

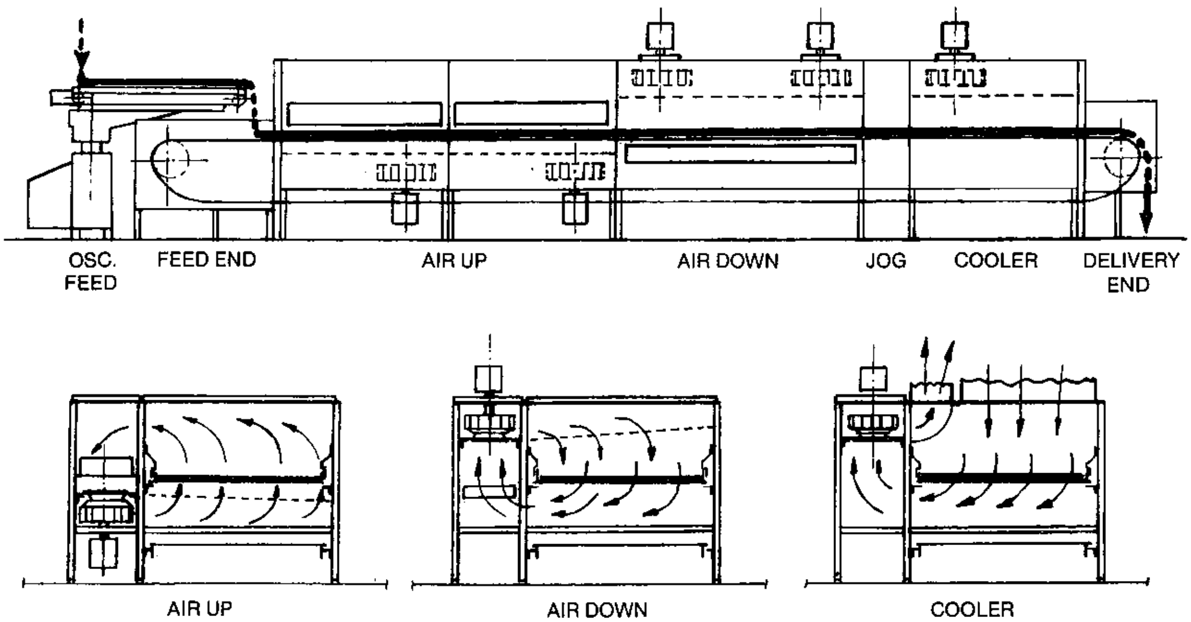


FIG. 2 Side-elevation and cross section of typical single-conveyor dryer (courtesy Proctor & Schwartz, Ltd.).

Finally the product passes through an air-down cooling zone within which ambient or chilled air is drawn through the bed by another turbine fan discharging to an exhaust duct. The product is then dumped from the dryer conveyor, typically onto a cross-conveyor for transport to the next stage in the process.

Figure 2 portrays the machine of Fig. 1 in side elevation and cross section, showing more clearly the directions of airflow as described above. Note particularly the positions of the perforated air distribution plates or baffles. Note also that a neutral zone or "jog space" with no air circulation is employed to isolate the cooler from the preceding dryer zone.

Dryer housings are typically built in standard length modules (here, 1 m), sized to optimize utilization of commercial-size materials. This standardization permits efficiencies in engineering and manufacture as well as in on-site assembly.

Each of the airflow direction zones in a conveyor dryer can be further subdivided by partitions into one or more temperature control zones to permit controlled changes in entering air temperature as drying progresses. Similarly, compartment-by-compartment control of exhaust (extraction) and fresh air makeup airflows can be used to maintain wet-bulb temperature (humidity) at the optimum level for each phase of drying.

Note that during constant rate drying the product will be essentially at wet-bulb temperature, so that control of air humidity can effectively control the temperature of the product. In some applications high humidity during the early phases of drying is used to inhibit too-rapid surface drying which could result in surface cracks. In other instances it is used to prevent "case hardening," the formation of an outer sealing layer that can inhibit the loss of internal moisture.

Bed depths in conveyor dryers are most typically of the order of 100 mm but can range from a monolayer of particles to over a meter in some instances. Conveyor loadings range up to about 600 kg/m^2.

