FREEZING OF WATER IN SUBAQUEOUS MAINS LAID IN SALT WATER AND IN MAINS AND SERVICES LAID ON LAND.*

By William Whitlock Brush.

THE transformation of water from the liquid to the solid state, known as ice, as a result of the abstraction of heat from the water, is a process familiar to all, but the exact conditions under which such transformation takes place are not so generally known. This withdrawal of heat may be by means of radiation, conduction or convection, the transfer of heat being accomplished by any one of these agencies operating singly or in combination.

Fresh water increases in density as the temperature is lowered, until a maximum is reached at 39° F. There is then a gradual reduction in density to the temperature of 32°, when the liquid changes to the solid form, known as ice, with a specific gravity of 0.89. It is this transformation that is particularly interesting to waterworks men, and some of the more important features of such transformation will be briefly discussed. The temperature of water is remarkably constant while ice is forming or melting. The temperature of the air may be many degrees below zero, but the temperature of fresh water, even though it be in a rapid running stream, will not be more than 0.01 below 32° F. Again, as long as there is ice in the water the temperature will only be a similarly small fraction of a degree above 32° F., even though the temperature of the air be many degrees above the freezing point. A mixture of ice and water forms the most constant temperature known to physicists.

It is popularly believed that running water may be lowered to a temperature of several degrees F. below the freezing point before ice will be formed. This is an error. Absolutely still water may be cooled to approximately 10° F. below the freezing point without ice forming, but as soon as there is the slightest agitation of the water an immediate formation of ice takes place and continues until the heat released by the change from water to ice warms the remaining portion of the water to the freezing point. The latent heat of water at the freezing point is large, amounting to 80 calories per gram, or sufficient to raise 143 pounds of water 1° F. for every pound of water changed to ice.

Ice is divided into three kinds, based upon the manner in which it forms, *i.e.*, surface ice, frazil ice and anchor ice.

Surface ice is the common form which appears on the surface of the water when the temperature of the water is cooled to the freezing point. It appears first near the shore and gradually extends out as the deeper water is cooled, the entire surface being eventually covered after the temperature of air remains below the freezing point for a sufficient period to cool the entire surface water to just below 32° F. After the ice is formed, the thickness increases, mainly through the conduction of heat from the water through the ice, it being necessary to conduct not alone the heat in the water but also the latent heat previously in the water, which is released as the water changes to ice. As the conductivity of ice is low, being only one thirty-second of that of iron, this process is relatively slow and the thicker the ice sheet the slower the increase in depth of ice.

*Abstract of paper read before the 4 States Section of the American Waterworks Association.

Frazil ice is the form which appears in running water when the temperature of the water falls below 32° F. and where an ice sheet cannot form due to the agitation of the water. It forms at the surface and may be made up of flat plates, if the surface is not greatly agitated, but more frequently is in the form of minute needle crystals which join together and form a bulky mass, floating lower in the water than the ordinary surface ice.

Anchor ice is ice which is found attached or anchored to the bottom of a river or a stream, and results from the cooling of the material at the bottom of the river by radiation, and the resultant freezing of the water which comes in contact with the surfaces, which have been cooled below the freezing point. It will only occur under a clear sky and where there is nothing to interfere with the process of radiation. As dark objects radiate heat more rapidly than light-colored ones, anchor ice will form more rapidly on a dark stone than on a light one. It will not be formed under a bridge where radiation is interfered with, nor under ice, which also prevents radiation. When the sun's rays strike the masses of ice, earth and stone, they are absorbed and frequently the whole mass will become loosened and float to the surface. Large rocks are thus raised and carried down stream with the ice.

These three forms of ice are all of interest to the waterworks engineer, not alone as affecting the problems to be met at the source of supply, when such source may be a reservoir or stream, but also in the distribution of water, as will be shown later.

It is generally considered that ice is a poorer conductor than water. This belief is probably founded upon the very material protection which ice or snow gives against frost penetration. Such protection is mainly due to the resistance of ice and snow to the transmission of the heat waves of radiation. Clear water offers little resistance to the radiation of heat, but is a very poor conductor of heat. Due to the difference in density of water at different temperatures, water will transmit heat through convection, or the movement of the molecules, much more rapidly than will ice, by conduction. The molecules of ice are unable to move freely, and transmission of heat through ice, by convection, is therefore negligible.

Pressure lowers the temperature at which water changes to ice, but its effect is very slight, thus, a pressure of 1 pound per square inch will lower the freezing point 0.009° F. Assuming the normal pressure in a water main to be 40 pounds per square inch, the lowering of the freezing point by such pressure would amount to less than 0.04° F.

The introduction of certain chemicals into the water lowers the freezing point. The most common chemical found is salt, and all are familiar with the lowering of the freezing point caused by the presence of salt. The volume of salt determines the temperature at which the ice forms, the salt being thrown out by the crystallization of the water, so that ice formed in salt water is fresh. The ordinary sea water will freeze at about 27° F. and the temperature of the water is therefore well below the freezing point of fresh water. As the percentage of salt in the water decreases, the freezing point rises, but this freezing point is probably below 30° F. in the tidal waters surrounding our sea-board cities.

Formation of Ice in Water Mains.—The formation of ice in water mains is dependent upon the temperature of the water in the main and the velocity of current, the pressure being of negligible effect, as has previously been shown. It is probable that the water as drawn from a