[redacted]

VENTILATION IN A DRY KILN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison, Wisconsin
In Cooperation with the University of Wisconsin
November 1931

VENTILATION IN A DRY KILN[1]

By

W. KARL LOUGHBOROUGH, Engineer

A new point of view for an old problem often helps to solve the problem. The engineering point of view, as distinguished from the empirical one, will be somewhat new in work on the problems of ventilation and circulation in a dry kiln, and making use of it should help matters. In conformity with his point of view and method of attack, the engineer first determines the laws that govern an action and then applies them, and since the general principles covering ventilation in a dry kiln are well known our first task is merely to select the proper ones.

Although it is true that the laws governing the flow of air are perhaps less understood than those of almost every other branch of engineering, for air flow at pressures as low as those found in the dry kiln a thorough understanding of thermodynamics is unnecessary. The same formula commonly used for the flow of water may be used for the flow of air without introducing any errors of practical magnitude; contrary to an idea that is all too prevalent, there is no mystery about the general principles governing ventilation in a dry kiln.

The primary purposes of this article are to direct more attention to the problem of ventilation in a dry kiln and to urge consideration of the problem with the analytical method of the engineer. Carrying out these purposes will require showing how the weights of air are affected by various conditions, such as temperature, relative humidity, and barometric pressure. The next step will then be to show how the changes in weight of air affect ventilation in dry kilns of various types. Moreover, the function of ventilation and also the bearing ventilation has on circulation in a kiln will be discussed. The matter of circulation will be considered in a later article.

Since this article deals primarily with ventilation, a clear understanding of the difference between ventilation and circulation is desirable. Ventilation is the renewal of good air in a substantially closed space, such as a dry kiln, by the admission of fresh air and the expulsion of old air. Circulation, on the other hand, primarily means a going around in a circle, and it always involves the idea of a cycle as distinguished from a replacing movement. It is merely the travel of the air within a closed space, and, unlike ventilation, in itself has nothing to do with either the admission of fresh air from the outside or the expulsion of used-up air from the inside.

---

[1] Published in Wood Products, November and December, 1931.

WEIGHT OF AIR

The weight of dry air in pounds per cubic foot may be calculated from the formula

$$\frac{0.0028862\ b}{1 + 0.0021758\ t} \qquad (1)$$

where $\underline{b}$ is barometric pressure in inches of mercury and $\underline{t}$ is temperature in degrees Fahrenheit. A slide-rule calculation gives the weight per cubic foot of air at 160° F. and a standard barometric pressure of 29.92 inches of mercury as 0.0641 pound per cubic foot. To find the weight of moist air, formula (1) is modified by the subtraction of a quantity to take care of the effects of the pressure exerted by water vapor, thus:

$$\frac{0.0028862\ b - 0.001088\ e}{1 + 0.0021758\ t} \qquad (2)$$

where $\underline{b}$ and $\underline{t}$ have the same meanings as in formula (1) and $\underline{e}$ is the vapor pressure in inches of mercury. For example, the weight of a cubic foot of saturated air at 160° F. and a barometric pressure of 29.92 inches is by substitution

$$\frac{0.0028862 \times 29.92 - 0.001088 \times 9.6500}{1 + 0.0021758 \times 160} = 0.05637 \text{ pound per cubic foot.}$$

Fortunately, it is rarely necessary in dry-kiln problems to calculate the weight of air under various conditions. Every handbook on the subject of heating and ventilating gives in tables and curves the weights of air in almost every condition of temperature, relative humidity, and barometric pressure. The two formulas just presented will serve their purpose if they show how the factors involved affect the weight of air; the higher the barometric pressure the more the air will weigh, and the higher the vapor pressure and the temperature the less it will weigh. Figure 1 shows how the weight of dry air changes with temperature, how the weight of water vapor necessary to saturate a cubic foot of dry air and vapor mixture increases with temperature, and finally how water vapor displaces dry air in a mixture of saturated air and thus reduces the weight of the dry air and vapor mixture per unit of volume.

