HIGH - HUMIDITY CHILLING OF CARCASSES IN FORCED AIR.

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The rel. humidity of the air of localities where meat is stored under refrigeration is to be kept at certain well-known values, slightly varying from one kind of meat to another and closely depending upon some other factors, first of all temperature.

The problem of what rel. humidity should be chosen for the meat- cooler is much more difficult to solve. Different commercial methods of chilling meat give different values of the rel. humidity, so methods used in America give rel. humidities differing during substantially the whole chillingperiod from those attained by methods normally used in Europe.

The problem is most important, not only, or not even primarily, because of the difference in the total loss of drip and cooling resulting by using different chilling - methods, but also because different methods give very different results what keeping qualities, low shrink and yet dry surface, fast cooling, firm carcasses, and preservation of the bloom of the meat are concerned.

Since so many qualities have to be taken into consideration and some of them are rather complex, it is easily understood that different investigators report apparently inconsistent results. Often even the loss of cooling cannot be compared, say the quantity of condensed water on the surface varies. Such water will give a fictitious "gain" in weight, a "gain" which is normally lost in the further treatment of the meat. The real gain in weight obtained by using a correct chilling method, when the meat always has a dry surface, will remain after several meat-treating operations.

A good deal of research-work what problems connected with chilling of meat are concerned, has been performed in many countries, also in Sweden (1 - 4). As a rule the common methods used commercially have been studied under varied conditions as to temperature, rel. humidity and velocity of air circulation.

During the last 4 years the use of exceptionally high humidity has been studied with interest. It is true that Zarotschenzeff (5) and others several years earlier made use of refrigerated air into which brine or water was introduced into the refrigerated space as a fine spray or aerosol in amounts in excess of that capable of being present in the air as water vapour, but not until the fascinating idea of using air supersaturated in respect to water vapour and interesting trials were made according to this idea (6, 7) high humidity chilling of meat was studied in detail. By the term supersaturated is meant the presence of water in vapor form in the air in amounts in excess of that which the air is normally able to retain under the temperature and pressure conditions existing as distinguished from the presence of excess moisture in the air in the form of free water, as in particle or aerosol form but in which the amount of moisture vapour present is no greater than that which can be retained at saturation.

Commercial plants. Only a couple of plants using supersaturated air for chilling meat on a commercial scale have been built. Though some pilot plant work has been done in Sweden no commercial plants using the system have yet been erected there. The author is very grateful for permission to study the method in detail in U.S. and wants to thank his american colleauges for their kind help in his work over there.

Technical means. The practical methods developed by Morrison, Union Stock Yards & Transit Co; Hagen, Chicago Stock Yards Turbo Refrigerating Co, and Anderson and co-workers, Armour and Co. all in Chicago, involve the following operations.

To provide cooled air in supersaturated condition to a refrigerated chamber, the air within the chamber is recirculated and, during recirculation, it is subjected to a compression, cooling and expansion cycle. In the compression stage the air that is withdrawn from the chamber at or near saturated condition is compressed, as by means of a centrifugal fan or other device. The work performed upon the air during compression generates sufficient heat to cause the temperature of the compressed air to be raised by as much as 5 - 15 degrees over and above the air entering the compression stage, depending upon the amount of compression, so that the air issuing from the compression stage may have 5 - 15 "degrees of unsaturation" that is the amount of moisture in vapor form in the compressed air would be sufficient to saturate at a temperature 5 - 15 degrees lower. The compressed and unsaturated air is advanced from the compression stage to a heat exchange device through which refrigerant is circulated at a temperature to maintain the temperature of the coils preferably slightly above the temperature of the air entering the compression stage from the refrigerated chamber. In the heat exchange device, heat of compression is extracted from the air without cooling the air to a temperature below that at which it enters the compression stage and without exposing the compressed air to any surface colder than the temperature at which it enters the compression stage. As a result, the amount of water vapor retained in the air as it passes through the cooling stage remains substantially equivalent to the amount in the air entering the compression stage but because the air is at higher temperature, the amount of water vapor is slightly less than that for saturation. Under such circumstances, there will be no tendency for any of the water vapor in the air to condense on the surfaces of the cooling coils or otherwise to precipitate or condense from the air in the cooling stage.

From the cooling stage, where the compressed air issuing is for all practical purposes considered to be saturated or within a few degrees of saturation with water vapor, the air is advanced to turbines for expansion to normal pressures while doing work in driving the turbine whereby the air cools upon expansion by an amount depending upon the extent to which the air has been compressed. Under normally preferred and practical conditions wherein compression of from 0.5 - 3.0 pounds per square inch is possible, the air will cool from about 3 - 12° F. Upon cooling by expansion while doing work, the water vapor originally present in the air remains in vaporous form in what will hereinafter be described as a metastable state except for such small amounts as may precipitate upon dust particles or other nuclei floating in the air which are present mostly at the beginning of the cooling cycle. Since the amount of moisture vapor present in the air prior to expansion was at or within a few degrees of saturation, the amount of moisture vapor which remains in the air reduced in temperature by 3 - 12 degrees will be in excess of that capable of being retained in the air under saturated conditions and will be what will hereinafter be referred to as having X degrees of saturation, that is the amount of water in vapor form contained within the air would be sufficient for saturation at a temperature X degrees higher.

