STORAGE FOR APPLES AND PEARS

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STORAGE FOR APPLES AND PEARS[1]

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INTRODUCTION

Holding apples and pears in cold storage in producing areas rather than at market terminals or at points in transit has become a common practice. In the Pacific Northwest this change has been more or less coincident with the decline of speculative buying of the fruit by eastern interests and with the growth of cooperative marketing enterprises owned and controlled by the growers. As a result, the available cold-storage space in the fruit-growing districts in Washington and Oregon has been materially increased,[2] but even yet it is inadequate for the needs of the industry. Many of the existing cold-storage plants are inadequately equipped to handle satisfactorily the tonnage stored. Year by year existing plants are remodeled and expanded and new plants are built to provide additional refrigerated storage space. The construction of new controlled atmosphere storages has increased greatly in the last 4 or 5 years. Some of the storages are well designed and carefully and efficiently operated.

The purpose of this publication is to present in concise language, as nontechnically as possible, the essential features in the design and operation of cold-storage plants and in the handling of the stored fruit in the Pacific Northwest, although the same principles will be found equally useful in other parts of the country.

The principal fruits requiring refrigeration for extended storage are apples and pears. Grapes also are stored extensively in some places, particularly in California. Refrigeration is used also for the precooling or short-time storage of other fruits, such as cherries, plums, and apricots.

Rural electrification and automatic refrigeration equipment are now universal, and individual fruit growers or small groups of growers have been building cold-storage plants at or near their orchards instead of relying on large plants that serve a whole community or a large number of growers. This has been coincident with the development of better handling and packing methods. The handling methods, transportation equipment, and facilities required for sorting and packing extended the distance that apples can be moved from orchard to the cold-storage house so that packing and shipping will not be under the pressure of getting the job done in a matter of a few days after picking. Having refrigeration facilities at hand has permitted the orchardist to give his fruit optimum protection while it is awaiting packing and to employ a comparatively small crew of skilled harvesters instead of having to mobilize large crews. This has prevented fruit from wasting and allowed it to be handled economically in large volume.

Many of the cold-storage plants designed and operated along lines found satisfactory for general cold storage have been neither efficient nor economical for fruit, owing to specialized

[1] The previous publication, Cold Storage of Apples and Pears, published February 1946, was written by W. V. Hukill and Edwin Smith, both of whom have retired.

[2] Total gross refrigerated warehouse space in Washington and Oregon increased from 109 million cu. ft. in 1951 to 231 million cu. ft. in 1967 alone. (Agricultural Statistics 1969 and 1952.)

requirements for the rapid cooling of the fruit and the maintenance of its temperature within narrow limits. For best possible returns on investments, emphasis must be placed upon both the design and the efficient operation of a fruit cold-storage plant.

Many cold-storage operators, including foremen and plant engineers, will desire more detailed information on many subjects that necessarily are greatly condensed in a publication of this kind. For this reason, attention is called to other publications on refrigeration engineering and fruit storage listed under Literature Cited (p. 48).

RESPONSE OF FRUIT TO STORAGE CONDITIONS

Before undertaking to design and operate a cold-storage plant, the nature of the product to be stored must be understood. Apples and pears are alive at the time of harvest; the length of time they may be held for consumption in the fresh state depends upon how long the end of their life can be delayed. Their storage life begins the day they are picked, even though they may remain temporarily in the orchard or packinghouse. The length of storage life varies with the variety, orchard, district, and conditions of growth, the stage of maturity at which the fruit is picked, and the temperature and humidity at which it is held. For additional discussion on these subjects, see reference (*32*).[3]

Respiration and Ripening Processes

An apple or pear consists largely of water and contains sugars, fruit acids, and, in and between the cell walls, pectin. The pectins cement the cells together, and the degree of adhesion or disintegration of the cells determines whether the flesh of a fruit is firm, tough, crisp, and juicy, or soft and mealy. The chemical changes that take place in fruit during ripening are very complex. Starch changes to sugar; acids and insoluble pectins decrease; and volatile constituents are given off. These changes go on until the fruit becomes overripe and unpalatable, with subsequent collapse. During the ripening process, oxygen is consumed from the air, water and carbon dioxide are produced, and heat is generated. All these activities are embodied in what is spoken of as respiration.

The chemical changes taking place in ripening fruit, and consequently the rate of respiration, are retarded as the temperature is lowered. The quicker heat is removed from fruit after picking to bring it to an optimum storage temperature, the earlier the ripening processes will be retarded and the longer the fruit can be kept.

The generation of heat during the respiration and ripening processes (referred to in more detail on p. 28) is greater than is commonly realized and deserves important consideration in the design and operation of fruit cold-storage houses. The faster a fruit ripens, the greater the quantity of heat generated. A Bartlett pear ripens faster than an apple at a given temperature, and, therefore, its greater heat of respiration results in larger refrigeration demands, even when it is taken into storage at the same temperature as the apple (table 1).

Storage Temperatures

Research by Magness and others (*17*) has shown that when apples are stored at 30° F. about 25 percent longer time is required for them to ripen than at 32°. When stored at 40°, the rate of ripening is about double that at 32°. At 60° the rate is about three times that at 40°, and at 85° the softening and respiration rates have been found to be about double those at 60°. These findings emphasize the importance of having the cold storage designed to quickly establish and maintain uniform low temperatures. A study on the effect of hydrocooling apples (Red Delicious, Golden Delicious, and Winesap apples) "Indicates that for long storage of apples, hydrocooling offers no advantages over air-cooling in cold storage rooms, providing the cooling to approximately 32° is accomplished within a week. If there is in-

[3] Italic numbers in parentheses refer to Literature cited, p. 48.

TABLE 1.—*Rates of evolution of heat by fresh fruits when stored at various temperatures* [1]

Kind of fruit	British thermal units (B.t.u.) per ton per day at indicated temperature				
	32° F.	40° to 41° F.	59° to 60 ° F.	68° to 70° F.	77° to 80° F.
Apples	500–900	1,100–1,600	3,000–6,800	3,700–7,700	----------
Apricots	----------	1,800–8,300	8,300–15,100	13,200–27,500	----------
Cherries, sour	1,300–2,900	2,800–2,900	6,000–11,000	8,600–11,000	11,700–15,600
Cherries, sweet	900–1,200	2,100–3,100	5,500–9,900	6,200–7,000	----------
Peaches	900–1,400	1,400–2,000	7,300–9,300	13,000–22,500	17,900–26,800
Pears, Bartlett	700–1,500	1,100–2,200	3,300–13,200	6,600–15,400	----------
Pears, Kieffer	400–500	----------	2,400–5,300	3,400–6,100	4,300–6,300

[1] Condensed from Lutz and Hardenburg (*15*).

sufficient refrigeration capacity in a warehouse and a number of storage units are involved, hydrocooling might be advisable" (*28*).

Uniformity of Temperature

Uniformity of temperature relates both to its range on the thermometer scale and to the maintenance of a like temperature throughout a storage room. In some plants, cycles of compressor operation cause a fluctuation of 2° to 4° F. in air temperatures. Slight fluctuation does not injure fruit unless it is downward to a point resulting in freezing or in low-temperature injury. Apples or pears exposed to a temperature fluctuating from 30° to 32° will keep as long as if stored at a constant temperature of 32°. If the fruit is stored at a uniform temperature of 30°, however, its life may be lengthened by 25 percent (*17*).

Maintaining uniformity of temperature in all parts of a storage room is more important than avoiding small fluctuations at a given point. Marked variation in temperature within the storage room will bring about different rates of fruit ripening. This frequently results in mixing overripe and prime fruit in shipment, or it may result in undetected deterioration and decay of fruit in inaccessible locations.

Thermometers and Uniform Temperatures

Because fruit is a living matter, it is generating a small quantity of heat continuously. The air circulation is not uniform in all parts of the storage room, therefore, the fruit temperature will not be the same at all locations. The heat generated must be given up to the air to prevent a rise in fruit temperature. For this reason, it is not possible to have the same air or fruit temperature in all parts of a storage room. In some storage rooms, the temperature variation may be only a fraction of a degree, while in others it may vary several degrees even after the fruit has been cooled to its final temperature.

Because of these variations in temperature, readings from thermometers placed in the aisles may be misleading. To operate a plant to the best advantage, the highest and lowest fruit temperature in each room should be known. Since the fruit stored in packed boxes may be one degree or more higher than the circulating air the core temperature must be known. This temperature determines how well the fruit will keep. The use of thermometers to take temperature readings of the fruit in all parts of the storage room after it has been filled with fruit is difficult.

There are times during the season, as fruit is shifted or loaded out, when it is possible to take core temperatures. Often, if temperature conditions are known, steps can be taken to make them more uniform. When fruit-temperature readings are not taken, temperatures shown on the thermometer in an aisle are frequently assumed to prevail throughout the room. This is not true, and wide temperature variations may occur, especially for the first few weeks of storage. (See the discussion on use of thermocouples for reading temperatures in these inaccessible places, p. 26.)

The influence of the temperature of fruit on the rate of ripening has special significance in cold-storage management. Apples at 70° F. ripen as much in 1 day as they would at 30° in 10 days; a delay of 3 days in an orchard or in a warm-packing shed may shorten their storage life as much as 30 days, even if they are then stored at 30°. Storage temperatures recommended for various fruits are shown in table 2.

Effects of Rapid Cooling

Apples and pears are not injured by rapid cooling if the surface temperature of the fruit stays above freezing or the fruit is not of a variety susceptible to injury by low temperature occurring above the freezing point. Some low-temperature injuries of apples are discussed on pages 39 to 42.

Freezing in Storage

Because of the dissolved constituents in fruits and vegetables (chiefly sugars and acids), the freezing points of these products are appreciably below that of water. The average freezing point of apples is 28.4° F. It ranges from as high as 29.7° to as low as 27.3° in some of the summer varieties, but it is between 28.0° and 29.0° for the principal winter varieties that are stored. The freezing temperatures of pears are slightly below those of apples. Average freezing temperatures of some fruits are given in table 2. Lutz and Hardenburg (*15*) and Whiteman (*36*) have more complete information on this subject.

Humidity, Moisture Loss, and Waxing

The loss of moisture from apples and pears in storage, resulting in shriveling or wilting, is

TABLE 2.—*Recommended storage temperature, relative humidity, and freezing temperature of fresh fruit* [1]

Kind and variety of fruit	Storage temperature	Relative humidity	Freezing temperature	Approx. length of storage period	Specific heat
	° F.	*Percent*	*° F.*		*B.t.u./lb./° F.*
Apples:					
Delicious	30–32	85–90	28.4–29.3	4–8 months	0.87
Golden Delicious	30–32	85–90	28.4–29.3	[2] 4–8 months	.87
Jonathan	35–36	85–90	28.3–29.3	3–6 months	.87
Winesap	30–32	85–90	28.2–29.0	5–8 months	.87
McIntosh	[3] 36–38	85–90	28.4–29.3	4–8 months	.87
Yellow Newtown	[3] 38–40	85–90	28.0–29.3	5–8 months	.87
Pears:					
Bartlett	29–31	90–95	[4] 27.8–29.2	[5] 2½–3 months	.86
Anjou	29–31	90–95	26.9–29.2	[5] 4–6 months	.86
Peaches:	31–32	90	29.6–30.3	2–4 weeks	.91
Apricots:	31–32	90	30.1	1–3 weeks	.88
Cherries:					
Sour	32	90–95	28.0–29.0	2–7 days	.84
Sweet	30–31	90–95	24.1–28.0	2–3 weeks	.87

[1] Condensed from (*15*).

[2] Polyethylene liners are needed for maximum storage of Golden Delicious.

[3] McIntosh and Yellow Newtown apples may develop brown core during extended storage at 32° F.; hence, they should be stored at the higher temperatures.

[4] Whiteman, T. M. (*36*) found in his research that the highest points of 11 varieties of pears ranged from 26.7° to 29.2° F. He also states, "In general, the average freezing points decreased as the soluble solids increased, but there was no consistent relation between these factors."