Air at constant pressure, expanding as it is heated, changes its volume almost exactly in proportion to its absolute temperature; for kiln temperatures, add 460 to the thermometer reading to get the absolute temperature on the Fahrenheit scale. Expressed as a formula for use with ordinary commercial temperatures, q, the volume at any temperature t, and q_o, the volume at any different temperature t_o, have the following relation:

$$q = q_o \left(\frac{460 + t}{460 + t_o} \right) \quad (3)$$

The relative volume of a given weight of air at different temperatures is pictured in Figure 2, B; air at 180° F., for example, has about 21 per cent greater volume per unit of weight than air at 70°. A similar relation holds for the weights w and w_o of a given volume of air at two temperatures, under constant pressure:

$$w_o = w \left(\frac{460 + t}{460 + t_o} \right) \quad (4)$$

When water vapor is admitted into dry air under constant pressure the vapor displaces the air. The amount of air displaced depends on the pressure of the water vapor, and the total pressure of the mixture is therefore unchanged; it is merely the constant sum of the pressures exerted by the dry air and the water vapor. Thus, because water vapor is lighter than dry air under the same conditions of temperature and pressure, the weight of air per cubic foot is decreased by an amount equal to the difference in weight between the water vapor and the dry air that it displaces. Finally, at 212° F. and normal barometric pressure, there is no dry air present; vapor pressure alone balances the barometric pressure. Figure 2, A, shows the relation for a wide range of temperature.

At 190° F. a pound of dry air with the vapor needed to saturate it occupies 3.29 times as much space as a pound of dry air at 70°. (Fig. 2, A.) This fact has some significance in the determination of the relative size of the inlet and the outlet ducts of a ventilated kiln.

Figure 3 shows the relationship between the space in saturated air occupied by a pound of water in vapor and in liquid form. At 212° F. the ratio is 1670. Figure 3 gives some idea of the large volume of air that must be put through a kiln in removing 1 pound of water from it, and how the required amount of air is affected by the kiln temperature. The curve brings out plainly the fact that the lower the temperature is, the greater the ventilation must be.

AMOUNT OF WATER REMOVED THROUGH VENTILATION

Kiln men often talk about moisture content expressed in percentage of the weight of the oven-dry wood, but few have tried to picture what moisture expressed thus means in terms of absolute water. The amount of water to be removed from a kiln in a given time must be known before the required ventilation can be determined. A simple calculation will give us some conception of how much ventilation is required to remove the water evaporated. Suppose that a kiln charge of 35,000 board feet of air-dried red oak has an average moisture content of 35 percent when entering the kiln, and that this lumber will be dried down to a moisture content of 10 percent. The approximate weight of a thousand feet of oven-dry red oak, which may be calculated from its specific gravity, is 2900 pounds. In drying 35,000 feet from 35 percent to 10 percent moisture content it will be necessary to evaporate 35 x 2900 x 0.25 or approximately 25,400 pounds of water. A gallon of water weighs 8.34 pounds and there are about 50 gallons of water in a barrel. Roughly then, 61 barrels of water, nearly a carload, must be evaporated from the 35,000 feet of air-dried oak.

VENTILATION IN A DRY KILN

Having discussed in a general way the various conditions that affect the weight of air, a preliminary matter, we are now in a position to consider the ventilation in a dry kiln. It is often said that air in a kiln moves by suction. Ordinarily this is a misconception. Air in a kiln moves primarily under the action of its own weight. When a volume of air grows heavier than the air around it, for any reason, it flows downward just as a liquid or any other gas would do under the same circumstances. Adequate appreciation of the effect of the weight of air in causing movement of air is necessary for a clear understanding of ventilation in a dry kiln.

