

surface. Under these conditions, artificially increasing the humidity of the surrounding air is often a valuable help.

Internal Moisture Gradient

In drying by surface evaporation, an internal concentration gradient is set up between the moisture content at the center of the material and the moisture content close to the surface. The steepness of this gradient is dependent upon the rate of evaporation at the surface and the rate of transfusion of moisture from the center outward. In general, the steeper the gradient, the faster the drying. Since raising the temperature increases the rate of transfusion, the rate of drying is thereby increased without increasing the steepness of the gradient. For this reason the maximum temperatures which can be used without injury to the material will usually be found to produce the maximum rate of speed consistent with safety.

In keeping the moisture gradient within safe limits, during those stages of drying when surface shrinkage is taking place, the drying should be retarded by preventing the surface from drying below a certain critical moisture content which must be determined experimentally for different materials. This control of surface drying is accomplished by regulation of the relative humidity of the air in the dryer in conjunction with the regulation of the temperature. The most inexpensive means of securing the desired humidity is to recirculate a sufficient portion of the air. This not only utilizes the moisture which has previously been evaporated from the goods, but also conserves the heat contained in the air.

Equilibrium Moisture Content

With every material having hygroscopic properties, a point of equilibrium is reached between the vapor pressure of the moisture in the air and the vapor pressure of the moisture in the surface of the material. Every combination of temperature and humidity produces a corresponding equilibrium moisture content in the material. It is, therefore, possible to so regulate the conditions in the dryer at any stage of the operation that moisture in the material cannot drop below a certain equilibrium point, as may be desired for best results.

In the drying of most hygroscopic materials, the drying is continued until a somewhat lower moisture content is reached than equilibrium under conditions in use, to allow for enough regain to balance the moisture remaining in the interior and surface to a uniform condition. It is usually undesirable to carry the drying much beyond the equilibrium point of the material in use, as over drying is liable to produce undesirable physical changes in the material, and such over drying also unnecessarily prolongs the time and increases the cost of the operation.

CONTROL OF THE DRYING OPERATION

Circulation

It will have been seen that in any successful dryer heat has to be applied and the water evaporated has to be removed. A circulation of air or gas inside the dryer is essential for three reasons. First, all the heat, except such as may be supplied by conduction and radiation, must be

supplied by the air circulation. Secondly, the air must carry away the water vapor resulting from the drying. Third, duty of the air circulation is to have sufficient velocity to sweep away the film, or layer of nearly saturated air that is apt to remain in close contact with the evaporating surface, and whose high vapor pressure retards further evaporation. During the saturated and unsaturated surface drying stages, the drying rate will vary directly with the velocity of circulation over the material. When the stage of sub-surface drying is reached the velocity of circulation at the surface becomes of less importance, except that it must maintain uniform temperatures about the material, in order to produce uniform drying.

Circulation is expressed either by the rate of air flow over the material per minute, or by the number of air changes in the dryer per minute or per hour. The former is the more logical method. The air change expression is really a relic of the days when all fresh air was used, while an efficient dryer often uses only a portion of fresh air and the bulk of the air is recirculated.

As will have been seen, the heat required for evaporation is extracted from the air. If a small quantity of air is circulated through the dryer, it will be evident that a great drop in the temperature of the air occurs. This causes a great variation of temperature in contact with the material. In addition to this drop in temperature, a small quantity of air means the absorption of a large amount of vapor. The combination of these two factors will result in widely varying drying effects in different parts of the dryer. The larger the amount of air circulated, the less will be the drop in temperature, the less will be the amount of vapor absorbed per cubic foot of air, and hence, the closer will be the drying effects of the air in various parts of the dryer. If this large quantity of air, however, is all fresh air and the entire amount exhausted, the air thrown away will be far from having reached the proper saturation and a great waste of heat will occur. It may be sufficient to exhaust only a very small percentage of the amount of air that would be best from a circulating standpoint. Therefore, to meet both conditions, it is usually best to determine the volume required for circulation, then to only exhaust the portion that is sufficient to carry away the moisture and to recirculate the balance, introducing fresh air only in an amount equal to the amount exhausted. The higher the temperature of the dryer and the higher the humidities carried, the greater becomes the amount of air recirculated.

In some dryers the recirculation is obtained by the use of propeller type fans inside the dryer for recirculating over and over while the proper amount of fresh air is discharged into the dryer by a separate fan located outside. In other dryers, the fans for circulating the air are located outside the dryer and so arranged that a large portion of the air is recirculated and the rest introduced as fresh air into the same fan. In other dryers, a rapid circulation is passed through one section of the dryer; the entire amount is withdrawn, treated as to temperature and humidity and then introduced into the next section of the dryer. This results in a very slight drop in the temperature of the air in any part of each section, and by adding heat at each stage, the temperature and humidity can be controlled as desired throughout the dryer.

Next to circulating the proper amount of air, the most important con-