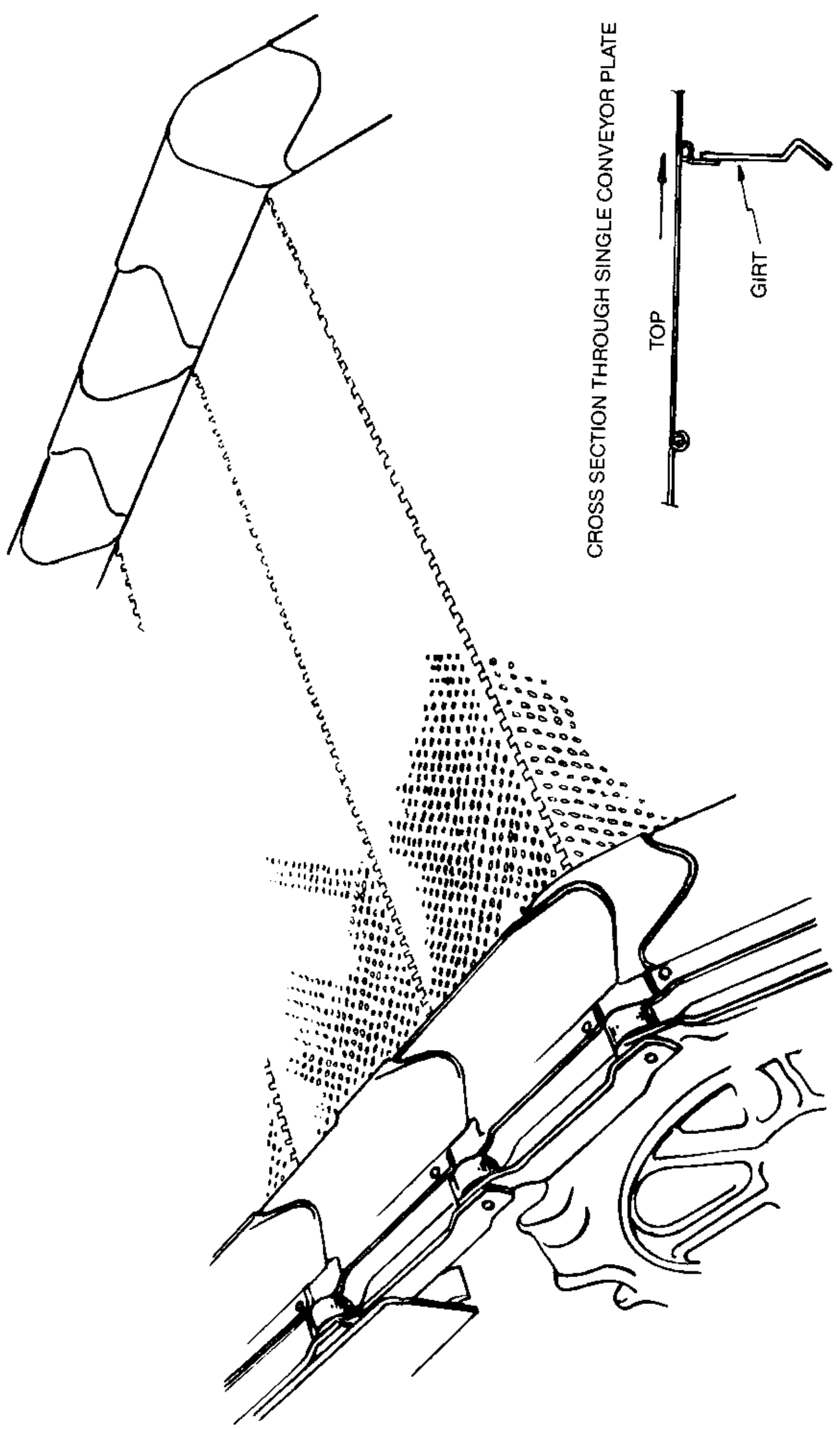


FIG. 3 Construction details of typical dryer conveyor (courtesy Proctor & Schwartz, Ltd.).

Air velocities through the bed of material are usually about 1.25 m/sec in single-conveyor dryers but can range from 0.25 to 2.5 m/sec in special applications. Static pressure drops across the bed are normally kept below about 25 mm water gauge to avoid problems with zone-to-zone leakage and blowout at the feed and discharge ends.

Operating temperatures can be up to about 400°C for the type of machines described here, but most applications are within the range of 100–200°C.

It should be noted that conveyor dryers are often used for processes other than, or in combination with, drying. These include toasting, puffing, curing, baking, and calcining, among many others.