Suppose, for example, that the temperature of a kiln is 150° F. while the outside temperature is 60°, that the vertical height from inlet to outlet is 25 feet, and that the outlet is closed so that no air can escape from the kiln. The weight of a cubic foot of air at 60° F. is 0.0764 pound; hence the weight at 150° formula (4) is 0.065 pound. The difference between the weights of a cubic foot of air inside and one outside the kiln is then 0.0114 pound, and the actual difference in the weight of the two 25-foot columns of air will be 0.285 pound. The interval column will be driven up against the cover at the top of the chimney with a force amounting to 0.285 pound per square foot. When the cover is removed the hot air will flow into the atmosphere because the pressure on the lower side of the cover exceeded the pressure on the upper side. As long as a temperature difference continues, air will continue to flow from the atmosphere through the kiln and into the atmosphere again, thus ventilating the kiln.

This illustration points out two things. One is that the greater the difference in air temperature between the inside and the outside of the kiln, the greater will be the ventilating action. The second is that the lower the intake with respect to the outlet, the greater the difference between the weights of the two columns of air and consequently the greater the ventilation.

An experimental kiln 13 feet high was built at the Forest Products Laboratory, so that cold air could enter at the top, middle, and bottom of the kiln wall and could leave the kiln through outlets built at different elevations in the kiln chimney. In operation, air is permitted to enter in turn at the three inlets and each time to escape in turn at one of the three outlets. Anemometer readings in the inlet, taken when the temperature of the kiln was 150° F., tend to show the effect of chimney height on ventilation. When the air was taken in at the bottom and allowed to escape at the top the anemometer gave a wind velocity of 360 feet per minute. Reversing the process, allowing the air to enter at the top and discharge at the bottom, made the air velocity so slight that it would not turn the anemometer over.

Yet inferring from this that kilns that take air in close to the roof and discharge it near the bottom will not dry lumber is not correct. A satisfactory location of inlets and outlets in a kiln depends very largely on the amount of ventilation required to remove the moisture evaporated from the wood. Obviously, the ventilating system in a kiln used for drying the green sapwood of softwoods should be designed so as to obtain a rapid turnover of air in the kiln. In kiln drying air-dried hardwoods, however, the location of the inlet and outlet ducts is relatively unimportant because only a small mount of ventilation is then necessary. If a kiln can discharge the moisture evaporated from the lumber that is all that need be expected from a ventilating system.

The standard formula

$$V = \sqrt{2\,gh} \qquad (5)$$

where _V_ is the velocity of the air movement caused by difference in density, _g_ the acceleration of gravity, and _h_ the head producing the air flow, shows the factors that must be considered in the manipulation of ventilation dampers during the drying operation. Removing large quantities of air tends to lower the relative humidity in the kiln, while a high rate of evaporation tends to increase it. The higher the temperature and the relative humidity, the greater the head. Hence, the adjustment of dampers, in its essentials, is merely the problem of ventilating no more air than the amount needed to reduce the relative humidity to the value desired.

The function of ventilation in a dry kiln is to remove the moisture that evaporates from the lumber. After the moisture has been converted into vapor it must escape from the kiln in some way, either from the doors or through properly designed and adjusted ventilators.

The quantity of air moved for this purpose is perhaps larger than we ordinarily think it. For example, our calculation showed that 25,400 pounds of water had to be evaporated from 35,000 board feet of oak in drying it from a moisture content of 35 percent to one of 10 percent. Since lumber can not be dried to low moisture values if the air leaves the kiln in a saturated condition, let us suppose that the average temperature and relative humidity of the air as it leaves the kiln of 150° F. and 50 percent, respectively. The weight of saturated vapor per cubic foot at this temperature is 0.01030 pound. At 50 percent relative humidity the weight of the vapor will be just half of this or 0.00506 per cubic foot. Then 5,020,000 cubic feet of dry air must leave the kiln in order to carry away the evaporated water. Supposing that it takes 12 days to dry this kiln charge, an average of 292 cubic feet of air must leave the kiln per minute, either through cracks around the doors or through the ventilators.

