APPLE STORAGE REFRIGERATION

PRINCIPLES

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In the fruit storage industry the cooling of warm apples presents an unusual refrigeration problem. The apples have had little chance to lose field heat. Cooling must be quite rapid to avoid the build-up of much respiration or "live" heat and to insure long keeping of the fruit. At the same time shrinkage or shrivel must be held to a minimum.

Rapid cooling requires air temperatures close to 35°F even during peak loading conditions and close to 32°F for the remainder of the time. This necessitates evaporator surface temperatures well below freezing. The evaporators may be ceiling or floor mounted, the latter becoming more common. Brine spray systems are no longer considered required or even advisable.

The performance of an apple storage depends on many factors in addition to the use of "dry" coils or brine spray. Each of the following items has an important effect on product quality and shrinkage: (1) The rate of cooling as effected by the capacity of the refrigeration system, (2) The surface temperature of the evaporator, (3) The method of controlling refrigeration capacity after the peak load is passed, and (4) The quantity of air circulated and method of circulation in the room. These items apply to any type of refrigeration system and the neglect of any one of them can influence performance more than the choice of brine spray or "dry" coils.

RATE OF COOLING

Rapid cooling of apples has been recommended by others to insure high quality, yet there has been some question as to whether low air temperatures in contact with the warm fruit might increase shrinkage. This is not borne out by field observations or theoretical considerations. On the contrary there appears to be a decided advantage toward minimum shrinkage by holding low air temperatures during the initial cooling period if proper controls are provided to maintain high humidity as the refrigeration is reduced. Well designed plants average close to one ton of available refrigeration capacity per 100 crates of apples loaded into the storage per day. This is approximately equivalent to one-half ton of refrigeration per ton of fruit loaded per day. This load would vary with the size of the storage as well as loading rate per day and thus a better way of stating the load requirements might be: 1 ton, 3/4 ton, and 2/3 ton of refrigeration per thousand bushels of storage capacity for loading rates of 10, 7-1/2, and 5 percent of storage capacity per day. Field crates slack or level full should be substituted for bushels as the former are lighter in weight and represent the common storage container. These figures include an average figure for heat leakage, respiration load, and other room loads in addition to the product load (field heat).

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EVAPORATOR CAPACITY

The capacity of an evaporator coil depends almost directly on the difference between air temperature entering the coil and the evaporating temperature of the refrigerant. This is commonly referred to as the "temperature difference" or TD. A large increase in cooling capacity can be obtained from the same cooling unit by operating at a larger TD. The increased capacity, however, requires lower surface temperature and causes lower humidity of the air and greater shrinkage. This relationship is reviewed in detail at the end of this paper. It is thus essential to have sufficient evaporator capacity to carry the load at a reasonable high surface temperature. Good practice with apple storages is to select evaporators on not over 10°F difference between air and refrigerant temperatures. As shown at the end of this paper, the surface temperature of the evaporator during this period has little or no effect on dehumidification. Thus it is practical to select cooling equipment on the basis of a wide temperature difference (TD) during the peak load condition with proper controls to reduce this TD as load falls off. Good practice indicates a selection of not over 20 and preferably 15 degree TD at the peak load capacity. With proper controls this TD should then reduce to less than 10 degrees toward the end of the cooling period.

WIDE RANGE REQUIRED

An apple storage cooler requires a wide range of refrigeration capacity between peak and minimum load. Rapid cooling with minimum shrinkage requires careful attention to the method of reducing the refrigeration capacity as the load falls off. The ideal arrangement is a modulating valve in the suction line controlled from a thermostat that responds to the room air temperature. This system reduces capacity by increasing the evaporating temperature in the cooling coils and thus keeps shrinkage or water loss of the fruit at a minimum.