3. CONVEYOR DESIGN

The details of construction of a typical conveyor are shown in Fig. 3. The individual conveyor plates are typically made of perforated stainless steel sheet perhaps 1 mm thick. Widths in the machine direction are from 50 to 300 mm, with a 200-mm pitch most common. The conveyor plates are perforated over about 6–45% of the net open area, with perforation patterns to suit the product size, cleaning requirements, and other factors. For example, a 1.5 × 6 mm slot running in the machine direction at about 25% open area might be used where it is necessary to brush the conveyor on the return run to remove residue. The very low open areas are used in applications in which the conveyor itself is employed to maintain uniformity of air distribution, as in instances of uneven product loading.

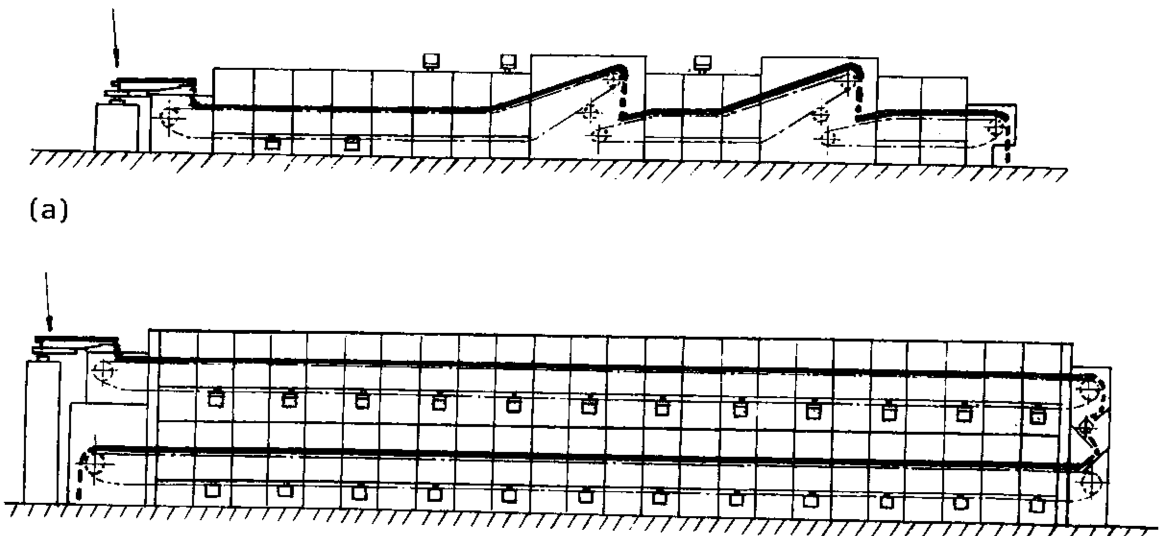
For products with a high fines content—bread crumbs, for example—the conveyor plates can be overlaid with a cover screen of 30–50 mesh polyester or similar material.

As shown in Fig. 3, the individual plates are hinged together, with a vertical reinforcing girt perhaps 100 mm deep running parallel with the hinge at each joint to minimize deflection under load. The plates are supported at their ends by attachments on a specially designed roller chain. Traveling guards are attached at the same points, designed to overlap in such a way as to minimize side-spilling of the product, especially as the conveyor passes around the sprocket at the dump point. Sheet metal stationary guards fastened to the main body of the dryer and fitted with a resilient rubbing seal between them overlap the outside of the traveling guard, ensuring both containment of the product and minimal bypassing of circulating air (see also the cross-sectional drawings in Fig. 2).

Scrapers, doffers, and pin breakers are often employed at the dump point to aid in transfer of product, and wash-brush systems can be employed for cleaning the conveyor on the return run.

4. ALTERNATE CONFIGURATIONS

Staging is the use of separate conveyors arranged in series so that one transfers its product load to the next (see Fig. 4). Staging is employed when a large amount of product shrinkage occurs during early drying (in onions, for example), or when the "green strength" of the product does not permit deep loading. Dumping and reloading with a deeper bed onto



(a)

(b)

FIG. 4 Examples of staged conveyor dryers (courtesy Proctor & Schwartz, Ltd.).

another conveyor permits more efficient utilization of dryer capacity. As many as four conveyors can be arranged in series for this purpose.

Staging can also be used to permit the quick predrying of a shallow bed of a potentially sticky product, followed by transfer to a deeper loading after sufficient surface moisture has been removed to minimize the risk of agglomeration.

As shown in Fig. 4, staging can be accomplished either by a horizontal arrangement of successive single-conveyor conveyors (Fig. 4a) or, to reduced floor space requirements, by stacking them vertically (Fig. 4b).