Possibly the air inlets and outlets in a given kiln do not function properly, making it easier for the air to escape from the kiln through cracks at the tops of the doors than through the ducts provided for the purpose. Now the pressure of the heavier outside air forces the lighter warm air out of the kiln. If a certain volume of heated air is forced out, it is forced out by an equal volume of cold air coming into the kiln, and if the air enters through leaks at the bottom of a door the temperature near the door will be lower than that in the center of the kiln. Some operators often think it more expedient to make the doors tighter than to provide larger air ducts of better design. Spending money on new doors is no solution of the problem of producing uniform temperatures in the kiln. The procedure is wrong in principle. This type of kiln must be ventilated, whether some moisture is removed through condensation or not. If air does not enter the air intakes satisfactorily and if the doors are made air tight, what will displace the vapor in the kiln? It is better for the air to enter around the kiln doors than not to enter the kiln at all.

On the other hand, the local chilling caused by outside air entering a dry kiln improperly is bad in every respect. Taking an extreme case for illustration, suppose that the kiln drying the 35,000 feet of oak just mentioned has no ventilating ducts, all the air entering through leaks around the doors. Then the heating coil nearest the door will have to supply ten times as much heat as the other coils in order to warm the entering air and keep the temperature of the kiln charge uniform. It can not supply so much heat, and in consequence the lumber near the door chills and fails to dry. Although this illustration is somewhat extreme, the general fact is true of all leaky kilns. Lack of uniformity in the heating requirements along a kiln makes it practically impossible to maintain a uniform temperature throughout the charge. The solution of the problem is to provide ample intake ducts designed to distribute the air along the length of the kiln. In this way the heating requirements of each unit length of the coils would at least tend to be the same. To prevent air from entering around the doors without providing a place where it can enter is poor practice.

Because of the effect of temperature on the density of air it is impossible to establish as great a difference between the weights of inside and of outside air when the dry kiln is operated at low temperatures as when a high-temperature schedule is followed. In other words, it is difficult to establish a rapid rate of air discharge from a ventilated kiln when such a kiln is operated at low temperatures. For example, to exhaust air at the same rate the cross-sectional area of ventilator space will have to be about one-third larger for a kiln temperature of 120° F. than for one of 150°. Hence, it is difficult to operate a ventilated kiln satisfactorily when the species of wood being dried demands a low-temperature schedule.

Water vapor is lighter than the air it displaces. Hence, the higher the relative humidity the greater the rate of ventilation. At a temperature of 150° F. and with other conditions constant, the draft caused by saturated air is 60 percent greater than that caused by dry air.

EFFECT OF VENTILATION ON CIRCULATION IN A DRY KILN

Ventilation, of course, plays some part in the circulation of a natural-draft kiln, but often too much is said about where the air leaves and where it enters and its effect on circulation; this effect is small. The function of ventilation is to get out of the kiln the moisture evaporated from the lumber. If it also induces a certain amount of circulation so much the better, but that is not the proper function of ventilation; increasing the ventilating characteristics of the kiln for the prime purpose of stimulating the internal circulation is generally expensive and always is an inefficient method moving air.

SUMMARY

The most important fact to keep in mind when considering ventilation in a dry kiln is that the air in the kiln moves under the action of its own weight. Both the designer and the operator should understand this clearly. Better kilns and better drying should come from proper attention to this one fact.