[5] For long storage, pears should be packed with polyethylene liners.

directly related to moisture in the form of water vapor in the storage atmosphere. When the relative humidity is maintained at above 90 percent, fruit rot is encouraged as well as surface-mold growth on the fruit and on the walls, ceilings, and floors of the storage room and on the packages. Apples and pears may be kept in cold-storage rooms without risk of excessive moisture loss with active air movement, under ideal conditions of humidity. When the relative humidity is low, shriveling is aggravated by moving air, particularly when the fruit is stored without wraps. A relative humidity of 85 percent is considered ideal for most fruits. Some storages are using a higher relative humidity, but higher humidities in cold storages are conducive to mold growth.

High-cost cooling surfaces and their accessories are necessary to maintain 90-percent relative humidity at full refrigeration load. To maintain a 95-percent relative humidity by cooling surface design is virtually prohibitive. Table 3 shows the difficulty in controlling humidity by coil surface alone.

One way of reducing condensation is by reducing the temperature difference between the cooling surface and the air (table 3). This may be done by improving liquid feed, regulating back pressure, having better defrosting, using clean evaporator coils, having higher air velocity through the coils, and having larger coil surfaces. Such reduced temperature difference is very effective in reducing condensation at low humidities.

Table 3 also shows that when the air is at 90-percent relative humidity, lowering the temperature difference from 20° to 4° F. reduced condensation by only one-third. At 95-percent relative humidity, the same reduction in temperature difference increased condensation. At this relative humidity, a 1° difference is necessary to substantially reduce condensation.

The principal value of polyethylene film box liners for apples is the reduction of moisture loss and shriveling (*29*). Dehydration is very noticeable when apples have little natural wax and the relative humidity of the storage room is below 85 percent. Perforated polyethylene liners are used extensively for Golden Delicious apples.

TABLE 3.—*Calculated condensation per 1,000 B.t.u. on cooling surfaces from air at 32° F.*[1]

Relative humidity (percent)	Temperature (°F.) difference between coil surface and air at 32° F.				
	1°	2°	4°	10°	20°
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
100	0.35	0.36	0.36	0.33	0.31
95	.11	.31	.34	.32	.31
90	---	---	.19	.28	.28
80	---	---	---	.18	.23
70	---	---	---	.02	.18
60	---	---	---	---	.14

[1] Developed from a discussion on humidity control by Guillou and Richardson, University of California, Davis, Calif.

Pears get the full benefit of polyethylene liners only when they are sealed (*29*). The fruit should be washed with an effective fungicide before being packed as the high relative humidity inside the liner may accelerate the growth of decay organisms.

The liners should be opened to allow ventilation when the pears are removed from cold storage for ripening. The use of polyethylene pallet box covers over nonprecooled apples and pears is not advisable as cooling is retarded and the fruit ripens faster (*12*).

Waxing fruit has generally been adopted in the Pacific Northwest. Schomer and Pierson (*30*) have the following to say on waxing:

> Commercial waxing is not sufficient protection against moisture loss to replace the "poly" liner for storage of Golden Delicious apples and Anjou pears. Application of sufficient wax to prevent shriveling would cause physiological damage. Consequently, the reduction of moisture loss due to waxing is relatively unimportant, especially since the fruits most susceptible to wilting still must be packed in "poly" liners which reduce moisture loss to an insignificant amount.
>
> Waxing enhances the appearance of apples and pears by imparting a shine which persists even after extended storage.
>
> There was no enhancement of quality or extension of storage life as a result of waxing [on apples].
>
> Wax on pears retards ripening and might extend shelf life. Because of the effect of wax on ripening, however, the amount applied must be controlled carefully.

Air Circulation and Ventilation

Apples and pears should be stored in an atmosphere free from pronounced odors. They acquire off-flavors when stored with potatoes, onions, cabbage, and certain other products. If stored by themselves, most fruits do not require a change of the air other than that occasioned by the opening of doors or ports under normal operation, provided the fruit is not overripe when received and is quickly cooled to an optimum storage temperature.

In most parts of the United States, substituting natural cold air for mechanical refrigeration during winter months is not practical; therefore, it is seldom advisable to make any special provisions in the storage designs for bringing in outside air.

In the storage of apples an active air movement about the packages is advantageous, particularly with varieties susceptible to apple scald. Less scald develops when they are stored in moving air. A heavy odor in an apple storage means that some of the fruit is reaching an advanced stage of ripeness, and the storage period should be terminated.

Ethylene, a gas given off by ripening apples, pears, and some other fruits, hastens the ripening of fruit stored at high temperatures but has very little effect at low temperatures. Even a very small quantity of the gas will cause accelerated ripening at favorable temperatures. This is an added reason for designing the cold storage for the rapid cooling of fruit in all parts of the rooms rather than providing for removing ethylene by ventilation.

Air Purification

In some closed cold storages, air purification becomes a necessity to prevent the fruit from taking on an objectional flavor or odor. Activated coconut shell carbon units have been used extensively for this.

Smock (*31*) says the main function of an air purification unit is to keep down foul odors in the room. Experiments with activated carbon as an air purifier by Gerhardt (*8*) showed that activated carbon did not lower ethylene gas concentration in storage rooms.

According to the findings of Gerhardt and Siegelman (*11*), the ripening effect of ethylene gas on stored apples and pears at 31° F. is of little consequence, but it does accelerate ripening at elevated temperatures. Some credit was given to the prevention of scald on fruit by the use of activated carbon filter, but according to recent developments in the use of diphenylamine (*22*) for the prevention of scald, the use of carbon filter for this purpose alone would not be justifiable. When activated charcoal has reached its practical saturation in service, it must be reactivated, usually at the manufacturer's plant (*1*). Gerhardt and Sainsbury (*10*) experimented with brominated carbon for absorbing volatiles from the air of the storage room. He found that brominated carbon was a more efficient absorbent of ethylene than was activated carbon but both were about the same when it came to removing volatiles other than ethylene. Brominated carbon is very corrosive on metalic containers so it is not used.

Controlled-Atmosphere, or Gas, Storage

Reducing the oxygen content and increasing the carbon dioxide in the atmosphere of a storage room slows down the respiration, softening, and ripening process of apples and pears.

Controlled-atmosphere (C.A.) storage has the greatest advantage for apple varieties that may be injured at low-storage temperatures of 30° to 31° F., such as McIntosh, Jonathan, and Yellow Newtown varieties.

The use of C.A. storage for Delicious and Golden Delicious apples has expanded very rapidly in the Pacific Northwest. A law in Washington State requires that apples labeled as C.A. fruit must meet export standards at time of shipment. This law has resulted in a price advantage for C.A. stored fruit.

Several methods are used in obtaining a C.A. storage room. The oldest method practiced is to seal the storage room until it is essentially gas proof with a sheet metal lining or high-density plywood and caulked joints. The fruit then consumes the oxygen until it reaches the desired level, thereafter the concentration of the gas is controlled by permitting outside air to enter the room. The concentration of carbon dioxide is built up by fruit respiration; to limit this concentration level, the room atmosphere is circulated through an atmospheric washer containing a dilute solution of caustic soda (NaOH) to absorb the excess carbon dioxide. Refrigeration equipment also is necessary since the fruit must be held at its normal cold storage temperature.

Van Doren (*34*) states that, "The concentration of the solution of (NaOH) should not exceed 5 percent of caustic sodium hydroxide and operators who use the flake caustic soda should not exceed ½ pound of the caustic soda per gallon of water in the scrubbing solution. Lower concentrations are to be desired, with only enough caustic soda being put in the water to keep the increase of CO_2 removed from the storage air." Van Doren (*34*) further states, "It is wise to plan on having about one pound of caustic [soda] per bushel of apples stored, although most operators will use only about ½ pound per bushel per season."

The use of dry-lime scrubbers is becoming popular for C.A. storage rooms because of the scrubber's simplicity, efficiency, and economy. Sacks of dry-hydrated lime are placed directly in the room or adjoining room and the room air circulated by the sacks of lime. The lime absorbs the carbon dioxide (CO_2) from the air. When the CO_2 concentration of the room air begins to increase, these sacks are removed and replaced with fresh sacks. Some operators use atmospheric equipment in conjunction with the dry-hydrated lime. This machine generates the desired atmosphere outside the storage room and delivers it into the room at a designated pressure of about ⅛ inch of water. By doing this the rooms do not have to be so airtight and plastic air bags, or breather bags, are not used to take care of changes in atmospheric pressure. Usually a small water seal trap with a ⅛-inch water seal is provided for any unforseen large variation in pressure (fig. 1).

The CO_2 may also be scrubbed from the air of the storage room with water. Glycol is added to the water to prevent it from freezing. The water or brine flows over cells inside the storage room where the room air is blown through it. The brine cools the air as well as absorbs the CO_2. The brine is then pumped (or flows by gravity) from the room and discharged

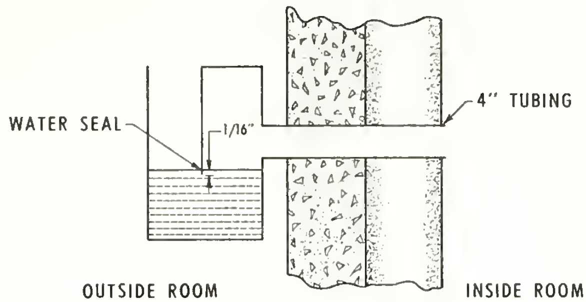

FIGURE 1.—Section through water trap with the water seal indicated.

over cooling coils where it is chilled to the desired storage temperature at the same time being aerated, and the excess CO_2 is given off to the outside air.

Some trouble has been experienced when this method is used. The brine may give off oxygen to the room air, raising the oxygen level above the level desired. Operators have reported that when a defoaming agent was added to the water the increase of oxygen in the storage room air stopped.

To keep the air temperature in the room from fluctuating too widely, a volume of air of approximately 1 cubic foot per minute per box of apples stored should be used. A large volume of brine should also be circulated. By using this method relative humidities of 95 percent can be obtained easily.

When the air velocity is increased, high humidities will prevent weight loss from the stored product. A commercial external gas generator can also be used with this method.

Where the oxygen level in a controlled atmosphere room is dependent upon the stored fruit, the room must be tightly sealed. The use of external generators to supply the desired oxygen level of air to the room allows some tolerance in the sealing. The amount of air leakage is fixed by the size of the room and type of generator used. Generally, some auxiliary method must be used in C.A. rooms to produce a high relative humidity of 90 to 95 percent. Usually water is sprayed directly into the air of the room.

In some storages where a commercial generator is not available, the room atmosphere can be obtained by flushing the rooms with nitrogen. This method is expensive and should be used only in bringing the room atmosphere to the desired composition when natural absorption of the oxygen from the room air by the fruit is not fast enough.

The oxygen content in air of a C.A. room will not support human life. Therefore, an oxygen mask should be worn when entering such a room or the door to the room should be left open for several hours before entering. Someone should be outside the room as a safety man while a workman is in the room if the oxygen content is low.

For further reference on C.A. rooms, see reference (*15*) and the references listed therein. Table 4 gives the recommended storage temperature and oxygen and carbon dioxide levels for C.A. storage of selected varieties of apples.

Pears respond very well in C.A. storage but require a high relative humidity of at least 90 to 95 percent. Use of C.A. storage for pears has been slow, however, because of the excellent results obtained when pears are packed and stored with polyethylene-lined containers (*15*, *9*).

TABLE 4.—*Oxygen, carbon dioxide, and temperature requirements for controlled atmosphere storage of selected varieties of apples* [1]

Variety	Carbon dioxide	Oxgyen	Temperature
	Percent	*Percent*	*° F.*
Cortland [2]	2–5	3	38
Delicious [3]	1–2	2–3	30–32
Golden Delicious [3]	1–2	2–3	30–32
Jonathan	3–5	3	32
McIntosh [2]	2–5	3	38
Northern Spy	2–3	3	32
Rome Beauty	2–3	3	30–32
Stayman	2–3	3	30–32
Yellow Newtown	7–8	2–3	38–40

[1] Adapted from Lutz (*15*).

[2] Cortland and McIntosh varieties are stored in 2 percent CO_2 the first month and 5 percent thereafter.

[3] In Washington State, 1–3 percent oxygen is recommended for Delicious and Golden Delicious varieties, rather than 2–3 percent oxygen.