The multiple conveyor dryer (Fig. 5) is often employed when the product requires relatively long-time, gentle drying and when the process conditons (air velocity, temperature, and humidity) can remain constant throughout the drying process. The multiple conveyor dryer is essentially a heated enclosure with no zoning or partitioning through which the product progresses from 1 (of 2–15) vertically arranged conveyors to the next. Air circulation is a combination of cross flow and through-circulation, and through-bed velocities of 0.25–0.5 m/sec are typical. The speed of the lowest conveyor(s) can be reduced to produce deeper loading. This induces a larger proportion of air to flow through the thinner beds on the upper conveyors, sometimes yielding greater overall drying efficiency.

Typical applications of the multiple conveyor dryer are in the drying of pasta products and in the predrying of cereal pellets to the proper moisture content prior to puffing. Figure 5 illustrates two of several possible configurations: the side elevation shows product loaded onto the top conveyor and then dumped successively onto lower conveyors, each of which moves in a direction opposite to that of the one immediately above. As noted above, up to 15 conveyors are used, but 3–5 are most common.

The cross section on the left in Fig. 5, corresponding to the side elevation above, shows turbine fans arranged to force return air through vertically mounted steam coils and then through baffles into the conveyor space.

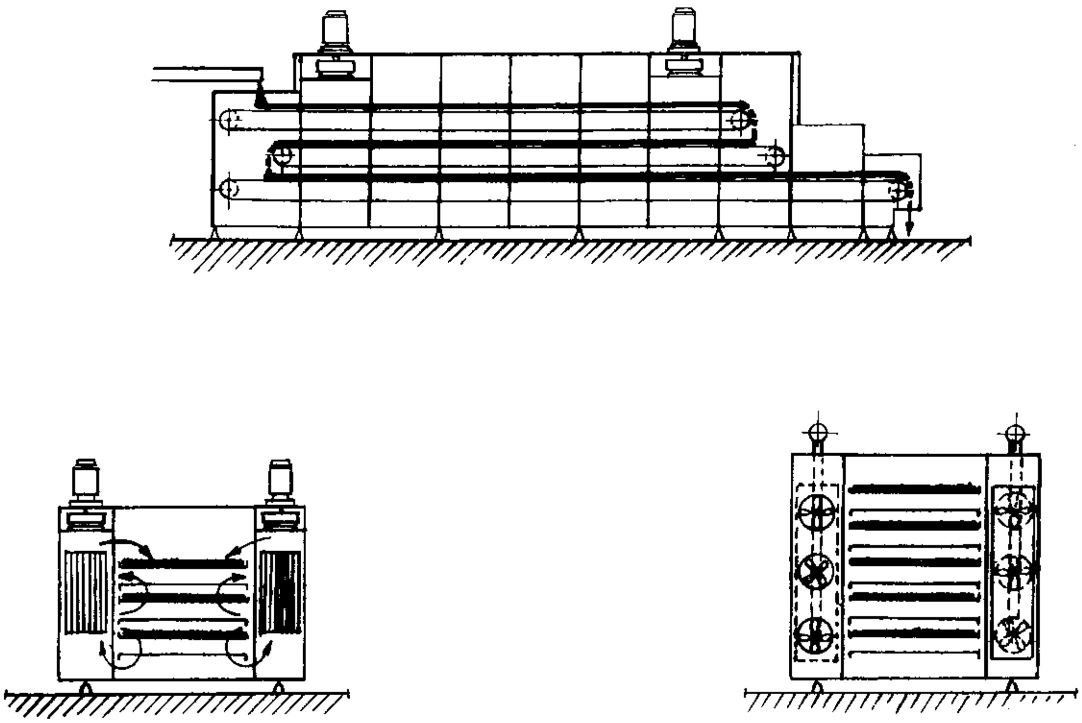


FIG. 5 Multiple-conveyor dryer (courtesy Proctor & Schwartz, Ltd.).

The baffles are arranged in this case so that air passes down through the top conveyor, up through the second conveyor, and down again through the bottom conveyor, before returning to the fan intake. This alternation of air flows, along with the mixing that occurs at the dump points, results in excellent uniformity of product treatment.

Turbine fans in a multiple conveyor dryer offer the advantages of simplicity and efficiency. As the number of conveyors increases, however, considerations of air distribution and overall height favor a vertical array of propeller fans (as shown in the right-hand cross section of Fig. 5), which can move large volumes of air at the low static pressures normally encountered in machines of this type.