By refrigeration with air issuing in a supersaturated state from the expansion turbine for introduction into the refrigerated chamber, evaporation of moisture from the surface of the meat or other perishable material is substantially completely avoided thereby to reduce and, in fact, practically eliminate any loss in weight in the meat product during the chilling and refrigeration cycle. Because of the existence of the air in a supersaturated condition, it is possible for the first time to move the air at high velocity past the meat or other produce to minimize the thickness of the static layer of air insulating the meat or produce and thereby greatly accelerate the rate of heat transfer from the meat without increasing loss in weight by desiccation. In the past, rapid movement of the air past the meat or other produce was undesirable because the rate of desiccation was increased by amounts incapable of compensating for the more rapid rate of cooling.

Thus, refrigeration with air supersaturated with moisture in vapor form, as distinguished from the presence of free moisture or unsaturated air, greatly accelerates the rate of heat transfer from the meat product or other perishable material without sucessive desiccation markedly to reduce the length of the chilling cycle thereby not only to reduce the time available for loss of weight but also to increase the turn-over for more efficient use of the refrigerated space.

In general, at any given temperature and pressure that is below the boiling point of water a certain amount of moisture as vapor can be retained to saturate a given weight of air. For example, a pound of air at 31° F. and at normal pressure of 29.921" Hg will be saturated when it contains 0.003621 pound of water vapor. When the pressure is increased to 31" Hg, saturated air would contain about 0.003495 pound of water in vapor form. At 40° F. and 29.921" Hg, a pound of air would be saturated when it contains 0.005212 pound of water vapor and at 31" Hg, the amount of water vapor for saturation would decrease to 0.005029 pound.

In the conventional cooling systems now in use, wherein refrigerant is circulated through cooling coils to provide cold surfaces for lowering the temperature of the surrounding air, the cooling coils will condense moisture on the surfaces thereof when the moisture vapor in the air within the refrigerated chamber approaches that of saturation and the air within the chamber will have an amount of moisture less than that for saturation so that moisture will be extracted from the meat products during cooling. By way of example, in a cooling chamber having an average temperature of 34° F., the air circulated past the cooling coils will enter at about 36° F. and will leave the cooling coils at about 32° F. for entrance into the refrigerated chamber. Assume for the moment that at the pressure conditions existing within the chamber, the air leaving the cooling chamber at 36° F. is saturated at 29" Hg and therefore contains about 0.004756 pound of moisture in vapor form per pound of dry air. For reducing the temperature of the 36° F. air to 32° F. for introduction into the refrigerated space, the temperature of the coils will be maintained at about 30° F. or below. At 32° F., the air can support only 0.003908 pound of water vapor per pound of dry air and the differences between 0.004756 and 0.003908 pound of moisture vapor per pound of dry air will be condensed on the cold surfaces supplied by the cooling coils over which the air passes. In addition, the 30° F. temperature existing at the surfaces of the coils will reduce the amount of moisture contained in the air adjacent thereto by a greater degree further to reduce the moisture vapor available in the air introduced into the refrigerated chamber.

As the air at 32° F. and containing less than 0.003908 pound of water vapor per pound of dry air enters the refrigerated chamber and is raised upon mixture with the remainder to the average of about 34° F., the amount of moisture vapor present will be far short of the 0.004237 pound necessary for saturation. As a result, the unsaturated air is capable of taking up moisture which is supplied by and removed from the products being refrigerated. This desiccation of foodstuffs, such as meat, fruits, vegatables and the like, results in a loss of quality, tenderness and freshness, as well as weight.

According to Morrison the following holds further true. When saturated air is circulated through the refrigerated space, it is unable for the most part to accept additional moisture from materials within the refrigerated chamber. When the air is extracted from the refrigerated space for circulation into the compression stage of the cooling device, the increase in pressure generated by the fans in the compression system will be accompanied by a rise in temperature in accordance with the formula $\frac{P1}{P0}\ 1/na\ \frac{-1}{a} = \frac{T1}{T0}$

where n is the compression efficiency, the ratio of specific heats of the air-water vapor mixture, P0 the initial pressure, P1 the final pressure and T1 and T0 the final and initial absolute temperature.