IDEAL SYSTEM

The operation of such a system is shown diagrammatically in Figure (1). During loading hours full compressor capacity is utilized and a large difference exists between air and evaporating temperatures, air leaving the evaporator is at a minimum and a little below freezing. After the completion of loading, when air temperature in the storage has dropped to the control point, the thermostat begins to throttle the valve in the suction line. As the apples continue to cool, refrigerant pressure (and temperature) in the evaporator along with the air temperature leaving the evaporator, gradually increase. Throttling of the suction line causes a decrease in suction pressure which can be used to automatically unload compressor cylinders or otherwise reduce compressor capacity. The operation of one such system might be of interest. In this system a modulating valve in the suction line is controlled from a thermostat in the return air stream set for 32°F. During peak load this temperature rises above 32°F for a short period of time, then returns to the control point and holds there during the remaining cooling period of the day. During peak load the valve in the suction line is wide open for full compressor capacity, with the evaporating temperature holding at 18°F. As load decreases the suction line valve begins to close and the evaporating pressure in the coils increases, usually reaching an evaporating temperature of 25°F before the storage is opened the next morning.

This system will work either with individual compressors for the apple room or on a plant system. In the example above two compressors are on staged pressure control and both compressors are provided with cylinder unloaders so

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that a gradual reduction of capacity is obtained with the smaller of the two compressors carrying the final hours of the day if the load was not too heavy. Such a system may also be provided with two-speed fan motors with fan speed increased during the peak load by an additional thermostat responding to the rise in room air temperature during that period.

EXPLANATION OF FIGURES

The behavior of water vapor in air as it goes through cooling and heating processes is well established and can most readily be represested on the psychrometric chart. Figure (2) is a schematic diagram of the psychrometric chart in which the horizontal scale is temperature and the vertical scale is moisture content or humidity of the air. The heavy line (furthest to the left) is the saturation curve. Any point along this curve represents air in the saturated condition, while the area to the right represents unsaturated air with the relative humidity decreasing with the distance away from the curve.

The operation of a cooling coil can be represented on the psychrometric chart by considering that part of the air passing through the coil is reduced to the temperature of the cold surface and then mixes with the remaining uncooled air. (see figure (3) also). If the surface becomes frosted, the air in contact with the surface must be saturated and can be represented by a point on the saturation curve.

Thus point A represents the temperature and moisture content of the air entering the cooling equipment whose surface temperature is at S_1. If we now assume a coil that is wet or frosted, S_1 must lie on the saturation curve and the air leaving the cooling equipment will be represented by a point on the line drawn between A and S_1 such as at B. Thus the temperature of the air on passing through the equipment has been reduced from A to B, while its humidity has been reduced from A to C. Suppose now we select equipment that has less cooling surface as for instance a barepipe cooler as compared to a finned cooler. It would then be necessary to operate the reduced amount of surface at a lower temperature such as S_2 in order to obtain the same leaving air temperature. Since the leaving air must now be on the line A-S_2, the moisture content of the leaving air will be lower as indicated by point D even though its temperature remains the same as in the previous example. Thus, for the same rate of cooling, more moisture will be removed with this second arrangement and there will be a greater tendency to dehydrate the apples.

An unusual condition exists during the early stages of apple cooling. In figure (2) point E, representing air at the apple surface, is at high temperature and due to the fact this air is near saturation, particularly if the fruits are wet with dew as they enter storage, this air (point E) is close to the saturation curve. Note that the lines drawn from E to S_1 and from E to S_2 have practically the same slope. Thus a reduction of evaporator surface temperature during the peak load period will increase capacity of the evaporator with little or no effect on dehumidification. If the apple surface is not wet, it is thought that the water loss is still slight during the loading-in period in spite of the wide TD of the coil during this short period.

Figure (3). To understand what happens when air in an apple storage room held at 35°F is cooled by passing over the cooling coil or evaporator its changes may be plotted on a schematic diagram of the psychrometric chart. Heat and

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water vapor transfer to the wet surface of the cooling coil can be completely described by its contact efficiency and its by-pass factor. The by-pass factor is given for all cooling coils. On the wet surface is an absorbed air film which is saturated with moisture and is substantially at the coil surface temperature.