The multiple conveyor dryer offers a large conveyor holding area for the floor space employed. The product, however, must be able to withstand repeated dumps, which are prone to generate fines even with the aid of transfer chutes between conveyors. Sticky products or those requiring frequent washdown are difficult to deal with unless a built-in clean-in-place (CIP) system is employed. The precise process control possible with the zoned single-conveyor dryer is also not available in a multiple conveyor dryer.

The multiple conveyor dryer is not inherently more energy efficient, as is sometime claimed, but owing to its compact configuration and functional simplicity, lends itself more readily to the installation of energy-saving devices, such as automatic controls and heat recovery discussed below.

Sometimes the best choice is a combination of types, for example, a single conveyor predryer to remove surface moisture (or stickiness), followed by a multiple conveyor for final drying.

A special class of single-conveyor dryer is the impingement dryer, in which the drying air does not pass through the product bed but instead is blown against the product by special nozzles. A typical airflow arrangement is shown in Fig. 6. The product is usually in sheet form but can also be a monolayer of individual pieces arranged on a conveyor. The conveyor itself can be perforated sheet metal or woven wire or can be a solid sheet, in which case heat transfer from the bottom nozzles is wholly by conduction.

The nozzle boxes in Fig. 6 are fed from a plenum from which they recieve heated air under fan pressure. After impinging on the product from the nozzle slots, the cooled and moisture-laden air returns around and between the nozzles to the heater and fan, where some is exhausted and the rest recycled.

Nozzle exit velocities range from 5 to 20 m/sec. The jet of air from the nozzle slot impinges first upon the product directly below the nozzle, then sweeps along the product surface for some distance before joining the return airflow. The average heat transfer coefficient across the product surface is a function of nozzle exit air velocity, slot width, and nozzle-nozzle and nozzle-product spacing. A typical value is 50 W/m^2-°C. Nozzle design is a careful trade-off between requirements for uniformity versus cost and fan horsepower.

Impingement dryers are used for drying sheet tobacco and other materials in sheet form. Another application is discussed in the next section.

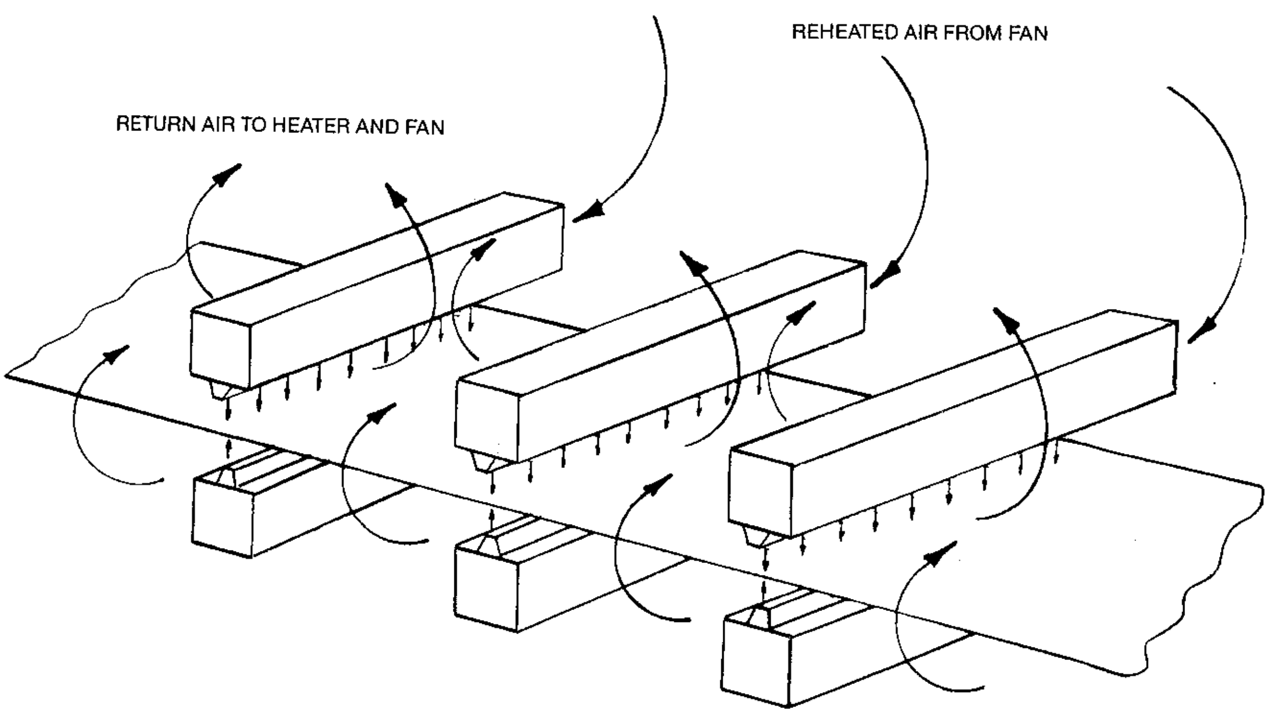


FIG. 6 Typical airflow arrangement in an impingement dryer (courtesy Proctor & Schwartz, Ltd.).