Storage Sanitation

A storage interior free from decayed fruit, dirt, and mold is a criterion of good management. The growth of surface molds within a storage, however, may indicate favorable conditions of relative humidity and does not particularly menace stored apples and pears packed in closed containers. The use of fungicidal paints or the annual whitewashing of walls, ceilings, posts, and air ducts and the oiling of the floors will largely prevent the growth of surface molds. Mold growth and spores may be killed by spraying the empty storage with a sodium hypochlorite solution having 0.8 percent available chlorine. The rooms should be closed for a few days after spraying.

Chlorine vapor from a spray of sodium hypochlorite is an irritant to the mucous membrane. Workmen should therefore be protected from injury while spraying. This may be done either by using fans to produce an air movement to carry away the fumes or by wearing an all-service gas mask in nonventilated rooms.

For further discussions on this topic, see (*15*).

Ozone

Ozone as used in cold storages is a deodorizer and a deterrent to surface molds which develop in high humidities. Although it is not too widely used in cold storages of apples and other fruits, a few commercial storages use it regularly.

Ozone is a powerful oxidizing agent, and is used mainly to oxidize many objectional odors and gases that are associated with storages. It is made by the condensation of oxygen from the air with a high voltage current.

At low concentrations, ozone has a pleasant odor, but prolonged exposure to concentrations above 0.1 part per million (p.p.m.) should be avoided.

Schomer and McColloch (*27*) report that in their experiments ozone did not check decay of the fruit in storage, but air-borne spores were killed by continuous exposure to ozonized atmosphere, so that viable spores occurring naturally in the atmosphere were reduced to an insignificant number. Mold on the surfaces of packages and walls of the storage room was prevented.

Ozone did not reduce the scald enough to provide a satisfactory control. Some varieties of apples develop lenticel injury due to prolonged storage in strong concentrations of ozone. In addition to injury of lenticel tissue, other serious effects of extended exposure to 3.25 p.p.m. of ozone may occur, such as the skin of the apple having a sticky and varnishlike appearance. The flavor of some apples is also impaired. The extent of this off-flavor varies with the variety.

Schomer (*27*) also reports that ozone appeared to have no effect on major physiological activities of apples such as ripening during the storage period as measured by pressure tests, composition of internal atmosphere, pH, and total acidity.

STORAGE BEHAVIOR OF APPLES AND PEARS

Success in the storage of apples and pears is dependent upon consideration of their inherent characteristics and upon their normal cold-storage life. The handling of the fruit before storage is also important. "Maximum storage life can be obtained only by storage of high-quality commodities shortly after harvest" (*15*).

Apples

A temperature of 30° to 32° F. and a relative humidity of 85 to 88 percent give best results in the storage of most varieties of apples in most parts of the United States. Certain varieties, however, sometimes will not tolerate continuous low-temperature storage. Yellow Newtown, McIntosh, and Rhode Island Greening apples should be held at 35° to 38° to prevent development of internal browning and brown core. Grimes Golden should be held at 34° to 36° to prevent soggy breakdown. Under conditions described below, certain other varieties should be stored at temperatures higher than 32° to avoid storage disorders.

The higher the storage temperature the faster the apples will ripen and the sooner the end of their storage period will be reached. Apples stored at distant points from markets must have sufficient life left when withdrawn from storage to withstand the higher temperatures of transportation and distribution. The longer apples are stored the shorter their life after removal to higher temperatures. Thus, when distribution requires 10 days to 2 weeks, apples that leave cold storage in apparently good condition may reach the consumer overripened and mealy with many decayed fruits. Some forms of deterioration of apples in storage are discussed here.

Ammonia Injury

Ammonia injury on apples is recognized by a prominence of the lenticels, which become white at the center, with some or many of them surrounded by bands of black on the red surfaces or of green on the yellow-green surfaces. Even short exposures to small concentrations of ammonia will produce these color changes. When ammonia concentrations are 2 to 5 percent, an exposure of 5 to 8 minutes results in prominent lenticels with the surrounding discoloration spreading between the black or green rings. After the apples have been exposed to the fumes for a short period, they partially recover when aerated. The residual damage may be only a slight skin blemish around the lenticels or it may be more serious and affect the flesh tissue.

Apples Rots

Apple rots are caused by fungi commonly referred to as molds (*7*, *25*). From the standpoint of the cold-storage operator, a most important characteristic of rot-producing fungi is that their growth and the germination of spores are either entirely stopped or greatly held in check at temperatures of 30° to 32° F. The riper the apples are before being handled, the more susceptible they become to injury and rot infection. The growth of such important fungi as blue mold, gray mold, and *Alternaria* progresses slowly at temperatures of 30° to 32° once infection takes place. Gradual cooling over 2 to 4 weeks is a bad practice. It hastens the unseen development of rot fungi and later results in a greater percentage of decay than in fruit cooled quickly.

The cold-storage warehouseman needs to keep a close watch for ripening and decay in all storage lots. Certain "side rots" and the "bull's-eye" rot from perennial canker grow slowly until apples reach a certain stage of ripeness, whereupon these rots grow rapidly and become apparent in a few weeks, often causing severe loss before being detected. Susceptible lots should be inspected frequently and should be sold before becoming ripe, especially after the first signs of decay are noticed.

The effect of cold storage upon susceptibility to decay of the fruit before it is washed and packed depends upon the character of storage and the degree of ripeness of the fruit when handled. Firm apples of good quality should be placed in cold storage immediately after harvest. They should be cooled to a core temperature of 32° F. within 1 week. When apples are treated this way the danger from storage rot is decreased. This allows the packing season to be extended. When apples are to be held at temperatures conducive to ripening, it is preferable to pack them before storage and market them as soon as possible.

Bitter Pit

Bitter pit, sometimes called Baldwin spot or stippen and recognized by sunken areas or pits with brown spongy areas in the flesh, cannot be controlled in cold storage. Bitter pit is a disorder related to growing conditions and may become noticeable on the tree or after the fruit has been harvested and stored. Crops of susceptible apples intended for storage should be held at 30° to 32° F. for 2 months before being packed so that affected fruits may be sorted out.

Internal Browning, or Brown Core

The terms "internal browning" and "brown core" are used, respectively, to designate the effects of low-temperature injury in Yellow Newtown and McIntosh apples. The Yellow Newtown grown in the Pajaro Valley in California is especially susceptible, and in this variety the injury commonly appears as elongated areas of brown discoloration radiating from the core. As it progresses, it may spread throughout the tissue and resemble internal breakdown. In McIntosh, as well as in Yellow Newtown and some other varieties, it is characterized at first by a slight brown discoloration between the seed cavities that may later progress until the entire core area becomes brown, making the fruit unmarketable. Susceptible apples should not be stored at 30° to 32° F. but at 36° to 40° to prevent or minimize losses during storage. In districts where internal browning and brown core are serious storage hazards, the application of C.A. storage should be considered.

Internal Breakdown

Internal breakdown, recognized by a more or less general brownish discoloration of the flesh, usually outside the core and at the blossom end of the apple, is essentially death from old age. It manifests itself in various ways in different varieties. In Jonathan, an area on one side or in a zone beneath the skin may become brown and dry while the rest of the flesh is crisp and juicy. This is sometimes spoken of as "Jonathan breakdown." It is associated with fruit harvested at an advanced stage of maturity. It may occur early in the storage season.

In other varieties, internal breakdown may appear as brownish streaks in ripe, mealy tissue, later becoming badly discolored, dry, and spongy. This is designated as "mealy breakdown," and in some varieties the skin often ruptures. Late in the storage season or after removal from storage, this disorder frequently occurs beneath bad bruises, or in tissue near the core in a region affected with severe water core at the time of harvest. The risk of loss from internal breakdown is negligible when apples are harvested at the proper stage of maturity and stored promptly at 30° to 32° F. for normal periods for the variety. When found in a storage lot, it should be regarded as a signal for prompt disposal of the fruit.

A somewhat similar type of discoloration occurs in the fruit of some varieties in some districts before harvest. It is caused by a deficiency of boron. This type of breakdown does not become worse while the fruit is in storage.

Storage Scald

Storage scald is a browning of the skin and is distinguished from soft scald by being superficial, generally diffuse, and more pronounced on the green or unblushed surfaces. It is associated with fruit harvested at an immature stage. Storage scald may be entirely prevented in some varieties, including Delicious, by delaying picking until the fruit is sufficiently mature. It is thought to be induced by certain volatile products of ripening. If apples are not too immature when harvested, storage scald can be largely controlled by placing paper containing at least 15 percent of an odorless and tasteless mineral oil in contact with the fruit as soon as possible after harvest.

The present treatment for storage scald is the use of Diphenylamine (DPA) or ethoxyquin (Stop Scald). DPA is available in wettable powder, emulsifiable liquids, or in impregnated wraps (*22*, *23*).

Pierson (*22*) states,

> A concentration of 2,000 ppm should be used for Delicious and Winesap apples, and 1,000 ppm for Rome Beauty apples. The impregnated wraps can be used on all of the above varieties. DPA *should not* be used on Golden Delicious apples. Ethoxyquin emulsions or wraps should be used on this variety.
>
> Timing of application is important. Delicious should be treated as soon after harvest as possible, preferably with a delay of less than 10 days. For Winesaps a delay of 4–6 weeks is permissible.

Some operators apply DPA by submerging or dipping the pallet boxes into a tank of the solution or by drenching the apples by flooding the solution over them before placing the pallet boxes in cold storage. The pallet boxes of apples should be well drained after treatment.

The dipping tanks should have the solution agitated at all times and any scum that might have accumulated on the surface should be removed as it may contain DPA crystals. If these crystals are deposited on the fruit, they will injure or burn the fruit upon extended contact.

DPA may be applied by spraying the fruit just before it is packed, but the fruit should be packed soon after harvest. Application of DPA in a spray just before waxing or the inclusion of DPA in the wax will not control scald. When the fruit is to be waxed, it should be treated at least 6 weeks before waxing or it should be wrapped in DPA impregnated wraps (*22*).

Soft Scald

Soft scald is frequently confused with storage scald, but it has a different appearance and is radically different in its cause and prevention. Soft scald seldom occurs on fruit picked at the proper stage of maturity and stored immediately at 30° to 32° F. It is usually caused when susceptible varieties of apples are delayed at warm temperatures after harvesting and are then placed in low-temperature storage (below 36°). It cannot be prevented by the use of chemical dips or oiled paper wraps, or by picking at an advanced stage of maturity.

In its early stages soft scald may resemble storage scald, as faint patches of brown become apparent, but soft scald develops rather rapidly into slightly depressed areas of discolored skin. The margins of the affected areas are sharp, and the pattern is generally irregular. The apple may have the appearance of having been rolled over a hot stove. Another distinguishing feature is the brown spongy tissue beneath affected areas. In certain varieties the disorder may be confined to the small points of contact where apples press against each other. When limited to this type of manifestation, soft scald is sometimes referred to as "contact scald" and when found in midwinter it rarely develops to greater proportions. Freezing injury may look like soft scald.

Jonathan and Rome Beauty are the varieties most susceptible to soft scald. At the expense of a shortened storage life, susceptable lots of these varieties should be stored at 35° to 36° F. Controlled atmosphere storage will also provide good control of soft scald (*15*). The same applies to Golden Delicious if not stored within 4 days after picking. McIntosh, Delicious, and other varieties are sometimes affected. In the Winesap, soft scald is largely confined to fruit that has been held in common storage for a period and then moved into cold-storage temperatures of 30° to 32°. Soft scald can be prevented by holding the fruit in 25-percent CO_2 gas for 24 hours before storage at 30° to 32°.

Scaldlike Disorders

Golden Delicious and Yellow Newtown apples that hang on the tree with the cheek freely exposed to the sun may have sunburn that is not very noticeable at the time of packing, but after a period in storage these areas take on an appearance that is difficult to distinguish from apple scald. This disorder should be diagnosed as delayed sunburn. It does not materially shorten the storage life of the fruit and when found on occasional specimens does not require the early disposal necessary when occasional specimens are found with storage scald. The only prevention is a more careful sorting of sunburned apples at the time of packing.

Small sunken-scalded spots result from the contact of apples with Douglas-fir wood, such as with fir-tree props or bins constructed of this wood.