Under the conditions which are believed to exist in the process during the steady state, when the air enters the compression stage, it is believed to be at a temperature of about 36° F. and at a normal pressure of about 29" Hg During compression, the pressure is increased to about 31" Hg. Since for moist air

$$\frac{a - 1}{a}$$

will be about 0.286, for 100 percent efficiency the temperature of the compressed air will be

$$31/29{,}286 = \frac{T1}{496} \text{ or } T1 = 505° \text{ R. or } 45° \text{ F.}$$

Since no moisture is added to the air during the compression stage, the 9° F. rise in temperature will cause the air leaving the compressor to become less saturated so that it is highly unlikely that any moisture will be removed from the air during the compression cycle.

Calculating by Dalton's law of partial pressures, when Pmix = Pair + water vapor, at 29" Hg and 30° F., the pressure of the water vapor at saturation will be 0.218" Hg and therefore the pressure of the air will be 29-0.218 or 28.782" Hg. At 31" Hg, the partial pressure will increase in the ratio of 31/29 and therefore will be 0.232" Hg for the pressure of the water vapor and 30.786" Hg for the pressure of the air. The temperature at which saturation is present at 0.232" Hg is 38.3° F. so that the air mixture heated to 45° F. upon compression will have about 7° of unsaturation.

The saturating pressure at 45° F. is 0.30021" Hg and the relative humidity of the air issuing from the compression stage will be

$$\frac{0.232}{0.30021}$$

or 77.4 percent or will contain 0.004591 pound of water vapor per pound of dry air.

From these theoretical considerations, it will be apparent that a condensation of miusture from the compressed air will be incapable of taking place if no part of the air comes in contact with any surface colder than 38.3° F.
In the cooling stage for extracting heat of compression, the coils are therefore maintained at a temperature at or slightly above 38.3° F. Actually the temperature rise in the compression stage will be greater than 9° because of the inability to achieve 100 percent efficiency but the further rise will be relatively small. Assuming that the cooling coils under the conditions described are maintained at 38.5° F., the air will be cooled to about 39-40° F., depending upon the dimension of the cooling section and the efficiency thereof. At 40° F. and 31" Hg pressure, the relative humidity will be increased to 93.9 percent and the air will still contain 0.004591 pound of water vapor per pound of dry air. There is little, if any, tendency for water vapor to condense and settle out during the stage of extraction for the heat of compression unless the air entering the compression stage originally contained a substantial amount of supersaturation but this is highly unlikely in the steady state.

In the expansion turbine, the air returns to normal pressure of about 29" Hg for reintroduction into the refrigerated space. In undergoing this expansion, the temperature of the air drops according to the previous formula

$$\frac{T2}{T3} = \frac{P2}{P3}n\left(\frac{a-1}{a}\right)$$

where T2 and P2 are temperature and pressure at the inlet to the turbine and T3 and P3 are temperature and pressure conditions at the outlet. n is the turbine efficiency calculated to be about 0.8 and a is the ratio of specific heats of a water vapor mixture. Applying these conditions to the above formula

$$\frac{500}{T3} = 1.069^{0.243} = 492° \text{ R. or } 32° \text{ F.}$$

It has been established that water vapor can be present in amounts for supersaturation when created by an expansion process of the type described.

A supersaturated system formed upon expansion of near saturated air exists in what appears to be metastable equilibrium, that is in a state which remains stable in the presence of small or infinitesimal disturbances and in the absence of a major disturbance but is capable of precipitation to form particles of free water on nuclei such as dust particles or electrons introduced by electronic impulse. Such particles of free water will form in small amounts especially at the start of the cooling cycle until the particles of dust within the air system are removed and, while such particles of free moisture may be visible through a microscope, the amount of water vapor that condenses into free water appears to be unimportant with regard to the metastable state of supersaturation.

Practical chilling of carcasses. Experiments have been carried out using carcasses of beef as well as hogs. All carcasses were parted into two halves one of which was chilled according to the high-humidity method whilst the other was chilled by ordinary commercial method. Left and right sides were alternately chosen for the two methods. Print weight scales were used to check the kill floor weight and the weigts of carcasses entering and leaving the coolers. Beef carcasses were chilled to between 50 and 60° F in the deep round four to seven hours faster than in the control cooler. The comparable total weight loss (kill floor weight ÷ shipping weight) was found to be resp. 1 . 3 and **1.9** p.c. with a spreading of only some tenth of a percent.

As a rule a fine mist occurred, which sometimes could only be seen as a blue opalescence. Some details from pilot plant and commercial running of high-humidity coolers (Turbo-method) can be found in literature (8, 9).

The keeping quality of meat chilled in supersaturated air was found to be at least comparable with the keeping quality of the same kind of meat chilled according to older commercial methods. There is reason to believe that both keeping quality and appearance of meat chilled in supersaturated air may be better than that of ordinary meat though the shrink is less and remains less during shipping and through to the sales counter.

On the other hand there is an extra operating cost of the new chilling method. According to calculations made in collaboration of Armour & Co and The Turbo Refrigerating Co this extra cost is approximately 21 % of the savings effected by the Turbo chill method during initial chill, and 15 % of the additional savings effected during a 5 day holding period.

Literature

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