5. ANCILLARY EQUIPMENT

Various feeding devices are used to provide a uniform bed across the width of the conveyor. Probably the most common is the oscillating boom carrying either a passive chute or a vibrating or moving-belt conveyor, as shown in Figs. 1 and 2. The simplest type of feed is the full-width hopper with adjustable discharge gate (Fig. 7a), often used for nuts and other free-flowing products.

As noted earlier, efficient through-circulation drying depends upon establishing and maintaining a structural configuration that will permit the free passage of air through the bed of material. As an example, the rolling extruder (Fig. 7b) is used to convert heavy pastelike products (e.g., filter cake) into noodlelike extrusions, say, 6–8 mm in diameter, greatly increasing the surface area.

The rolling extruder shown in Fig. 7b consists of a pair of rubber-covered rolls that are driven back and forth on a curved perforated plate mounted across the full width of the conveyor. Product in cake form is distributed into a hopper supported between the oscillating rollers from which it is forced by the rollers through holes in the plate.

The extrusions fall freely to form an open bed on the conveyor. The amintenance of this structure depends in turn upon the gentle handling characteristics of the conveyor dryer; many extrusions are quite delicate and will slump into an impermeable mass if disturbed before an appreciable amount of moisture has been removed.

Other common preforming devices include auger extruders, briquetters, and pelletizers. Many natural products, such as vegetables, are sliced or diced prior to drying.

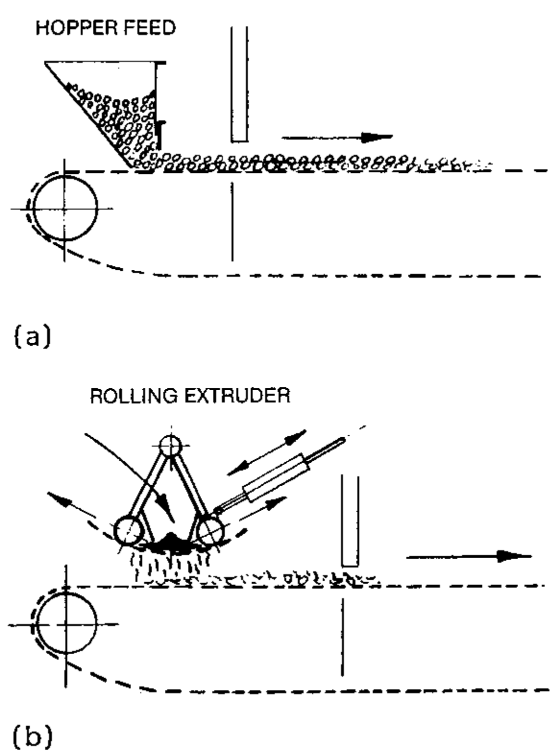


FIG. 7 Typical conveyor feed devices (courtesy Proctor & Schwartz, Ltd.).

Slurried products can also be spread onto a solid (unperforated) conveyor and passed through an impingement-type predryer. After the product has dried sufficiently to form a solid cake, it is scored, then broken into pieces as it is transferred to a perforated conveyor for through-bed drying in the conventional manner.

6. SIZING

Sizing of conveyor dryers is usually accomplished by scaleup from laboratory tests run on specially designed tray dryers. Such dryers are designed to permit accurate simulation and measurement of process conditions at each stage of drying, so that the configuration of the commercial-size machine can be optimized for the product characteristics desired.

Tests nowadays are being run with increasingly sophisticated equipment, including weigh-in-place devices for determining product moisture loss, automatic recording of process conditions, and computer analysis of results. Every effort is made to simulate as exactly as possible the conditions that will be met in commercial services, from preparation of the product to dumping from the discharge conveyor. Test planning will include analysis of the probable commercial-scale machine configuration, required preparation and/or preforming of the product, and allowable temperatures.