Freezing Injury

Injury from freezing ranges from no visible evidence following incipient ice formation in the flesh to a brown discoloration of the entire apple following "freezing to death" at prolonged low temperatures. Intermediate stages of injury may appear as follows: a slight softening of the flesh; a flaky or corky character in a flesh lacking normal crispness; brown discoloration of tissue around the 10 fibrovascular bundles and extending as threadlike fibers throughout the flesh; the appearance of sunken spots where the apples were bruised while frozen; and as soft scald. All of these manifestations should be interpreted as indicating a shortened storage life. After apples have been badly frozen, the skin becomes shriveled, the surface is discolored in irregularly shaped areas, and the tissue beneath may be translucent and water-soaked or have some shade of brown. Badly frozen tissue becomes dry and corky after prolonged storage.

When slight freezing occurs near refrigeration coils or cold-air ducts, the frost can be removed by raising the temperature at those points to 32° F. But when the apples are frozen deep in the piles, a storage-room temperature of up to 40° and an active circulation of air between the packages will be necessary to thaw them out. The fruit should not be moved while frozen, as this will result in severe injury. The thawing of frozen apples at a temperature of 32° to 40° is recommended. A high temperature will accelerate ripening and cause greater dehydration of the fruit. To prevent shriveling, the relative humidity should be kept as high as possible during the thawing process, preferably above 80 percent.

Jonathan Spot

Jonathan spot is a skin disease giving the apple a freckled appearance from small black or brown spots that appear usually on the deep-colored areas. Although it sometimes develops on other varieties, especially Rome Beauty, from a commercial standpoint it is of importance only on the Jonathan. It may be confused with the brown-freckled appearance of Jonathans caused by spray or washing injuries, but these diseases are distinguished by their appearing earlier in storage, regardless of temperatures. Jonathan spot is prevented almost entirely by picking the apples before they are overmature and storing them promptly at 30° to 32° F. The disease, an indication of "old age," may develop on fruit still on the tree. Its appearance in storage is a warning that the fruit is being kept beyond its commercial storage period.

Water Core

Water core occurs in the fruit before it is removed from the tree. As it is usually associated with advanced picking maturity, crops severely affected are ordinarily not considered well suited for prolonged storage. The water-soaked areas gradually become smaller during storage and, if they are not severe, may completely disappear. Apples affected with water core never completely recover, however, because the affected tissue has been weakened and is disposed to internal breakdown. In the Delicious, Rome Beauty, Stayman, and other softer varieties, internal breakdown may follow slight water core at the fibrovascular bundles. Apples that have apparently made a complete recovery while in cold storage frequently become worthless from internal breakdown within 5 or 6 days after removal from cold storage.

The disappearance of water core is hastened by holding them at temperatures that produce rapid ripening. As such ripening is not desirable, however, the only recommendation that can be made is to limit the storage season as much as possible and keep the fruit under refrigeration.

In 1962 an instrument was developed which can detect water core by transmiting light through the fruit (*20*). This instrument, known as a Difference Meter, is capable of rapidly measuring optical density differences of intact fruit. It is primarily a laboratory instrument, and its use is a nondestructive method of determining the amount of water core in an apple.

Pears

Pears have a slightly lower freezing point than apples and, not being subject to such low-temperature diseases as soft scald and brown core, can be stored at slightly lower temperatures, 29° to 31° being recommended.

As pears are rather susceptible to shriveling, the relative humidity of the storage room should be kept above 85 percent, preferably about 90 percent.

Pears are more responsive to high temperature than most varieties of apples, so that it is essential that heat be removed from them as rapidly as possible immediately after harvesting. They have a high rate of respiration, and the heat of respiration is an important consideration in storage, especially during the cooling period. For successful storage, therefore, the fruit at the center of packages must be cooled approximately to the storage temperature within 48 hours before the packages are stacked in the permanent storage piles. This can be done by circulating 26° to 31° F. air through widely spaced stacks of packages immediately after they are packed. After this initial cooling, packages should be stacked so as to provide air channels for the continuous removal of the heat of respiration and for uniform refrigeration throughout the piles. Stacking away from the walls and on strips or floor racks is necessary to prevent the conduction of heat to the fruit.

Pears may be held in cold storage and subsequently washed and packed without serious injury or disfigurement, provided ripening has progressed only slightly. The prevalence of scratches and other friction marks often found on fruit thus held depends on the stage of ripeness rather than being due to the influence of refrigeration. Holding the fruit for 2 or 3 weeks before washing and packing is safe if the fruit is kept at 30° to 31° F. from the time it is harvested.

Loss of Ripening Capacity

Following prolonged storage, certain varieties of pears may seem to be in excellent condition but when taken to ripening temperatures they fail to respond. Although the color of the fruit may become yellow in the ripening temperatures, the flesh does not soften or become juicy. Bosc, Comice, Bartlett, and Flemish Beauty exhibit this characteristic and do so earlier in the season when stored at temperatures higher than 30° to 31° F. These varieties should be stored at optimum low temperatures and for periods not longer than the varietal storage season. Following storage, ripening must proceed promptly at optimum ripening temperatures.

Optimum Ripening Temperatures

Commercial varieties of pears grown in the United States do not ripen satisfactorily for eating while held at 29° to 31° F. Some varieties gradually become softer at these temperatures, while others may turn slightly more yellow but scarcely soften. All pears need to be withdrawn from cold storage and held at higher temperatures to ripen for eating.

The optimum ripening temperature for most varieties is between 65° and 70° F. Bartlett has much better quality when ripened in this range than at higher temperatures. Bosc fails to ripen normally at lower temperatures. Kieffer has optimum quality when ripened at temperatures between 60° and 65°.

Pear Rots

Blue mold rot and gray mold rot are the most important storage rots in pears. Blue mold rot usually results from skin punctures. Gray mold rot may start at ruptures of the skin or at broken stems and spreads from fruit to fruit by contact. Once established, gray mold grows slowly in cold storage, but having the capacity to enter the unbroken skin of adjacent fruits, it often produces the so-called "nest rot" affecting a group of pears. The spreading from one pear to another can be prevented by packing pears in wrappers impregnated with copper. Sanitary measures in harvesting and packing, together with prompt cooling to temperatures of 29° to 31° F. are important factors in preventing losses from decay.

Pear Scald

In pear scald the skin of the fruit becomes dark brown and soft and sloughs off easily under pressure. The affected skin may become almost black and affords entrance for the decay fungi that usually follows. The disease does not appear until the fruit is aged in storage from being held too long or at too high a temperature. Pear scald, other than the type on the Anjou variety, cannot be prevented by packing in oiled wrappers, but susceptibility may be lessened by picking before the fruit becomes too advanced in maturity and by storing at temperatures of 29° to 31° F.

Anjou Scald

The Anjou variety is subject to a mottled surface browning or blackening in storage. Unlike pear scald, this does not cause a skin disintegration that is deep-seated, nor does the skin slough off. When the pears are wrapped in oiled paper containing basic copper carbonate (Hartman wrap), some benefit is obtained in the prevention of Anjou scald. Studies on this problem have been published (*24*).

Cork Spot

Cork, or cork spot, is characterized by small regions of dark-brown corky tissue appearing in the flesh of pears. When the affected tissue is near the surface, a small depression frequently appears and the skin at this spot may be slightly dark. Anjou is the variety frequently affected by cork spot. The disease is related to growing conditions in the orchard and is not caused by storage conditions. Affected fruit can be stored approximately as long as normal fruit, but its market value may be greatly depreciated if cork spot is very prevalent.

COLD-STORAGE PLANTS AND EQUIPMENT

Refrigeration

The best way to become familiar with refrigeration is to work with it and use it. Each cold-storage plant has characteristics of its own. To take advantage of its good points and to avoid difficulties that may not be common to other plants, the operator must be familiar with his particular plant. General principles of refrigeration apply to all plants, however, and knowing these principles will enable an operator to profit by his experience. These principles are covered in textbooks (*16*, *18*, *19*, and *35*); more specific information is given in handbooks (*1* and *33*) on characteristics of refrigerants; condenser, compressor, and evaporator; insulation values; fan and duct data; requirements of stored products; cooling surface; power requirements; and other matter.

Pumping Heat

The process of refrigeration might be likened to pumping air out of a tank until the pressure is lower than that of the atmosphere. Once the desired low pressure inside the tank is reached, the only additional pumping necessary is to remove any air that enters the tank by leakage, and then the pumping needed will depend entirely upon the leakage. In a refrigerated space, it is desirable to maintain a certain temperature below that of the surroundings. Heat is pumped out until the desired low temperature is reached, whereupon further pumping is necessary only to remove the heat that enters the chamber by leakage through walls and open doors or heat that is generated within the space.

When pumping air from a vacuum tank, if only a slight approach to vacuum is required, less power and a smaller pump are needed than for a high vacuum. The size of the pump required and the horsepower of the motor depend upon two factors: (1) The quantity of air to be removed and (2) the pressure inside the tank. If too much air is allowed to enter the tank, the pump cannot remove it and the desired vacuum cannot be maintained. Similarly in a refrigerating system, if only a moderately low temperature is required, less power and a smaller compressor are needed than where a very low temperature is desired. Furthermore, if the refrigeration machinery does not have the capacity to pump out heat as fast as it enters the chamber, the desired low temperature cannot be reached.

In extending the comparison, the factors determining the size of the pumps for the vacuum are (1) pressures, usually expressed in pounds per square inch (p.s.i.), and (2) quantity of air, expressed as pounds per minute. In the refrigerating system the factors are (1) temperature, expressed in degrees, and (2) heat, commonly expressed as British thermal units (B.t.u.). The term British thermal unit (the heat required to raise the temperature of 1 pound of pure water 1° F.) corresponds to the term pound (in pumping air), in that both express definite quantities of the matter to be handled.

Quantity of Heat

Heat is not a substance and cannot be measured as to quantity by pounds or cubic feet but must be measured by the effect it produces. Heat is measured in intensity in units of temperature and in quantity by units of heat.

In dealing with refrigeration problems, it is just as necessary to consider the quantity of heat to be handled as to speak of pounds of air or gallons of water when computing the necessary sizes of air or water pumps for given jobs. Just as 1 pound represents a very definite and measurable quantity of air, and it is still the same regardless of the pressure under which it is placed, so 1 B.t.u. represents a definite and measurable quantity of heat, and it too remains the same regardless of existing temperatures.

The refrigeration demand upon the machinery is frequently spoken of in tons. This usage had its origin in a comparison of refrigerating capacity, or demand, with the refrigeration obtained from melting 1 ton of ice. As 144 B.t.u. of heat are required to change 1 pound of ice to water at the melting point, 288,000 B.t.u. are required to melt 1 ton of ice. Where 288,000 B.t.u. of heat must be removed in 24 hours, 1 ton of refrigeration is required.

If, for example, a temperature of 32° F. is to be maintained in a storage building, the refrigeration system will have to remove a quantity of heat just equal to that which enters the building. The heat entering may come from many sources. In the first place, if the outside temperature is above 32°, some heat will come in through the walls. This infiltration can be reduced by insulation, but not even the best insulation will exclude all heat leakage. If the building has cracks, or if the doors or windows are open and permit warm air to enter, an increased quantity of heat will be introduced, depending upon the outside temperature and the quantity of air. Materials having temperatures above 32° placed in the cooled space will introduce still another quantity of heat, depending upon the temperature, weight, and nature of the material. If the materials are living, as for example, apples, they will produce heat continually; this heat is in addition to that which they contained when first put into storage.

The heat from these and other incidental sources combines into the total quantity of heat the refrigerating system is expected to remove. If the system has sufficient capacity, the heat can all be pumped out. If the heat introduced into or produced within the building exceeds the capacity of the refrigeration system, some of it will remain in the fruit and cannot be taken out until the rate of heat intake drops below the rate at which it can be removed.

Flow of Heat

Heat always flows from the warmer to the colder object or substance. Heat will permeate everything, and no substance or material is known that will totally prevent or stop its flow. Some materials, known as insulating materials, will retard or resist the flow of heat. These materials such as cork, rock wool, styrofoam, and urethane are used as insulation in the walls and ceilings of cold-storage houses.

Other material, like bright aluminum foil, prevent the passage or flow of heat by reflecting it away or back.

Heat passes from substances or bodies of higher temperature to those of lower temperature by (1) conduction, (2) convention, and (3) radiation, or (4) by a combination of these means.