Heat and water vapor transfer occur almost entirely by the mixing of the molecules of the air stream with the molecules of the absorbed air film. Molecules which momentarily become a part of this film while passing through the coil are said to have contacted the surface, while molecules which do not become a part of this film are said to have by-passed the surface.

The percent of the molecules which momentarily become a part of the absorbed film is termed the contact efficiency and the percent of the molecules which by-pass the surface is termed the by-pass factor. The contact efficiency is 100 percent minus the by-pass factor.
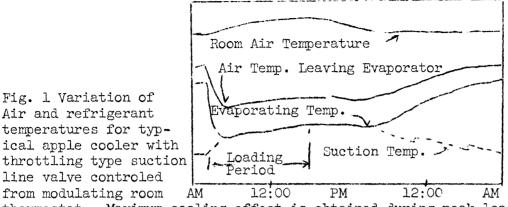
In figure (3) we have selected a storage held at 35°F and 80 percent relative humidity which results in a dew point (DP) of 31°F. The cooling coil is operating at a surface temperature of 27°F and has an 80 percent contact efficiency. The heat and vapor transfer process can be represented on the psychrometric chart by a straight line drawn from 35°F DB (dry bulb or air temperature), 31 DP to 27°F on the saturation curve (left curve). The air will be cooled 80 percent of the distance toward the saturation curve and will leave the coil at 28.6 DB and 27.8 °F DP.

This material was adapted with a few changes from a paper on meat carcass cooling in Ref. Eng. Journal, Nov., 1956, page 48, and from Ind. Ref., Jan., 1958, page 38.

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Fig. 1 Variation of
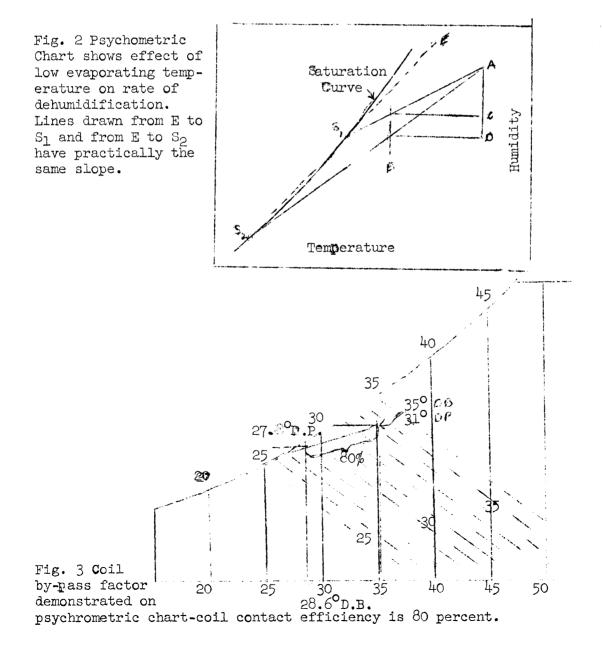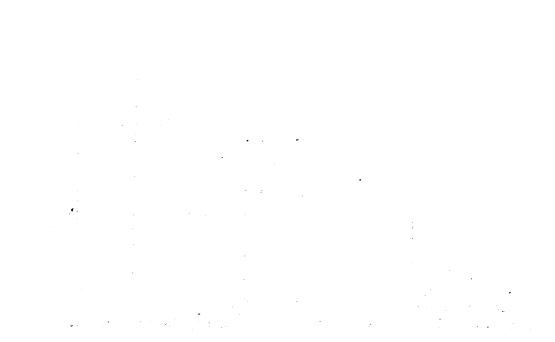Air and refrigerant
temperatures for typ-
ical apple cooler with
throttling type suction
line valve controled
from modulating room thermostat. Maximum cooling effect is obtained during peak load conditions and that reduction of capacity is accomplished by raising evaporating temperature.

Fig. 2 Psychometric
Chart shows effect of
low evaporating temp-
erature on rate of
dehumidification.
Lines drawn from E to
S_1 and from E to S_2
have practically the
same slope.

Fig. 3 Coil
by-pass factor
demonstrated on
psychrometric chart-coil contact efficiency is 80 percent.

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