

period of drying, the temperature of the material approximates the wet bulb temperature of the air. Therefore, high dry-bulb temperatures may be employed.

The nature of the material and its characteristics often determine the temperatures that can be employed with safety. For example, chemically combined water may be lost, cells may be steam exploded, charring may take place or exothermic reactions initiated if the product temperature exceeds a critical value.

Humidity

As previously pointed out, absolute humidity is the driving force for evaporation, therefore, a low humidity increases the drying rates. However, certain materials if dried too rapidly may case harden, i.e., form a nearly impermeable skin which greatly reduces the drying rate. Also, certain undesirable physical changes may take place such as the cracking and warping of lumber. In such instances, it may even be necessary to increase artificially the humidity to assure satisfactory drying by the recirculation of moist air or the use of water or steam jets.

In the case of substances that must be dried at relatively low temperatures (120-140 F) it is often necessary to dehumidify the air to secure satisfactory drying rates. In such instances, a closed system using the adsorptive methods described in Chapter 38, is frequently applicable.

Air Circulation

Air velocity and distribution are important factors only in the first two periods of drying when surface evaporation is taking place. During the varying falling rate period of gaseous diffusion enough ventilation must be provided to prevent stagnation. The velocity of the air passing over the surface to be dried determines the rate at which the moisture-laden air is swept away. The more rapidly this moist air can be removed the more rapidly can evaporation occur. It has been demonstrated that this drying rate is a function of the 0.8 power of the velocity. Air directed perpendicularly to the drying surface exhibits the greatest efficiency in dispersing the *dead air* film. The limiting factors in air velocity are the power requirements to remove the air and the danger of blowing away the lighter particles of material.

DRYING METHODS AND EQUIPMENT

Drying systems are sometimes classified according to the method of heat transfer that is employed since the entire problem of drying resolves itself into individual problems of heat transfer and the thermodynamics of air and water vapor. The methods of heat transfer are radiation, conduction and convection. Many types of dryers have been built on these principles for different purposes.

Radiant Drying

Sun drying, the oldest form known to man, is still practiced where the material is amenable to such treatment, where the necessary time can be allowed, and where there is little danger of rain or atmospheric pollution.

In artificial systems radiating surfaces, heated by steam, electricity or other means, afford a good method of heat distribution and control. Radiant heating sets up convection currents, and in low-temperature dryers only about one-third to one-half of the total heat for evaporation

is actually supplied to the material by radiation. At high temperatures the radiation output increases rapidly, according to the *fourth-power law*. The total radiation may be computed by the equations and tables given in Chapter 5. In general, fins and irregular surfaces do not increase radiation, hence the area to be used in calculations is the area of a smooth-surface envelope enclosing the radiating elements.

A certain amount of air circulation is required through a radiant dryer, in order to carry off the vapor.

Radiant heat from infra-red lamps has been accepted by certain industries as practicable for their specific problems. An example of successful application is found in the drying of lacquers.

Another highly specialized field coming under this heading is electronic drying in which ultra short waves are broadcast into the material and, by interference and adsorption, create heat internally. Some systems have a rather critical optimum frequency. Similarly a high frequency induction field may be employed (See Chapter 30).

Conduction Drying

Drying rolls or drums, flat surfaces, open kettles and immersion heaters are examples of the direct-contact method. Intimate contact of the material with the heating surface is important, and in some cases agitation is desirable to increase the uniformity of heating or to prevent overheating.

Greatest resistance to heat transfer occurs on the air side of the material being dried. The rate of heat transfer from the surface of the heated material to the air, and hence the rate of drying, may be increased by: (a) forced convection or air circulation and (b) vacuum operation to lower the boiling point of the liquid being evaporated.

A rather interesting method of conduction drying was put into practical use during the war for the drying of blood plasma and has since been expanded to other fields such as the preservation of bacteria and other micro-organisms. This has come to be known as freeze drying or drying by sublimation. The material to be dried is first frozen and then placed in a high vacuum chamber connected to extremely low temperature condensers. The water is removed by vaporizing from the solid directly to the gas without ever becoming liquid.

Convection Drying

A limited amount of convection drying takes place in almost any dryer such as those described in the preceding paragraphs. However, to be classified as a convection dryer the principal source of heat is the heated air or other gases circulated in the dryer. There are a number of mechanical means of accomplishing this circulation of air or gases, each of which has some particular virtue. Brief descriptions of some important types of convection dryers follow:

Rotary Dryers. These dryers are cylindrical drums usually having internal flights, as shown in Fig. 3, which cascade the material being dried through the air stream. The driers may be heated directly or indirectly and the air circulation may be parallel or counter flow. A variation is the *roto-louvre* type dryer, which introduces the air beneath the flights thus securing very intimate contact.

Cabinet and Compartment Dryers. These are generally considered batch dryers wherein each charge is dried to completion before removal. A wide range includes types from the heated loft with only natural con-