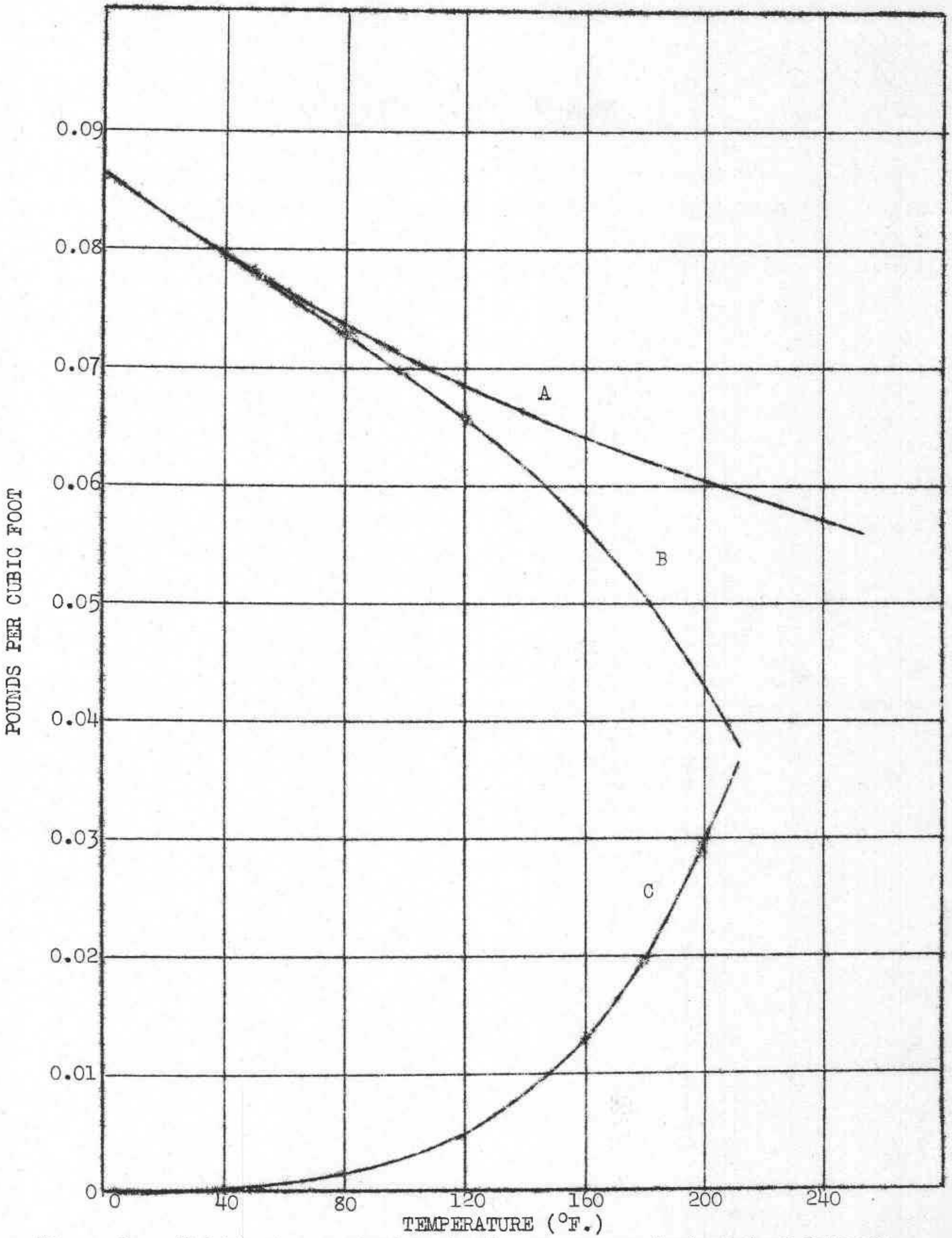

Figure 1.— Weight at normal atmospheric pressure and at various temperatures of — A.—A cubic foot of dry air. B.—A cubic foot of a saturated mixture of air and vapor. C.—The vapor necessary to saturate a cubic foot of dry air.