Test observations will include—in addition to drying characteristics—product shrinkage, fines generation, fume or smoke generation, and the tendency of the product to stick to conveyor plates. Test tray bottoms are fabricated using the same material (including nonstick coatings), and perforations as will be used in the proposed commercial-scale machine.

A scaleup factor is employed in converting from laboratory data to commercial-scale equipment, which is based on a combination of analysis plus laboratory and field experience; it can vary from less than 1.0 to 2 or more.

7. HEAT SOURCES

The next step in the design process is to select components: conveyors, fans, air distribution devices, ancillary equipment, and heat sources.

Direct gas firing with natural gas offers the greatest flexibility and quickest response at least cost; it also permits operation at higher temperatures than are easily obtainable by other means. Safety requirements are stringent. Propane has characteristics similar to those of natural gas but is more costly.

Most dryers nowadays are steam heated, offering isolation of product from products of combustion, along with simple control. Temperatures are limited (usually to about 150°C) by available steam pressure, however, and clogging of heat exchanger fins by fines is frequently a maintenance problem.

Direct oil firing is sometimes used in process industries, but seldom in food applications due to the risk of product contamination. Control flexibility is also limited by lower burner turndown ratios.

Hot oil (transfer fluid pumped from an external boiler to air heat exchangers in the dryer) offers higher temperatures than steam without the associated high pressures. Initial costs are higher, but without condensate losses overall energy efficiency is greater.

Electric heating is seldom used because of its overall poor energy-use efficiency and resulting high cost. Applications are generally limited to very high temperatures where product contamination by products of combustion must also be avoided.

Indirect oil (or gas) fired into radiant tubes is seldom employed due to low efficiency, sluggish response, and high engineering and materials costs.

8. ENERGY CONSIDERATIONS

The following tabulation shows a typical conveyor dryer heat load calculation, indicating how input energy is distributed. The first three components of the heat load are established by operational requirements of the machine; the last two are losses to be minimized. The loss levels shown are not necessarily typical but represent what can be achieved with good design and careful maintenance.

Component	W.	%
Evaporation (+ moisture, vapor)	528,000	55
Product heatup	117,000	12
Exhaust makeup	264,000	28
Product entry/exit losses	29,000	3
Radiation/convection losses	15,000	2
Total	953,000	100

Each component of the heat load should be examined during design for factors that could reduce energy consumption. Following are some guidelines.

The evaporative heat load can be reduced by reducing initial moisture (e.g., by mechanical dewatering) and by closer approach to the allowable final moisture through automatic product moisture control. Overall drying efficiency is critically dependent upon uniformity of product loading; uneven loading will allow bypassing of air, causing overdrying of thin spots in the bed and underdrying elsewhere.

The product heat-up load may be reduced by conserving heat already in the product from upstream processes and can be recovered by recycling air from a downstream cooler. Heat-up losses into the conveyor itself (included under the same heading) can be reduced by enclosing return runs and feed or delivery end extensions; and also by transferring product to a separate conveyor for cooling.

The exhaust (fresh air makeup) laod can be reduced by using constant ratio burners (when excess air governs exhaust levels). Decreasing overall exhaust levels may be possible without loss of capacity, but insulation of ductwork may be necessary to avoid condensation at lower dew points. Losses due to unnecessary exhaust during product interruptions and drops in initial moisture can be minimized by an automatic exhaust humidity control system. Sensible (and sometimes latent) heat can often be recovered from the exhaust.

Entry and exit losses can be minimized through proper seal design; careful adjustment and maintenance are also required to avoid bypass leakage. Special sealing devices and airlocks are sometimes employed, along with enclosed feed and delivery end extensions. In food dryers the latter require careful attention to temperature control to avoid creating biologic incubation sites. Automatic exhaust pressure balance controls are also used.

Typical dryer housing insulation consists of removable panels with inner and outer skins of aluminized or galvanized steel, stainless steel or aluminum, with an inner core of material wool or fiberglass insulation. Through-metal at the edges of panels has a significant effect on overall radiation and convection losses, and special designs must be employed to minimize such losses.

Fan horespower requirements can be minimized by optimizing dryer air velocity (along with temperature and humidity) to conform to the drying characteristics of the product. High fan horsepower may have an overall beneficial effect on dryer energy efficiency during constant rate drying but may be largely wasted when drying is diffusion limited.

