surface drying is involved. In other instances, the critical moisture content of a wet solid is sufficiently low that sub-surface drying starts almost immediately after the conclusion of the constant rate period. Thus the intermediate stage of unsaturated surface drying does not occur and the drying is of the sub-surface type during practically the whole of the falling rate period. With other kinds of material, particularly thin sheets, such as newsprint paper, sub-surface drying may occur at such a low moisture content that it is not encountered in commercial work, the falling rate period being confined solely in practice, to unsaturated surface drying.

Capillary and Hygroscopic Moisture

Most solid materials to be dried are of a powdery, granular, cellular, or fibrous nature and contain water in two characteristic forms which have a direct relation to the rate and character of the drying operation. The first form is known as *free* or capillary moisture and comprises the water which is contained in the capillary spaces between the particles or fibres of the material. The second form is called *adsorbed* or hygroscopic moisture and is intimately associated with the physical nature of the material, having a direct effect upon such physical properties as size, strength, electrical conduction, heat conduction, etc. Removal of the capillary water has little or no effect upon the material except to reduce its weight, while removal of the hygroscopic water causes definite changes in physical properties and characteristics.

Fiber Saturation Point

The total amount of adsorbed or hygroscopic moisture that a given amount of material can contain is definitely limited. This limit is known as the *fiber saturation point*[1] and corresponds roughly to the critical moisture content. Beyond this point, any additional moisture must be in free or capillary form and the amount of such free water that the material can hold will depend upon the relative volume of capillary spaces that may be present. The fiber saturation point is of particular importance in the drying of thick, bulky materials having a more or less colloidal structure such as lumber and clay products, in which the removal of hygroscopic moisture is accompanied by shrinkage, stiffening, hardening, loss of plasticity, and other physical changes. Successful drying requires that these changes be controlled within safe limits in order to avoid injury to the material.

Removal of Free Water

In most commercial products which require a drying operation, the free water contained will flow readily from the interior to the surface by capillary action, as in a wick. Textiles, paper, fiber board, clay products, and the sapwood of most species of lumber represent material of this type, as well as finely divided materials which come in granular or powder form. In such substances the free water is removed usually without difficulty in the successive stages of saturated surface drying and unsaturated surface drying, followed by the removal of the hygroscopic moisture in the form of sub-surface drying.

[1]U. S. Forest Service Bul. 70, p. 82, *Effect of Moisture on Strength*, Tiemann, 1907.

In certain other materials of thick and more or less rigid form, notably the heartwood of some kind of lumber, the free water contained in the capillary spaces appears to be, in a sense, *bottled up* and cannot be made to flow from the interior to the surface in appreciable amounts. To remove the free water from such substances necessitates sub-surface vaporization within the material at the boundary of the free water zone, followed by diffusion of the vapor through the surrounding zones either as vapor or as adsorbed hygroscopic moisture. In either case, the zone surrounding the free water must be dried below its fiber saturation point in order to lower the vapor pressure to a point below saturation and thus permit this diffusion to take place. This means that shrinkage and other physical changes, such as stiffening or hardening, must occur in this outer zone before the interior portions have lost their free water and are ready for such changes. Consequently severe and harmful tensile and compressive stresses are apt to be set up in the drying of this type of material, due to unequal and non-synchronous shrinkage in the different zones, resulting in such injuries as surface cracking, honey-combing, warping, and *case hardening*, or the setting of the surface portion in a stiffened expanded condition.

In obtaining maximum speed of drying of materials in which there is no capillary flow of free water to the surface, dependence is placed in most cases upon the effect produced by heated air or other gas surrounding the material. In such cases the speed of drying can be increased in only two ways, first, by lowering the moisture content at the surface through the use of a lower humidity, or second, by increasing the temperature. The risk of harmful shrinkage limits the first, and the risk of exceeding the critical temperature of the material limits the second. In many cases, however, increased speed of drying can be secured by increasing the temperature of the air, and at the same time, increasing its humidity. In this way the amount of heat passing into the material is increased, while the increased humidity prevents the surface drying too fast and case hardening. An extreme example of this method is turning steam into a dryer in which green lumber is being dried.

The use of too high a temperature in removing the free water from fibrous or cellular materials of this kind, increases the plasticity of the structure and, at the same time, is apt to create a liquid tension within the cells themselves. This force, which may amount to many atmospheres under certain conditions, tends to draw the walls of the cells together, thus producing a *collapse* of these cells. This phenomenon is the cause of much injury in the drying of certain kinds of lumber and is probably present, to a greater or less extent, in the drying of all refractory material of a cellular nature through which the free water cannot flow by capillarity.

Another result of trying to force the drying of these refractory materials at too fast a rate, is the increasing resistance to the passage of heat from the surface to the interior and the passage of vapor outward, as the dryness of the surface increases. With many materials of this type, if the surface is allowed to dry below a certain point, it becomes increasingly difficult, not only for additional heat to penetrate to the interior, but also for vapor to work its way outward through the dry outer zones to the