Conduction is the flow of heat through a solid substance or from one body to the other that are in contact. Heat flows readily through some materials like iron, copper, and aluminum. These materials are known as conductors.

Convection is the transmission of heat by the flow of liquids or gases after contact with a heated source. The heat is conveyed from the warmer to the colder substance where heat transfer takes place. In cold-storage houses air currents are the most common agents conveying heat by convection. The circulating air is warmed by contact with the fruit and then the heat flows from the air to refrigerator cooling coils as it passes through the evaporator units.

Radiation is the transmission of heat through intervening substances without heating the substance. The heat supplied to the outside of a building by the sun is by radiation, since the sun's rays do not heat the air through which it passes but does heat the building walls or substance where it is absorbed.

Three Steps in the Refrigerating Process

Heat, like air, is handled in definite quantities, but unlike air it cannot be moved bodily from one point to another. By its nature, heat moves from a place of high temperature to one of low temperature. A refrigerating system, or heat pump, takes advantage of this tendency.

Heat from the storage room moves through the walls of the evaporator cooling coils to the ammonia or other refrigerant inside, which is at a lower temperature. The compressor then takes the vaporized gas with the heat it has picked up in the evaporator and by compressing the gas raises its temperature. The heat from the hot gas finally is transferred into the condenser water because the water is at a lower temperature. Thus, the heat from the storage is now in the condenser cooling water, which may be either wasted or cooled by aeration for recirculation. These three steps in heat removal are accomplished by the three essential parts of the refrigerating system—the evaporator, the compressor, and the condenser (fig. 2).[4]

[4] Bowen *(6, pp. 2-3)* describes the operation of the refrigerator shown in figure 2 as follows:

> To utilize its latent heat of vaporization for refrigeration and to conserve the refrigerant, application is made of the physical law that the temperature at which a fluid boils or condenses is raised or lowered, respectively, by increasing or reducing the pressure. To cause the refrigerant to boil at a low temperature in the evaporating coils and hence absorb heat on a low-temperature plane, the pressure in the coils is lowered by suction of the compressor. . . . To free the fluid of the heat absorbed in the refrigerator and return it to liquid form, the cold refrigerating gas coming from the evaporating coils is compressed until its temperature is raised above that of the water flowing through the condenser so that the contained heat can pass from the gas to the water. (In very small machines, air may be used instead of water.)
>
> The essential parts of a compression-refrigerating system are an evaporator, a compressor, and a condenser.
>
> In the evaporator (the coils in the refrigerator) the liquid boils and in the process absorbs heat from the surrounding medium. The compressor is a specially designed pump that takes the gas from the evaporator coils and compresses it into the condenser coils, reducing its volume and increasing its temperature. The condenser consists of coils of pipe over or through which water or air flows to absorb the heat from the gas, which is thereby liquefied. In some systems the cooling water passes through an inner tube and the gas from the compressor through the annular space between the inner and the outer pipes. From the condenser the refrigerant passes first to a liquid receiver, and then through a throttling or expansion valve into the evaporator coils, to repeat the process of transferring heat from the refrigerator to the water flowing through the condenser. The temperature of the liquid ammonia is reduced from the temperature of the receiver to that of the refrigerator by vaporizing a part of the liquid.

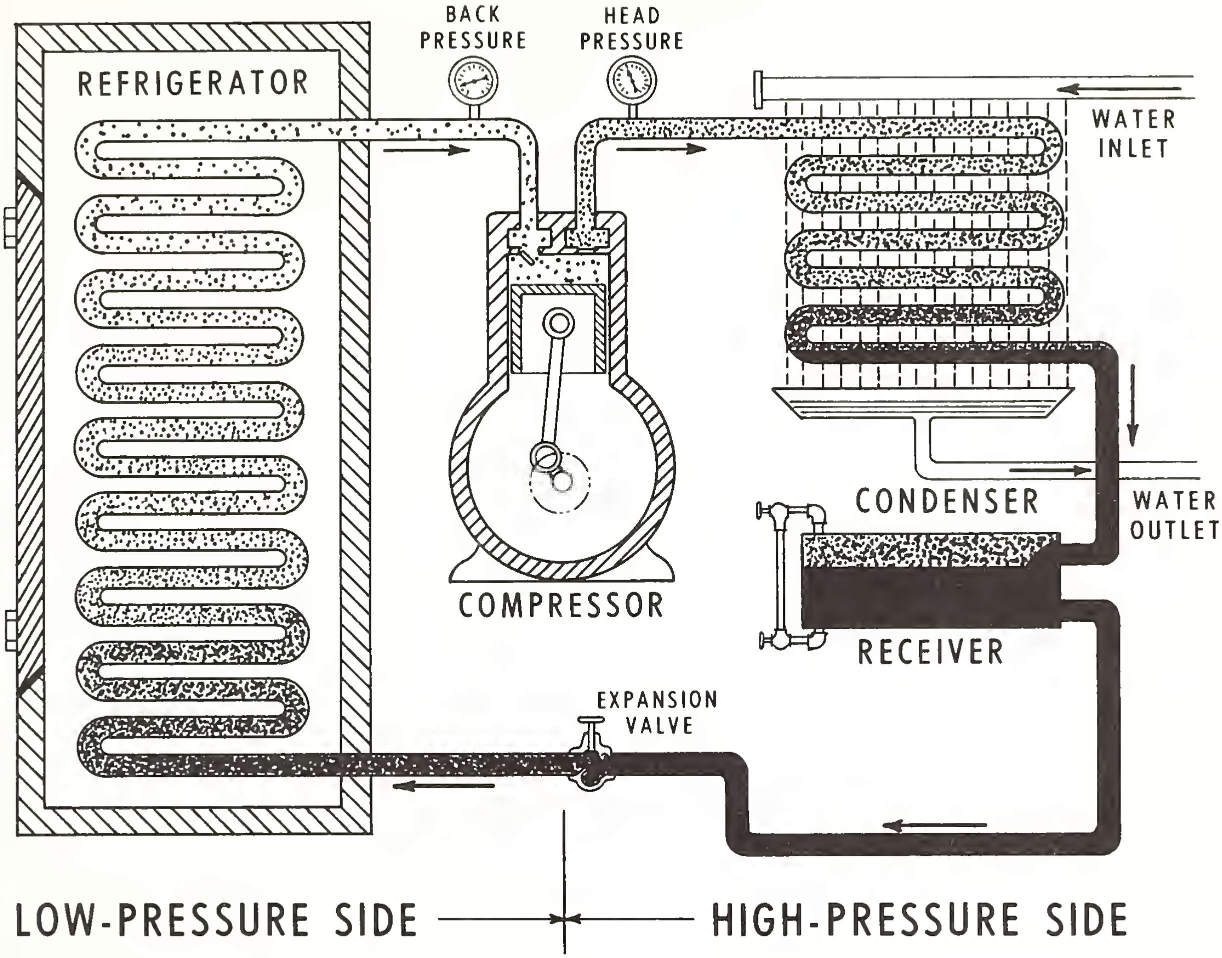

FIGURE 2.—Essential parts of a compression refrigeration system.

In the evaporator, or cooling coils, the quantity of heat picked up depends upon (1) the temperature difference between the refrigerant (ammonia or Freon) in the coils and the room air, (2) the area of coil surface exposed, and (3) the resistance to heat flow through the walls of the pipes or tubing. The resistance to passage of heat into the coil in turn depends not only upon the cleanness of the coil but also upon the velocity of air (or brine if a brine cooling system is used) passing the coil and the velocity of the refrigerant (whether liquid or vapor). The resistance is increased by an accumulation of frost, or if not enough piping surface is exposed, a large temperature difference will be necessary between the inside and outside of the coil to permit sufficient heat to pass into the coils. This requires a low-gas temperature. If, because of resistance or insufficient surface in the cooling coils, it is necessary to maintain a low gas temperature (which means low-suction pressure), the compressor is forced to boost the temperature from a low point, and it cannot handle as much heat as when the suction temperature is higher.

The compressor must also discharge the gas at such temperature that heat will flow from it

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The expansion valve is of a special design and is capable of very fine adjustment. Its function is to so regulate the flow of the liquid refrigerant that suitable pressure and temperature conditions will be maintained. It is largely responsible for the control of temperature in the evaporating or cooling coils.

to the cooling water in the condenser. In general, a compressor can handle more heat if the temperature in the cooling coils is kept as high as possible and the temperature in the condenser as low as possible. The same conditions also reduce the power necessary to remove a given quantity of heat.

When the gas enters the condenser, heat passes from it into the cooling water. As in the evaporating coils, the heat passing from the gas to the cooling water depends upon (1) the temperature difference between the gas and the water, (2) the surface area exposed, and (3) the resistance to heat flow through the condenser pipes. Here also, the resistance to the passage of heat depends upon the water and the gas velocities and the cleanness of the coil. Scale, which tends to collect on the pipes from the cooling water, may increase the resistance markedly. If (1) scale builds up on the coil, or (2) sufficient cooling surface is not provided, then only by a large difference in temperature between the gas and the water can the required quantity of heat be transferred to the water. High temperature of the gas in the condenser reduces compressor capacity and increases power consumption. An adequate supply of water as cold as possible will help lower the temperature of the gas in the condenser and reduce power consumption.

Condenser

The condenser has one purpose. It must permit the passage of heat from the compressed gas to the cooling water (or air in an atmospheric condenser) and do so at as low a gas temperature as possible. It must transfer all the heat that has been taken up in the evaporator as well as that added by the work of the compressor. The passage of heat into the cooling water is facilitated by a large area of cooling surface, by a large quantity of cooling water, by a low water temperature, and by high velocity of the water and gas passing the surface. A high gas temperature also increases the quantity of heat retransferred to the cooling water, but it is the function of the condenser to receive the gas and discharge it at as low a temperature as possible. The design of the condenser and its operation should be such as to remove the required quantity of heat without excessive gas temperatures.

In the operation the effectiveness of the condenser may be judged by the head pressure indicated on the gage. If the head pressure goes too high, the effects on the system are that less heat is removed from the coldrooms and more power is required to operate the compressor. The effect of various high head pressures on power requirements at various suction pressures may be seen in the accompanying chart (fig. 3). For example, when operating at a 25-pound suction pressure, and a head pressure of 120 pounds, about 1.0 horsepower is required to remove 288,000 B.t.u. per day (1 ton of refrigeration); whereas, at a head pressure of 195 pounds, about 1.5 horsepower is required for removing heat at the same rate. That is, the power cost is about 50 percent higher at a 195-pound pressure than at a 120-pound pressure. At the same time, a high head pressure results in reducing the heat that the system can handle. This is illustrated in figure 4.

If the head pressure is too high when the plant is running to capacity, it may be because the condenser is too small, there is not enough

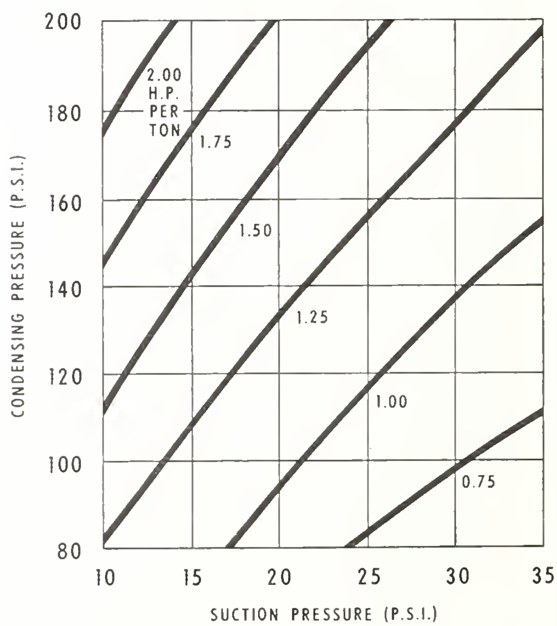

FIGURE 3.—Effect of condensing and suction pressures upon power requirements of a typical ammonia compressor.