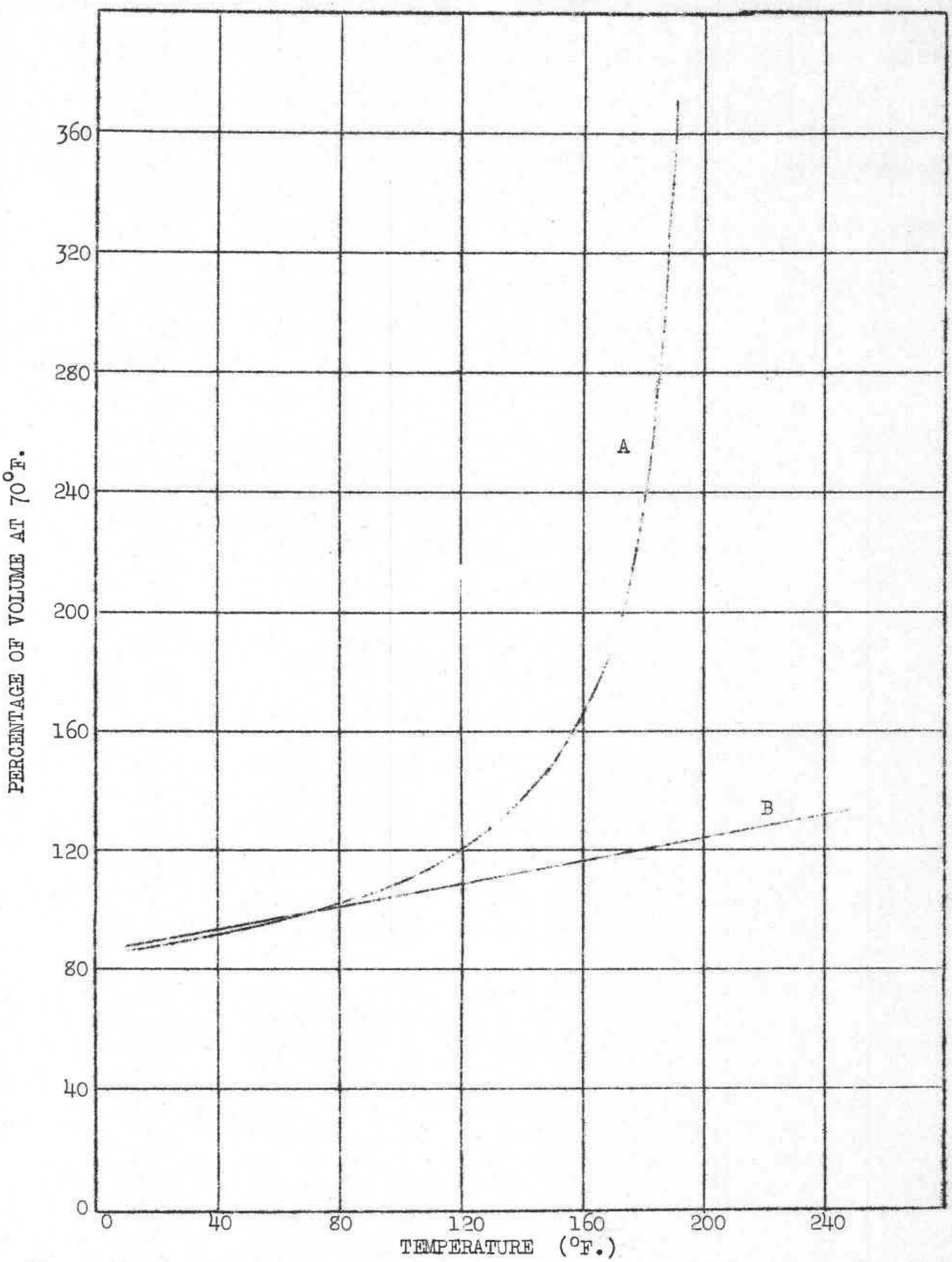

Figure 2.--A.--Volume at various temperatures of 1 pound of dry air plus the volume of the vapor required to saturate the air, expressed as a ratio to the corresponding total volume of dry air and vapor at 70° F. and normal atmospheric pressure. B.--Volume of 1 pound of dry air at various temperatures expressed as a ratio to the volume at 70° F. at normal atmospheric pressure.

