Actual dryer operation is somewhat more complicated because even if radiation and conduction losses are neglected, the wet-bulb temperature of the air remains constant only as long as surface evaporation of water is taking place. When sub-surface evaporation is occurring, some heat from the air is used to heat the material and hence, there is a drop in wet-bulb temperature. Fig. 10 illustrates the drying process in a tunnel dryer in which the air is flowing parallel to the product.[2]

In design calculations using Equation 26, the following steps outline the procedure:

1. The unit drying rate, pounds of water per hour, is determined from the experimental drying time curve and the amount of product to be dried per hour. The drying time may also be approximated from previous experience.

2. The experimental data or experience also determine the drying condition, *i.e.*, point L Fig. 9. This fixes H_2. Where experimental data are lacking L may be approximated from Regain Tables (see chapter Industrial Air Conditioning) since the relationship between the vapor pressure in the product and in the air at equilibrium for the desired final moisture content must prevail in the dryer. The air temperature must be not greater than the maximum permissible product temperature.

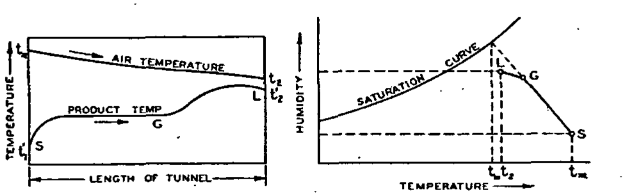

FIG. 10. TEMPERATURE AND MOISTURE CONDITIONS IN A TUNNEL DRYER
Parallel Flow Air and Product

3. The rate of air circulation N_a must be determined and also the supply air condition S. In the design of some dryers, such as rotary or tunnel types, it is customary to determine S first and then to calculate the air rate N_a. In other types of dryers, such as tray dryers or through circulation dryers, where a fixed air velocity is maintained, N_a is calculated first and then point S is found. Because of the many variables involved, it is generally not possible to select S except on the basis of past experience or on the basis of experimental drying tests.

4. The prevailing outside air conditions establish point A and hence, the line A L. The percent of recirculated air can then be calculated.

5. The physical arrangement of the dryer must then be selected to handle the desired quantity of product, and at the same time circulate the calculated air quantity at the desired velocity.

6. Equation 26 can then be used to calculate the heat requirements.

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.

Drying systems can also be classified, according to the method of product handling, as batch operation, semi-continuous and continuous.

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.

Lacquers and similar surface films can be very effectively dried by radiation. Special electric lamp units have been developed which give off a high percentage of infra-red and similar heat rays. For continuous manufacturing processes these units are mounted in tunnels through which conveyors pass. For local applications, as for example paint drying in automobile repair shops, they may be mounted on portable racks. Objects of relatively large surface area in proportion to their weight, and fabricated materials having a rather high heat absorption, may be satisfactorily heated by such a source.

For drying, baking, pre-heating and de-hydrating, where a low temperature infra-red heat source is desired, or where use of glass-enclosed radiant lamps is objectionable for safety reasons, electric heating units employing low temperature metal sheathed resistors, are available.

Conduction Drying

Drying rolls or drums, Fig. 11,[3] 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 over-heating.

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 (Direct Dryers)

A limited amount of convection drying takes place in almost any dryer such as those described in the preceding paragraphs. However, to be