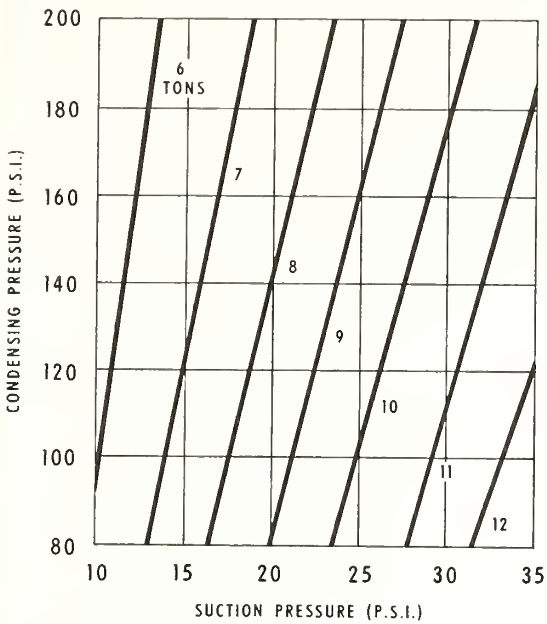

FIGURE 4.—Effect of condensing and suction pressures upon the capacity of a typical ammonia compressor.

cooling water, the cooling water is too warm, noncondensable gases are present, or the condenser tubes are dirty. The water used in the condenser usually contains impurities that corrode the pipes and form deposits on them. If such deposits are allowed to accumulate over long periods, they interfere seriously with the exchange of heat.

Type of Condensers

Several types of condensers are available. The purpose of all of them, however, is to cool the hot ammonia gas, thereby changing it to a liquid. In each the hot gas is circulated through or around pipes that are exposed to a cooling fluid, usually water. In a double-pipe condenser the ammonia is passed through a bank of pipes. A smaller pipe carrying cooling water extends full length inside each section of ammonia pipe. Several banks of double-pipe condensers are usually mounted together to give the required capacity. In a vertical shell-and-tube condenser the ammonia gas enters the top of a large vertical cylinder and the condensed liquid drains off at the lower end. Numerous vertical pipes inside the cylinder are mounted so that a film of cooling water runs down the inside of each pipe. As the ammonia condenses on the outside of the pipes, it flows to the bottom of the cylinder where it is drained off to the receiver.

The horizontal shell-and-tube condenser is similar to the vertical, except that the shell is in a horizontal position and the water pipes carry cooling water under pressure. The water is usually passed back and forth through several tubes in series before being discharged. In this way its velocity is increased to give more rapid cooling without having to discharge large quantities of water.

An evaporating condenser has the ammonia gas pass through coils that are exposed to a spray or drip of water. At the same time air is blown through the water spray past the pipes and causes some of the water to evaporate. This evaporation keeps the water cool, so that it can be recirculated, and the only waste is the water that is evaporated or carried away in the air blast. This is particularly suited to conditions where cooling water is limited or expensive and where the atmosphere is relatively dry during the time large loads are expected on the refrigeration machinery.

Where a dry climate or limited supply of cooling water makes it desirable, the effect of evaporative cooling may also be obtained with shell-and-tube or double-pipe condensers by using a cooling tower or a cooling pond. In this type of condenser, the water from the condenser, instead of being wasted, is pumped to a tower (frequently on top of the building) or to a cooling pond adjacent to the building where it is forced through nozzles to form a spray. After falling through the atmosphere, where it is cooled by the evaporation of a small part, the water is recirculated through the condenser.

Another type, the atmospheric condenser, where cooling is obtained by blowing air over the condenser as frequently used with small cooling or freezing cabinets, usually is not as practical for larger installation. A few of this type are used satisfactorily where Freon is used as the refrigerant and the tonnage is not too great.

Compressor

The compressor, by pumping ammonia from the evaporator to the condenser, takes the heat that has been absorbed in the coils and, by raising the temperature, allows the heat to be carried away by the condenser cooling water. The rate of heat removal by an ammonia compressor running at a given speed depends only upon the head pressure and the suction pressure at which it operates; the higher the suction pressure and the lower the head pressure the more heat will be removed. If the speed is increased, the rate of heat removal will increase proportionately, assuming a given set of pressure conditions. It is good practice, therefore, to operate a compressor at as high a speed as its design will permit, especially during the season when warm fruit is being received.

In fruit storage the demand on the refrigerating equipment is at a maximum for only a short period in the fall. Much of the capacity of this equipment is unnecessary during the rest of the year. To get the most out of it for this critical period, while keeping the investment in equipment at a minimum, it is sometimes economical to operate the equipment at higher speeds than would be advisable for year-round operation. Compressors, however, should be speeded up only after consulting the manufacturer regarding the particular machine. Greater capacity may be obtained in some slow-speed compressors by changing the valves and lubrication system to permit considerably higher speeds.

The capacity of the refrigerating system should not be judged by the size either of the compressor or of the motor installed. The capacity will depend upon the whole system and the conditions under which it operates. Most refrigeration systems are rated either as tons of refrigeration capacity or horsepower. Since horsepower is only relative for one condition depending upon the head pressure, suction pressure, and volume of refrigerant used, it is not so easy to work with as tons of refrigeration. Therefore, for comparative purposes the refrigerating capacity of a compressor is normally expressed as standard tons when operating with a head pressure of 155 pounds and a suction pressure of 20 pounds, but the actual capacity will be influenced by conditions in the system as a whole that cause variations in these pressures. The capacity of and power required for typical ammonia compressors of various sizes are given in table 5.

For commercial purposes, as stated before, a pound of ice is considered to absorb 144 B.t.u. in melting, hence a ton will take up $2,000 \times 144 = 288,000$ B.t.u. This is done in 24 hours or at the rate of 12,000 B.t.u. an hour.

The quantity of heat that a refrigeration system can remove may be increased or decreased by the conditions under which it operates, but no manipulation of air movement or special stacking of boxes or other adjust-

TABLE 5.—*Capacity and power data for typical 2-cylinder ammonia compressors*

Size of cylinder (inches)	Displacement per revolution	Speed	Typical refrigerating capacity and power requirements at 155-pound condenser pressure and 20-pound suction pressure	
			Capacity	Power
	Cu. ft.	*R.p.m.*	*Tons*	*Hp.*
3 × 3	0.024	400	2.1	3.5
4 × 4	.058	375	4.7	7.1
5 × 5	.113	360	8.9	13.4
6 × 6	.196	360	15.6	21.8
6½ × 6½	.249	360	20.0	28.0
7½ × 7½	.383	360	31.0	43.0
8 × 8	.465	360	39.0	53.0
9 × 9	.662	300	48.0	63.0
10 × 10	.909	300	67.0	87.0

ment can prevent the accumulation of heat if it is being introduced or produced faster than it is being removed.

Evaporator

The evaporator, or cooling coil, absorbs the heat from the room. The refrigerant, having had its load of heat removed in the condenser, is expanded to a vapor. This expansion, or evaporation, under low pressure, reduces the gas temperature to such a point that it is ready to pick up more heat from the coldroom. This is done by direct expansion coils in the room or by air circulated from the room through a bank of coils or finned surfaces. Here, as in the condenser, conditions should be such as to permit the heat to flow with as little temperature difference as possible between the gas and the air in the room. If there is not sufficient cooling surface, if the surface is covered with frost, or if other factors retard the heat flow, the gas would have to be extremely cold. This would mean a low suction pressure, which reduces the capacity of the compressor. At low pressures ammonia gas is less dense, and the smaller quantity of gas drawn into the compressor at each stroke results in lower refrigerating capacity.

That the capacity of a typical compressor is increased markedly as the suction pressure is raised is shown graphically in figure 4. For example, at 140-pound head pressure and at a suction pressure of 24 pounds, the compressor delivers 9 tons. An increase of 4 pounds in suction pressure changes the capacity of the same machine to 10 tons. If by increased cooling surface or careful operation the pressure could be increased to 36 pounds, about 12 tons of refrigeration would be obtained, or a gain of 33 percent. Similar changes in suction pressure in an ammonia machine of any size would result in approximately the same percentage increase in capacity. Ample evaporator coil surface will permit the cooling to be done without excessively cooling the air that touches the coils. The results of cooling the air to low temperatures are shown in table 6.

In more recent developments a number of overhead evaporators with proper propeller fans are hung in the truss spaces above the center aisle. These evaporators are arranged so that the cold air is circulated from the center of the building overhead to the sidewalls then down and back through the stacks of pallet boxes to the center aisle and up to the evaporators to be cooled and recirculated. Aspiration of room air into the cold air stream from the evaporators is considerable before the air starts its passage through the fruit stacks. In this way, the total quantity of air in motion is very large and the change in temperature in passing through the evaporator and fruit is quite small. Resistance through the unit is low, and there is no duct resistance.

Large quantities of air can then be circulated economically throughout the room. This method is considerably easier than circulating air

TABLE 6.—*Relation of coil-room temperatures to relative humidity in storage room*

Temperature to which air is chilled (° F.)	Maximum relative humidity when the temperature (° F.) is raised to—								
	24°	26°	28°	30°	32°	34°	36°	38°	40°
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
16°	68	62	57	52	47	43	40	37	33
18°	75	68	62	57	52	48	44	41	36
20°	83	76	69	63	57	53	49	45	39
22°	91	83	75	69	63	58	54	49	44
24°	100	91	83	76	69	64	59	54	48
26°	---	100	91	83	76	70	64	59	53
28°	---	---	100	91	83	77	71	66	58
30°	---	---	---	100	91	84	78	72	64
32°	---	---	---	---	100	92	85	79	70

through ducts from one unit. The horsepower per cubic feet per minute (c.f.m.) of air circulated in the overhead system is about one-half that needed with the large unit and duct combination. Large evaporator surfaces can be obtained at low cost as the design of these cooling units is standardized and mass produced.

These units should have from 250 to 300 square feet of fin and tube surface per ton of refrigeration (T.R.). The quantity of air to be circulated through the units should be about 1,500 c.f.m. per T.R. (*14*).

Choice of Refrigerant

Requirements for a good refrigerant are ability to absorb a large amount of heat per pound handled, low temperature at pressures suitable for evaporation, high temperature of vapor at moderate-compression pressure, little danger of ignition of leaking gas at working temperatures, and low cost.

For large installations, ammonia is the refrigerant most commonly used. Ammonia has the highest heat absorption, but if leaks occur, it will injure fruit and it is dangerous. It is also flammable. Ammonia may attack copper also and brass, especially if water is present. At standard atmospheric pressure, ammonia boils at —28° F. and Freon -12 at —21.7°.

Comparison of heat of evaporation absorbed per cubic foot of refrigerant at 5 degrees is given below:

Ammonia	69.4 B.t.u.
Freon	46.65 B.t.u.

Choice of a refrigerant becomes a matter of which is most important—heat capacity, low condenser pressure, moderately high evaporation pressure, freedom from hazard, or cost of material—and which will give best economy under the working requirements of the system. Freon is nontoxic, nonirritating, and nonflammable. It is chemically inert at ordinary temperatures and thermally stable up to 1,022° F. At higher temperatures, it decomposes, forming with oxygen, hydrochloric and hydrofluoric acids, carbon dioxide, and phosgene. The last mentioned is dangerous when even 25 p.p.m. are mixed with air (*33*).

Cold-Storage Rooms

Cold-storage rooms for apples and pears, today, generally are designed with unit coolers located overhead in the truss space near the center of the building. In small rooms unit coolers can be installed overhead along the wall on one side of the room.

In old storage plants for apples and pears where ceilings were low, cooling was accomplished by (1) placing refrigeration pipes on the ceilings and (2) circulating cold air through the rooms. The first method is the direct-expansion system, though sometimes cold brine was pumped through the pipes from a brine cooler. The second method was the brine spray which flowed over a bank of cooling coils.

Fruit will keep equally well under any of these systems, providing they are installed so that cooling will be equally fast and temperatures kept uniform, with atmospheric humidity at about 85 percent.

The popularity of the unit-cooler system is its economy and ease of installation. Another feature is that it can be installed overhead in the truss space, saving storage space.

In today's storage rooms the use of pallet boxes to store fruit and forklift trucks for handling the pallet boxes has necessitated increasing the overall height of these rooms.

For a complete discussion and presentation on cold storages, see "Apple Packing and Storage Houses—Layout and Design" (*14*).

