vection, and usually poor and non-uniform drying, to the self contained units with forced draft and properly designed baffles which give positive results. It is also possible to evacuate some of the systems for low temperature drying of delicate or hygroscopic materials. These dryers are usually loaded with material spread in trays to increase the exposed surface. The trays are loaded directly into the dryer or may be stacked on trucks which are wheeled in.

Tunnel Dryers. Tunnel dryers are a modification of the compartment dryer and as a rule are continuous or semi-continuous in operation. Heated air or combustion gas is usually circulated by means of fans although a few natural draft units are still in use. The material is handled on trays or racks on trucks and move through the dryer either intermittently or continuously. The air flow may be parallel, counter flow or a combination of the two, obtained by center exhaust. Further, the air flow may be across the surface of the trays or up or down through the bed

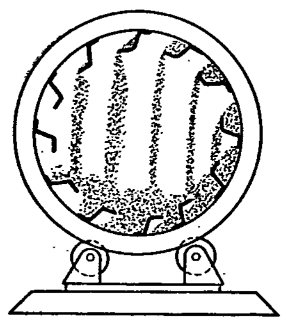

FIG. 3. SECTION OF ROTARY DRYER

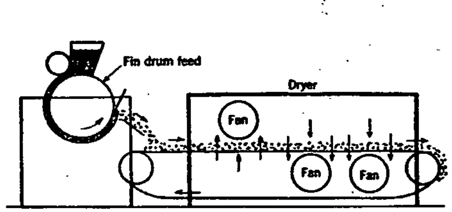

FIG. 4. SECTION OF CONTINUOUS DRYER, BLOW-THROUGH TYPE

or in any combination of directions. By reheating the air in this type of dryer or recirculating it a high degree of saturation is achieved before exhusting the air. This reduces the waste of sensible heat.

A variation on this type dryer is the strictly continuous type having one or more mesh belts which travel through the dryer carrying the product, such as Fig. 4. Innumerable combinations of temperature, humidity and air direction and velocity are possible. The labor requirement is low on such a dryer as it can be loaded and unloaded mechanically. There is the disadvantage of hot air leaks at the entrance and exit although these can be minimized by means of baffles or inclined ends where the material enters and leaves from the bottom.

Spray Dryers. In recent years the spray dryer has become important for the drying of liquids in many fields, especially in the food industry.

The liquid is atomized by means of pressure nozzles, air jets or centrifugal bowls into the air stream of a tower or chamber. Inlet air temperatures may run from 250-300 F up as high as 1200 F. Drying is almost instantaneous because of the minute particle size. The dry powder is separated from the air by cyclone separators which are sometimes followed by cloth bags or scrubbing towers.

Because of the high inlet temperatures and the relatively large volume of air required the efficiency of the spray dryer is not too good and consequently is seldom used for dilute solutions (less than 30 per cent solids).

CALCULATION AND DESIGN

Calculation of the factors involved in drying systems is very complex and frequently inaccurate. For typical examples of the calculations involved the reader is referred to the literature references. Under ideal conditions, however, the following relations hold for convection dryers during the constant rate period.

Constant-Rate Period

The rate of drying by air passing over a wet surface is directly proportional to the vapor pressure difference, and also proportional to the 0.8 power of the air velocity. For practical calculations the wet surface is assumed to attain the wet-bulb temperature of the air passing over it, and evaporation takes place at constant rate under equilibrium conditions. The equation may then be expressed in three forms:

$$R = C\,A\,V^{0.8}\,(\Delta P) \tag{1}$$

$$R = C'\,A\,V^{0.8}\,(\Delta H) \tag{2}$$

$$R = C''\,A\,V^{0.8}\,(\Delta T) \tag{3}$$

where

R = rate of drying during constant-rate period, pounds of moisture per hour.
A = area of bed or material in contact with air, square feet.
V = air velocity over material, feet per minute.
ΔP = difference between vapor pressure at wet-bulb (surface) temperature and at dew-point of air.
ΔH = difference between humidity ratio of saturated air, at the surface temperature, and the actual humidity ratio of the air stream, pounds of water per pound of dry air.
ΔT = difference between dry-bulb and wet-bulb temperatures of air, *i.e.*, the wet-bulb depression.
C, C', C'' = proportionality constants (for numerical values consult references).

These equations are useful mainly for computing the effects of changes in operating conditions, such as changes in air velocity, air temperature, humidity and surface area. The equations assume that the material is in equilibrium at the wet-bulb temperature of the air. If equilibrium has not been reached, or if heat is being added to the charge by radiation or conduction, such conditions must be taken into account. For large tray dryers or continuous surfaces, the logarithmic mean difference should be substituted for the simple difference in ΔP, ΔH and ΔT.

Calculations other than these are probably best left in the hands of experts since considerable data with respect to time, temperature, humidity, air velocity and direction, bed load, pressure drop, recirculation, etc., must be obtained. These data may be based on past experience but are preferably obtained from experiments employing the conditions which are expected in commercial large-scale practice.

Calculations involving the falling rate period are seldom satisfactory because of the number of variables involved but approximations may be made from empirical data obtained by experimentation.

ESTIMATING METHODS

Values based on practical experience are available for rough estimating of drying problems. The temperature will drop approximately 8.5 F deg per (grain of water evaporated) (cubic foot of air, measured at 70 F deg)