Drum Drying

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INTRODUCTION

Drum dryers were developed in early 1900s. They were used in drying almost all liquid food materials before spray drying came into use. Nowadays, drum dryers are used in the food industry for drying a variety of products, such as milk product, baby foods, breakfast cereal, fruit and vegetable pulp, mashed potatoes, cooked starch, and spent yeast.[1] In a drying operation, liquid, slurry, or puree material is applied as a thin layer onto the outer surface of revolving drums that are internally heated by steam. After about three-quarters of a revolution from the point of feeding, the product is dried and removed with a static scraper. The dried product is then ground into flakes or powder. Drum drying is one of the most energy efficient drying methods and is particularly effective for drying high viscous liquid or pureed foods.

SYSTEM DESCRIPTION

A drum dryer consists of one or two horizontally mounted hollow cylinder(s) made of high-grade cast iron or stainless steel, a supporting frame, a product feeding system, a scraper, and auxiliaries. Typical structures of single and double drum dryers are shown in Fig. 1. The diameter of typical drums ranges from 0.5 m to 6 m and the length from 1 m to 6 m.

In operation, steam at temperature up to 200°C heats the inner surface of the drum. The moist material is uniformly applied in a thin layer (0.5 mm–2 mm) onto the outer drum surface. Most of the moisture is removed at water boiling temperature. The residence time of the product on the drum ranges from a few seconds to dozens of seconds to reach final moisture contents of often less than 5% (wet basis). The energy consumption in a drum dryer may range between 1.1 kg steam per kg of evaporated water and 1.6 kg steam per kg of evaporated water, corresponding to energy efficiencies of about 60%–90%.[2–4] Under ideal conditions, the maximum evaporation capacity of a drum dryer can be as high as 80 kg H_2O/hr m^2.[4] A drum dryer can produce products at a rate between 5 kg hr^{-1} m^{-2} and 50 kg hr^{-1} m^{-2}, depending upon type of foods, initial and final moisture content, and other operation conditions.[2]

Drum dryers are classified into single drum dryer [Fig. 1(a)], double drum dryer [Fig. 1(b)], and twin drum dryer.[3] A double drum dryer has two drums that revolve toward each other at the top. The spacing between the two drums controls the thickness of the feed layer applied to the drum surfaces. A twin drum dryer also has two drums, but they rotate away from each other at the top. Among the three types, single and double drum dryers are most commonly used for fruits and vegetables. For example, large quantities of mashed potato flakes are produced using single drum dryers with specially designed roll feeding system. Double drum dryers are used in California to dry tomato paste. Twin drum dryers are used only for drying materials yielding dusty products.

For materials sensitive to heat damage, a vacuum drum dryer may be used to reduce drying temperature. A vacuum drum dryer is similar to other drum dryers except that the drums are enclosed in a vacuum chamber. In continuous vacuum drum dryers, receivers and air locks are designed to provide appropriate seal. Equipment and operation of vacuum drum dryers are relatively expensive, which limits vacuum drum drying to only high-value products or products that cannot be produced more economically by other means.

Perforated (suction) drum dryer is another variation from ordinary drum dryers. It utilizes heated air to heat the drum inside surface and the product is sucked to the perforated drum surface during drying. Several perforated drums can be linked together so that product can be transferred from one drum surface to another to achieve high production rates.

The advantages of drum drying include:

- The products have good porosity and hence good rehydration due to boiling evaporation.

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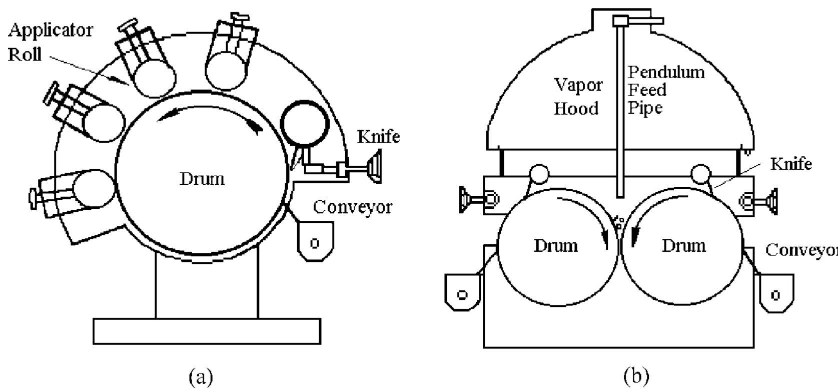

Fig. 1 (a) Single drum dryer and (b) double drum dryer.