Direct-Expansion System

In direct-expansion rooms, that is, where cold ammonia is circulated in exposed pipes near the ceiling, the air in contact with the coils becomes cold and, being denser than warm air, moves downward. As it picks up heat from the fruit, it rises to the pipes to be again cooled. This gravity circulation, caused by differences in air temperatures, results in heat movement by convection. Air velocities in such currents are relatively low, but take place in all parts of the room if the pipes are well distributed over the ceiling and produce fairly fast cooling. To dispose of the accumulated frost or condensed water, the pipes are usually put in groups or banks and gutters are hung under them to catch any drip.

In rooms where large areas of the ceiling are without coils, direct expansion alone cannot cool the fruit very promptly and the temperature in various parts of the room may differ markedly, even after the fruit has cooled to its final temperature. In these rooms, use of either portable or permanently installed fans operating in the room to stimulate air movement will tend to make the temperatures more uniform. Fans installed to give a positive air movement will give even better results. Fans blowing directly over the cooling pipes are effective in reducing both condensation and the danger of localized freezing of the fruit.

Brine-Pipe System

To avoid all possibility of accidental leakage of ammonia from the cooling system into the storage rooms, the cooling pipes are sometimes designed for carrying cold brine. The brine is cooled in a separate brine cooler and circulated by pumps to the various rooms. Other advantages of this method are that temperature control is simpler than in a direct-expansion system and a reserve of refrigeration is available in the cold brine to carryover short periods of shutdown. This system, however, is more costly than direct expansion, and for this reason it is not commonly used in fruit districts. In comparison with an air-circulation system, brine pipes otherwise have the same advantages and disadvantages as a direct-expansion system. A brine of calcium chloride instead of common salt (sodium chloride) may be used for this type of installation. Data on the density and freezing points of sodium chloride and calcium chloride brines are given in table 7.

Dry-Coil Bunker System

In the dry-coil bunker system of cooling, the ammonia coils are put in a separate room or bunker and air from a large blower is passed over them, then distributed through ducts into the storage room. If large quantities of air are used, prompt cooling and even temperatures may be obtained. The problem of accumulation of frost on the pipes remains, although disposal of the water and frost without damage to the fruit is simpler than under direct expansion. In some installations the pipes are defrosted periodically by spraying with brine or warm unsalted water. The blower is stopped while the defrosting is taking place. In other plants defrosting is done by pumping hot ammonia into

TABLE 7.—*Data on sodium chloride (NaCl) and calcium chloride (CaCl) brines* [1]

Specific gravity	Per 100 pounds of brine		Freezing point		Density per gallon	
	NaCl [2]	CaCl	NaCl	CaCl	NaCl	CaCl
	Pounds	*Pounds*	*° F.*	*° F.*	*Pounds*	*Pounds*
1.00	0	0	32.0	32.0	8.33	8.33
1.02	2.8	---	29.1	----	8.50	----
1.04	5.5	4.7	26.0	29.3	8.67	8.67
1.06	8.2	---	22.7	----	8.84	----
1.08	10.9	9.2	19.0	23.2	9.00	9.01
1.10	13.5	---	14.9	----	9.17	----
1.12	16.1	13.5	10.4	16.5	9.34	9.35
1.14	18.6	---	5.4	----	9.50	----
1.16	21.1	17.6	–.3	7.0	9.67	9.68
1.18	23.5	---	–3.6	----	9.84	----
1.20	---	21.5	---	–5.8	---	10.01
1.24	---	25.1	---	–21.5	---	10.35
1.28	---	28.7	---	–44.3	---	10.68

[1] From 1966 and 1967 Guide and Data Books (*1*).

[2] Common salt.

the coils. Dry-coil bunkers have been replaced with brine-spray systems in more recent installations.

Brine-Spray System

In the brine-spray system of cooling, air from a large blower is moved over banks of ammonia coils that are continually being sprayed with a solution of salt in water. Sodium chloride (common salt) is generally used in these systems. The salt prevents accumulation of frost, and the fine spray, being in intimate contact with the air, cools it effectively. A far smaller bank of pipes can be used than in a dry bunker, and cooling can be done with a higher ammonia temperature. After cooling, the air is distributed to the storage rooms. When a continuous brine spray is used, baffles, or eliminators, are needed in the air stream to prevent particles of brine from being carried in the air into the storage rooms. Treating the brine with chemicals, as recommended by equipment manufacturers, is necessary to reduce its tendency to become unduly corrosive. Because eliminators increase the resistance to airflow, and brine tends to cause corrosion, the overhead unit cooler system has replaced brine-spray chambers.

Unit-Cooler System

A modification of the brine-spray or the dry-coil bunker is the unit cooler. This type of cooler contains extended surface coils and blowers for moving the air through the coils and discharging it into the room (figs. 5 and 6). Some of these coolers are defrosted by washing the coils periodically with fresh water to remove the frost. Warm water from the condenser is generally used for this purpose. Some coolers have a hot-gas defrost, while others are defrosted by heating the units with an electrical element.

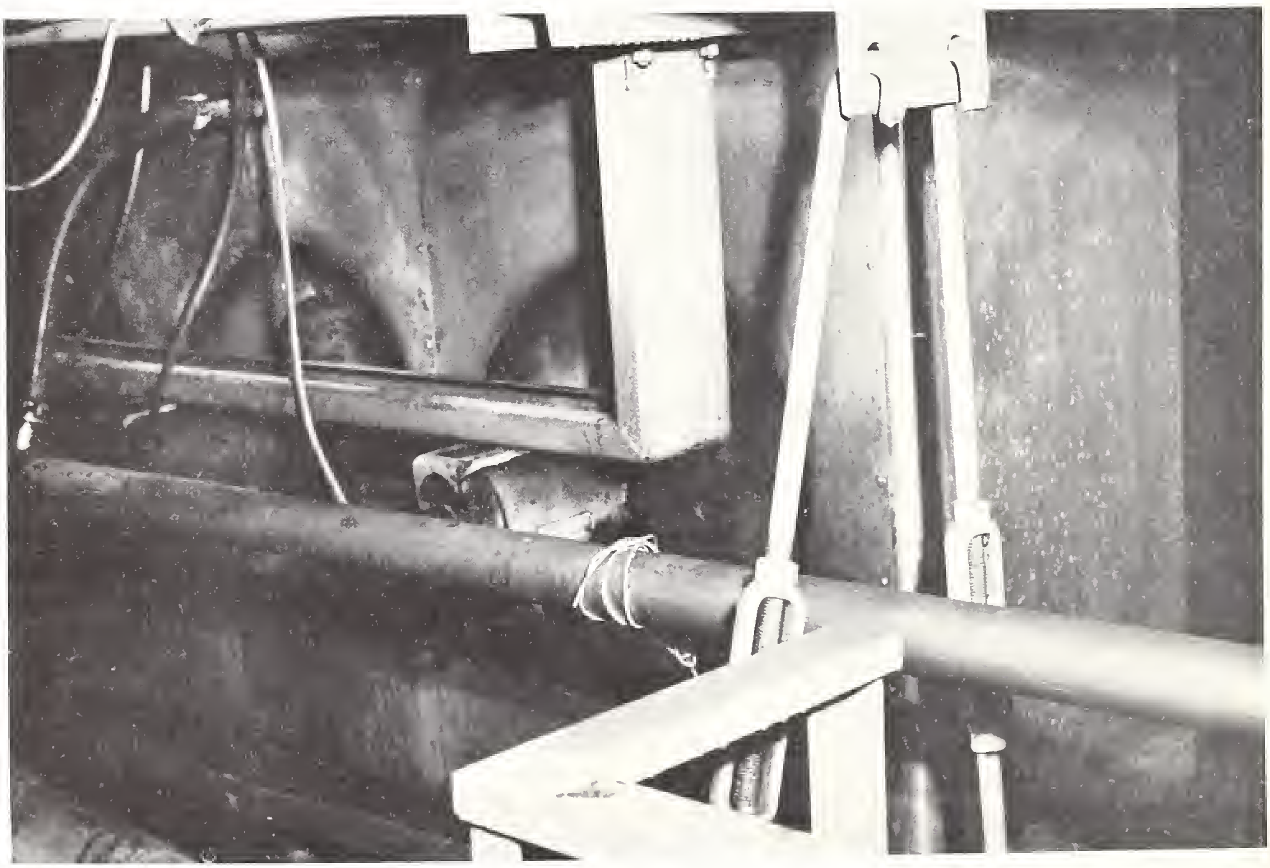

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FIGURE 5.—Rear view of a three-fan unit cooler.

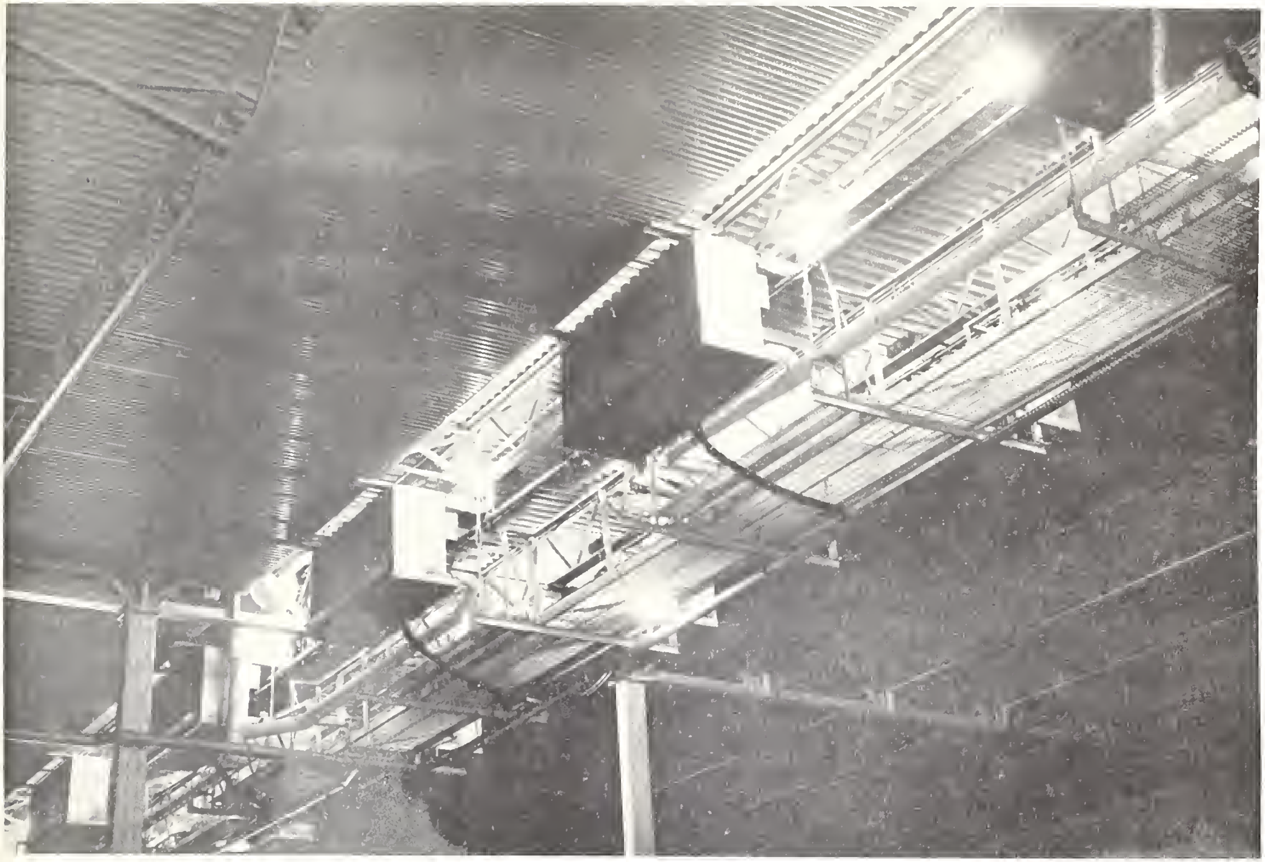

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FIGURE 6.—Looking up at unit coolers, pipes, and catwalk located overhead in the center of a cold-storage room.

These units usually discharge air horizontally by the use of one or more fans forcing the air through the coils. The cold air flows over the top of the stacks of fruit then down through the rows and back to the unit cooler to be recirculated.

Defrosting is intermittent, but should be done as often as necessary to keep the coils fairly free from frost. A thin layer of frost not only interferes with heat transfer just as on other types of coils but also reduces the quantity of air circulated because of the close spacing of the cooling surface.