Exhaust heat recovery is rapidly becoming an integral part of new dryer installations, and retrofitting is often justified for older units. Figure 8 shows the basic parts of a typical heat recovery system; the hot exhaust air from the dryer is passed through one side of an air-air heat exchanger where 50–70% of the available sensible heat is transferred to the incoming fresh airstream, which is thus preheated for injection as makeup air. Other system elements include booster fans, exhaust air filters as required, ductwork, and bypass dampers. It should be noted that the cost of the heat exchanger itself—plate, wheel, or heat pipe—is only a fraction of total system cost. The economic feasibility of such an installa-

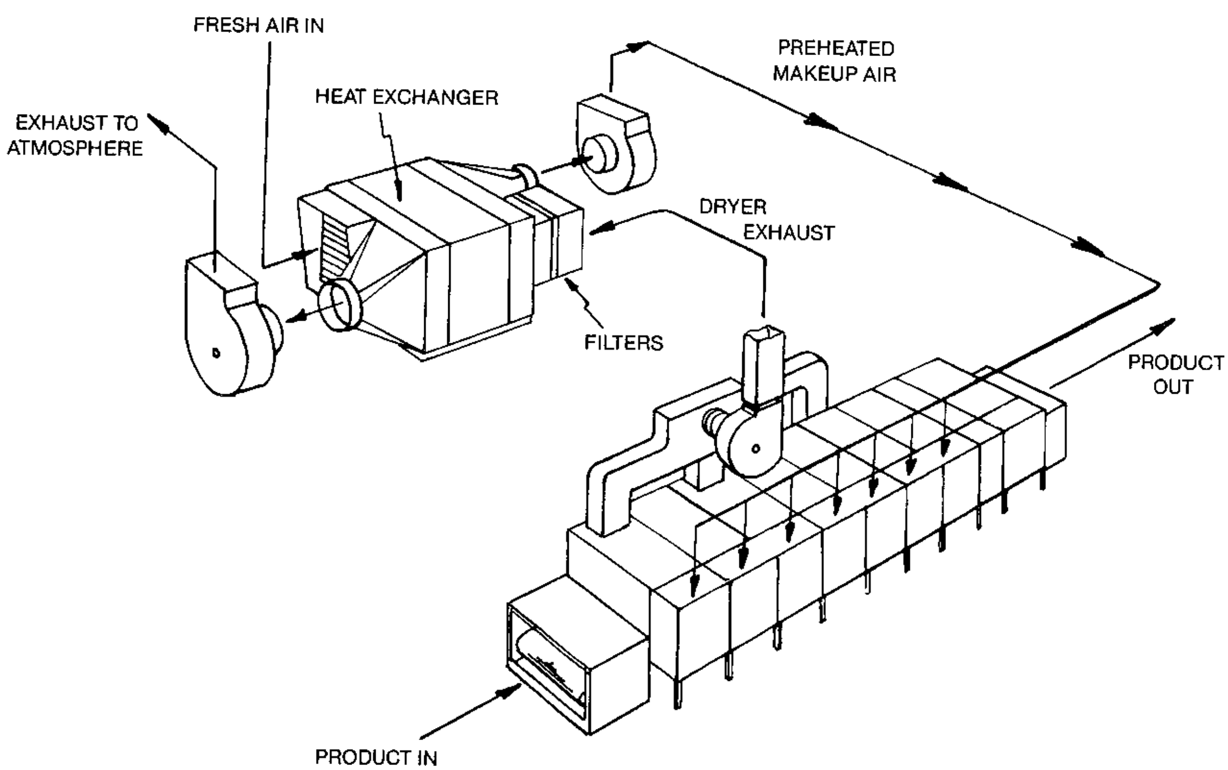


FIG. 8 Typical conveyor dryer heat recovery system (courtesy Proctor & Schwartz, Ltd.).

tion can be checked quickly. If an acceptable payback (1–3 years) is indicated, a more detailed design, cost, and justification analysis can be carried out, which should include probable escalation in the price of fuel.

9. CONCLUSION

In summary, the conveyor dryer provides gentle physical handling of products, which must in general be preformed in some manner to permit free passage of air through the bed. The conveyor dryer also offers the opportunity to closely control process conditions at each stage of the product drying cycle to optimize both product quality and energy utilization. The various configurations available—single, staged, and multiconveyor, used singly or in combination—allow a great deal of flexibility in process design.

The well-engineered conveyor dryer is outwardly a simple machine, robustly constructed, with easy access for cleaning and maintenance. Most of its technical sophistication lies in subtleties of air handling and process control. To obtain maximum benefits in capacity and efficiency the potential user must be sure the dryer manufacturer clearly understands present and projected process requirements, and must follow the manufacturer's recommendations with regard to operation and maintenance.