- Drum dryers can dry very viscous foods, such as pastes and gelatinized or cooked starch, which cannot be easily dried with other methods.
- Drum dryers normally have high energy efficiency.
- Drum drying can be clean and hygienic.
- Drum dryers are easy to operate and maintain.
- The dryers are flexible and suitable for multiple but small quantity production.

The disadvantages of drum drying are the following:

- Some products may not form a good film on the drum surface and are not suitable for drum drying.
- Some products, especially those with high sugar content, may not be easily scrapped off from the drum.
- Relatively low throughput compared to spray drying.
- High cost of changing drum surface because of the precision machining that is required.
- Possible scorching of the product to impart cooked flavor and off-color due to direct contact with high temperature drum surface.
- Not able to process salty or other corrosive materials due to potential pitting of drum surface.

FEEDING METHODS

The method of applying product onto the drum surface differs, depending on the drum arrangement, the solid concentration, viscosity, and wetting ability of the product. Industrial drum dryers use five basic feeding methods, namely, roll feeding, nip feeding, dipping, spraying, and splashing, as shown in Fig. 2.[2–5]

Roll feeding [Fig. 2(a)] is used in both single and twin drum dryers. It is particularly effective for viscous and glutinous materials. Multirolls are often used to increase the film thickness, and hence the throughput. The gap between the rolls and the drum can be adjusted individually and the peripheral velocity of the rolls may or may not be the same as the drum. Roll feeding is sometimes used in combination with other feeding methods to meet the needs in the drying of certain product.

Nip feeding [Fig. 2(b)] is the simplest feeding method solely used in double drum dryers. It is suitable for drying of thin solutions, such as milk and whey. Nip feeding utilizes the adjustable gap between the two drums as a means to control the film thickness. The uniform distribution of the feed over the length of the drums is essential. Pendulum feed or perforated pipe is used to supply material into a pool in the space between the two drums for most applications.

Dipping is used in both single and twin drum dryers [Fig. 2(c)]. With this method, the dryer is partially submerged in a tray and product in the tray adheres to the surface as the drum rotates. It is good for certain suspensions of solids and used usually with a recirculation of material to prevent setting of the solid in the tray. For materials that cannot stand prolonged exposure to heat, a small tray may be used with constantly supplied fresh material.

In *spray* feeding [Fig. 2(d)], the material is atomized by nozzle onto the drum surface. Spray nozzles can be located at the bottom of the drum or other locations. The quantity of the product applied is controlled by the nozzle system and independent of other operational parameters.

Splashing [Fig. 2(e)] is a method especially suitable for products with a high rate of sedimentation. It can be used in single and twin drum dryers.

As the quality of the product film will directly affect the quality of the dried product, the control of the system, the throughput of the dryer, the proper selection of feeding method is very important. Usually the decision to select a proper feeding method relies on previous experience and/or by conducting tests with pilot units.

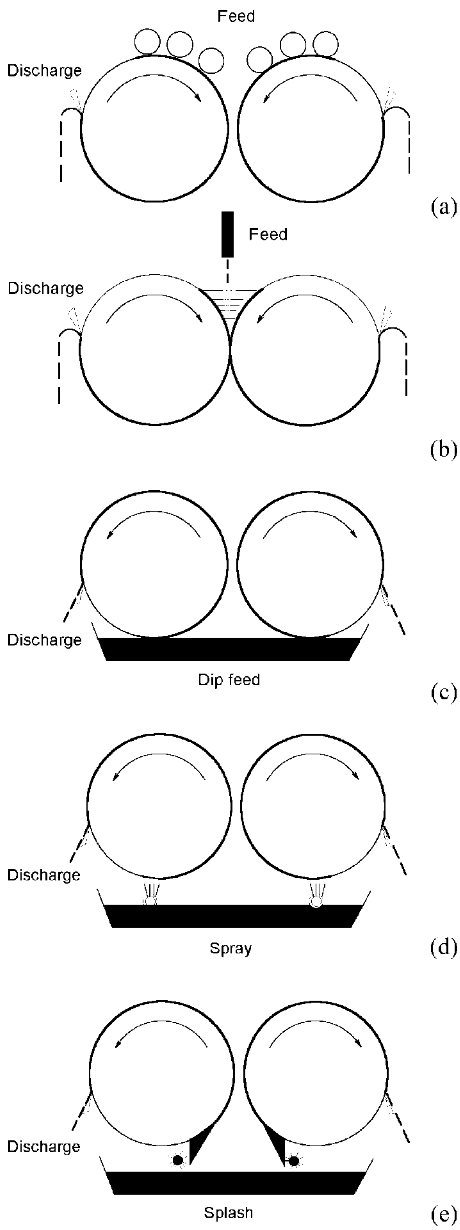

Fig. 2 Feeding methods used in drum dryers: (a) roll feed; (b) nip feed; (c) dip feed; (d) spray; and (e) splash.