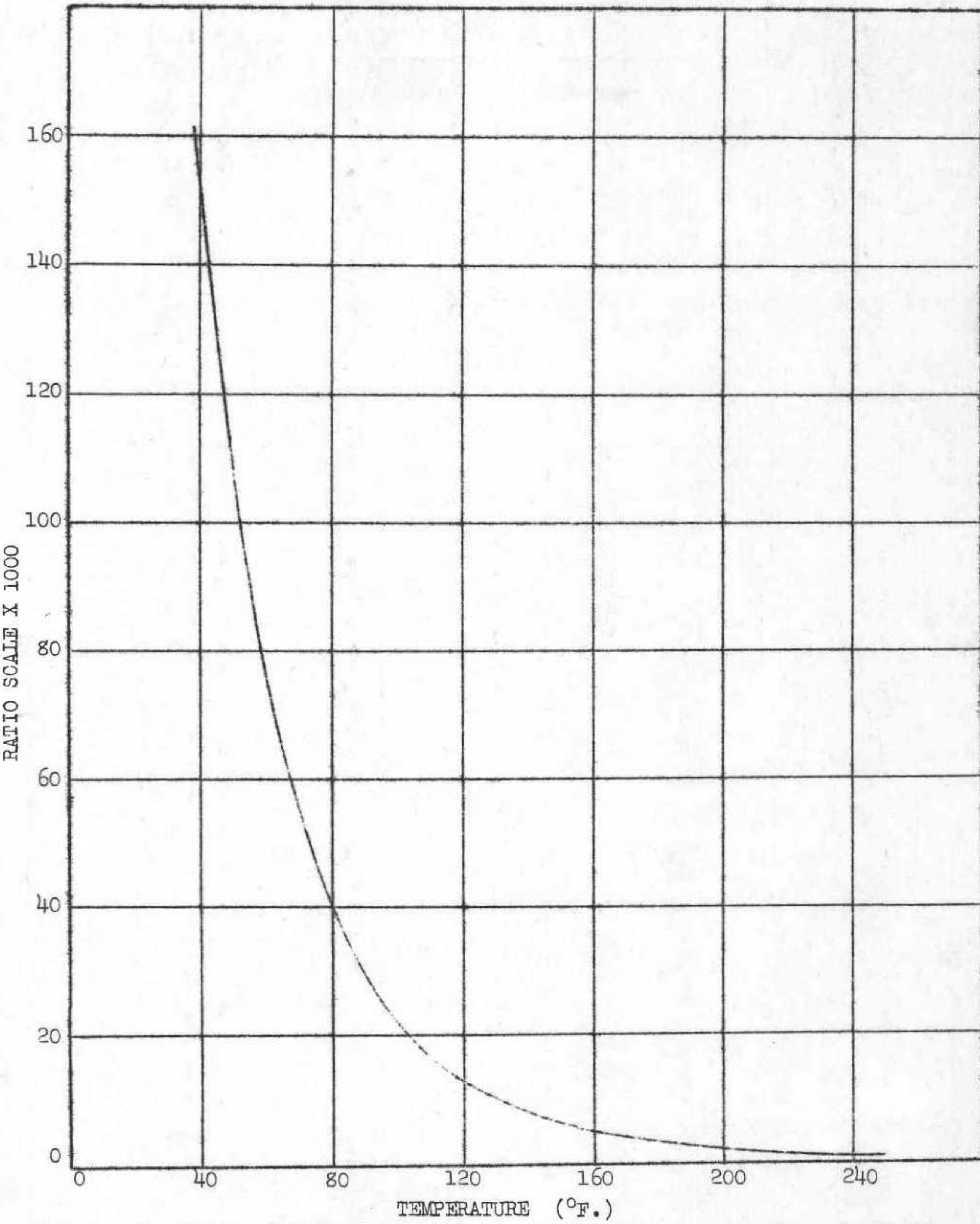

Figure 3.—Ratio of the volume of 1 pound of water vapor to the volume of 1 pound of water at the same temperature. The volume of the water vapor is independent of any air that may be present.