PRINCIPLE AND DESIGN EQUATIONS

In drum drying, a large amount of thermal energy is released by the condensing steam in the drum and conducted through drum wall to the product. During drying, a product may go through three general periods. *Initial heating period*: after wet material is applied onto the drum surface in a thin layer, intensive heat transfer takes place due to a great temperature difference between the drum surface and the wet product. Product temperature increases rapidly to reach the boiling point of free water (Fig. 3).[5] *Constant product temperature period*: after reaching the boiling temperature, a large amount of free water evaporates and product temperature remains constant. The drum surface temperature, however, decreases due to an intense evaporative cooling. *Rising product temperature period*: after removing most of the free water, the amount of moisture for evaporation is dramatically reduced. The heat transferred from the steam gradually exceeds the energy used for evaporation. As a result, drum surface temperature increases. The bound water starts to play a major role in controlling the rate of evaporation. As bound water has a higher boiling temperature, product temperature gradually increases as drying proceeds. This trend continues till it reaches the knife where the dried product is scraped off. After the product is removed from the dryer, drum surface temperature continues to increase until new wet material is applied.

The evaporation rate of free water can be estimated by the following relationship[6]:

$$\frac{\mathrm{d}M}{\mathrm{d}t} = 30.94V^{0.8}\Delta P \tag{1}$$

where $\mathrm{d}M/\mathrm{d}t$ is the rate of moisture removal per unit drum surface (kg H_2O/hr m^2), V is the velocity of ambient air (m sec^{-1}), and $\Delta P = p_s - p_a$ (atm) is the difference between the vapor pressure at product surface p_s and the vapor pressure in the ambient air p_a. In period III, the drying rate is controlled by moisture diffusion as well as heat transfer.

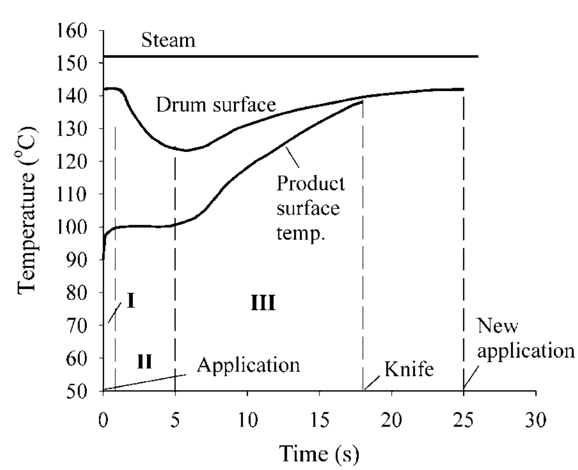

Fig. 3 Product and drum surface temperatures during one revolution of drum drying in three different drying periods. (From Ref. 5.)

Alternatively, water removal rate may be estimated from an energy balance equation:

$$\frac{dM}{dt} = 3.6\frac{h(T_w - T_{evp})}{L} \tag{2}$$

where T_w is temperature of the drum surface (°C), T_{evp} is temperature of evaporating surface (°C), L is latent heat (kJ/kg H_2O), and h is an overall heat transfer coefficient ($W\,m^{-2}\,°C^{-1}$). The value of h varies between 200 and 2,000 ($W\,m^{-2}\,°C^{-1}$), depending on the type and the thickness of the film being dried.

OPERATION

In the operation of a drum dryer, a delicate balance needs to be established among feed rate, steam pressure, roll speed, and thickness of the product film. It is desirable to maintain a uniform film on the drum surface to ensure maximized throughput and consistent final moisture content. Problems, however, are often encountered due to fluctuations in the moisture content and thickness of the feed. Accumulation of noncondensable gases in the drum also influences drying uniformity. Drum surface temperature may vary along the drum width as much as 20°C. All these factors may result in inconsistent drying performance and nonuniform final moisture content in the dried product. Means have been developed to automatically detect the moisture content and temperature, integrated with automated feedback control to minimize the fluctuations.[1,7]

Products containing high sugar contents, such as tomato puree, may be difficult to remove from the drums at high temperatures due to the thermoplasticity of those materials. A cooling mechanism (e.g., a jet of cold air) may be used at the location just before the product reaches the scraper. The purpose of the cooling is to bring the product from a rubbery state into a glassy state to facilitate separation of the product from the drum surface. An understanding of the glass transition temperature and its relation to moisture content is beneficial.

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