Atmospheric Moisture

The humidity, or moisture content, of the atmosphere in a storage room depends largely upon the temperature to which the air is cooled in contact with the pipes or the brine.

If doors to the storage room are left open in warm weather, the warm air entering the storage may be a source of moisture but the frost on the pipes or the overflow in the brine tank is largely from water vapor transpired by the fruit. This transpiration should be kept at a minimum by maintaining a relative humidity of approximately 85 percent. Maintaining this relative humidity may be done by limiting the quantity of water picked up on the coils or in the spray. Some moisture in the form of gas or vapor is contained in the atmosphere. The lower the temperature, the less the quantity of vapor that can be held. As the temperature of the air drops, a point is finally reached at which some of the water can no longer exist as vapor and it condenses to form water or frost. The greater the temperature drop, the greater the consequent condensation.

Therefore, operating the cooling system without reducing the air temperature lower than necessary is essential. In an air-circulation system, this is done by using large quantities of air and plenty of cooling surface. If too little air is used, its temperature must be reduced greatly and, as a result, excessive condensation will occur. If there is not enough coil surface in a direct-expansion system, the pipes will have to be extremely cold and the air coming in contact with them will lose a large part of its moisture. Contrary to common belief, a brine spray, when used for cooling, does not add humidity to the air but tends to pick up moisture. For this reason some of the brine must be drained off occasionally and more salt added. If a brine-spray system resulted in higher humidity than a direct-expansion or dry-coil bunker system, it had removed less moisture than the others. The reason for this is that the cooling surfaces with which the air comes in contact are not as cold as when brine coils are used.

In well-designed and well-filled cold-storage plants, maintaining desirable conditions of atmospheric humidity during the greater part of the storage season is not difficult. If the relative humidity cannot be maintained above 80 percent by steps directed toward running the compressor with higher back pressures, then a humidifying apparatus should be installed even though it throws moisture into the atmosphere only to be taken out on the evaporating coils. The humidifier is constructed on two principles: One is that of an atomizer; the other is that of vaporization of water by heating. The use of the last-mentioned principle avoids the danger of freezing where air temperatures are below 32° F.

Circulation of Air

In all plants the temperature usually varies in different parts of the room. This variation, however, should be kept at a minimum. The equalization of temperature in all parts of the room depends almost entirely on circulation of air, either by gravity or by forced draft. Gravity cannot be depended upon for adequate circulation unless the whole ceiling area is flooded with cold air or is provided with cooling coils.

As the air circulates in a storage room, it picks up heat which raises its temperature. If the air is not picking up heat, it is not doing any good. The air returning to the brine spray or unit coolers is therefore warmer than that leaving. The difference in temperature between delivery and return is often referred to as the "split," and this is directly related to the volume of air circulated and the quantity of heat picked up in the room. If the split is too large, the only way to reduce it without cutting down the heat picked up is to increase the volume of air circulated.

For each ton of refrigeration used, an air volume of 1,000 c.f.m. results in a split of about 10° F., which becomes less as the water transpired by the fruit condenses on the coils. This relation applies to any combination of refrigeration used, to the volume of air, and to the resulting split. For example, if 1,000 c.f.m. of air is used in picking up the heat equivalent to 2 tons of refrigeration, the split will be about 20°; or if 2,000 c.f.m. gives a split of 5°, about 1 ton of refrigeration is being supplied.

Usually, air-circulation systems are designed so as to provide for about 1,000 c.f.m. per ton of refrigeration capacity. For example, a 25-ton plant would circulate about 25,000 c.f.m. This volume gives a split of about 10° when the machinery is working at full capacity. After the fruit has been cooled and some of the compressors are shut off or slowed down, the same volume of air will result in a lower split. When the refrigeration load is down to 5 tons and 25,000 c.f.m. is still used, a split of about 2° will result. Here, a variation of at least 2° may be expected in fruit temperature in different parts of the room. With less air volume, the variation will be greater.

Thermocouples

In large plants certain parts of the cold-storage rooms are often inaccessible and temperatures cannot be taken with ordinary thermometers. Here, thermocouple equipment is useful. The wires of this instrument may be strung from the center of piles where actual fruit temperatures are desired and readings made in aisles or in the compressor room. Thermocouple equipment suitable for cold-storage use is illustrated in (fig. 7). The core

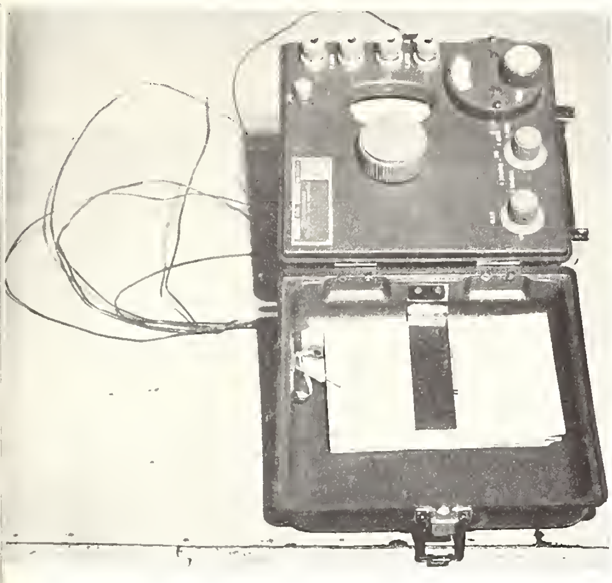

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FIGURE 7.—Thermocouple equipment for reading fruit temperatures at remote parts of cold-storage rooms. The wires may be installed for reading temperatures at a central point or the reading instrument may be carried from room to room. Caution should be used as some instruments do not read accurately when the ambient temperature is less than 45° F.

temperatures of the fruit may be read at any time during the storage season. When warm spots are located, more air can be directed into them to cool the fruit.

A thermocouple consists of two dissimilar metalic wires fused or joined together at one end. This junction is sensitive to temperature changes and generates a very small voltage which varies as the temperature changes. The voltage can be read with a small instrument (known as a potentiometer), and the temperature at any particular point determined. See appendix on how to construct a thermocouple.

Required Capacity of Refrigeration System

The storage season may be divided into two distinct periods. The first is during the harvest, when warm fruit is being put into the plant. The principal problem at this time is cooling the fruit, or removing the field heat. The second period is the holding period, when the main problem is maintaining low temperatures as uniformly as possible. The heat load during this second period is relatively low, consisting of the respiration heat generated by the fruit, the heat entering through the walls, and heat from workmen, power equipment, lights, air entering from outside, and other incidental sources.

With use of pallet boxes for handling apples and pears into the cold-storage room, additional cooling requirement was placed on existing refrigeration equipment because of the speed with which the fruit could be brought into the storage rooms.

Capacity of the cold-storage room was increased about 20 percent when pallet boxes were used instead of pallet loads of the standard wooden boxes (*13*).

Nature of Heat

A discussion of the heat from various sources that has to be removed by a refrigeration system is more or less technical and includes terms that may not be familiar to all readers. The discussion is not difficult to follow, however, if one keeps in mind that heat is just as real as air or water. It can be moved from one place to another, but it cannot vanish completely. If heat is taken from one place, the same quantity must show up somewhere else. For this reason we can think of units of heat as quantities that have a definite meaning, just as we think of gallons of water. The important thing to remember is that a British thermal unit is a definite quantity of heat that can be pushed around or divided up, but it still exists somewhere.

The capacity of the cooling system required for a given job depends upon how much heat must be removed each day. In apple and pear storage this heat comes from several sources, each of which can be considered separately. The total load is the sum of the heat from all sources.

Field Heat

When fruit is placed in storage, its temperature is ordinarily higher than that desired. The heat to be removed in cooling it to the storage temperature is called field heat. About 0.9 B.t.u. is needed to change the temperature of 1 pound of apples by 1° F.[5] If the temperature must be

[5] This quantity of heat is known as specific heat (sp. ht.) for apples.

reduced from 65° to 32°, for example, the change is 33°, and for every pound of apples 29.7 (0.9 × 33) B.t.u. must be removed. On the assumption that a box of apples weighs 50 pounds, every box cooled from 65° to 32° requires the removal of 1,485 (29.7 × 50) B.t.u. If 1,000 boxes are stored under these conditions, 1,485,000 B.t.u. of field heat are introduced in the storage room. If the fruit is cooler or warmer, the heat load will be correspondingly lesser or greater.

Heat of Respiration

Fruit continues to live as long as it is fit for food. It is therefore continually generating heat by breaking down some of its constituent materials. Bartlett pears or peaches starting at 60° F. in a nonrefrigerated, well-ventilated room probably would reach a temperature of 85° to 90° after 4 days and might go even higher. Kieffer pears and grapes produce heat more slowly and probably would not warm up to above 65° or 70° under the same conditions. Storage varieties of apples would very likely be intermediate between these two groups. One can easily see that if Bartlett pears or peaches were not refrigerated they might become worthless within a week, even if they did not suffer from decay.

The rate at which this heat is generated depends upon the fruit temperature. At 32° F. a box of apples gives off about 20 B.t.u. each day. At 60° the figure is seven or eight times as great. Prompt cooling therefore reduces the total quantity of heat to be removed from a storage room. If a packed box of apples is cooled from 65° to 35° in 1 week, its heat of respiration during this period is estimated to amount to about 500 B.t.u.; for 1,000 boxes the heat load would be 500,000 B.t.u., which is about a third as much as the field heat load. If cooling is so slow that 2 weeks are required to reach 35°, another 500,000 B.t.u. will have been generated. Even after apples are cooled to 32°, they continue to give off heat. Each 1,000 boxes generates about 20,000 B.t.u. per day at this temperature. Thus, 1 ton of refrigeration (removal of 288,000 B.t.u. per day) will handle the heat from about 14,000 or 15,000 boxes after they are cooled. The approximate refrigeration required for cooling and storing apples if 1,000 boxes are received daily and the fruit is cooled to 32° in 7 days follows:

Initial temperature (° F.)	*Tons of refrigeration* [1]
55	4.9
65	6.9
75	8.8
85	10.8

[1] Allowance for open doors, workmen, motors, and other incidental sources of heat may increase this requirement by 15 to 20 percent.

Incidental Heat Sources

In addition to the fruit itself, other sources of heat are from workmen, motors, boxes or pallet boxes, and lights. Each workman is assumed to give off 1,000 B.t.u. per hour. The heat from motors can be estimated at 3,000 B.t.u. per hour for each horsepower. Each 100-watt light burning adds about 350 B.t.u. per hour.

Air Infiltration

There are always times when outside doors or conveyor ports must be left open, and in some rooms the doors are open almost continuously during the harvest season. Outside air entering the coldroom may carry in large quantities of heat. Under ordinary conditions, estimating very accurately the heat load thus added by infiltration of air is impossible.

If we assume that a draft having a velocity of 200 feet per minute (f.p.m.) is leaving a coldroom at 35° F. through the lower half of a doorway 4 feet wide and 7 feet high and an equal current of dry warm air at 65° is entering the upper half, the quantity of heat entering the room can be estimated; 200 f.p.m. is about 2¼ miles per hour and is not a very noticeable velocity. Under these conditions, however, 100,000 B.t.u. per hour would enter through the open door. If the air were not very dry, the quantity would be even greater and would keep an 8-ton machine busy just to remove this heat.

At best, open doors permit a large entrance of heat, or loss of refrigeration, and prevent holding low temperatures in the room. Where forklift trucks are used and full-sized doors are left open, the use of light-swinging doors that close after each truck has passed or air-curtain doors (*21*) will reduce the loss of refrigeration.

Air Doors

Since the publication on air doors was released in 1961 (*21*), air doors are used almost exclusively in cold storages for fruits.

Several types are available, but the two mainly used are the vertical airflow curtain nonreturn type and the horizontal airflow recirculating type. Air doors prevent warm air from filtering into the cold-storage rooms when the main doors are open, thus saving refrigeration for cooling the fruit.

Air doors are only partly effective in reducing this air infiltration, but a well-constructed air curtain should be from 75 to 90 percent effective against the air interchange.

Heat Passing Through Insulation

Even when there is no infiltration of air through doors, windows, or cracks, heat still enters through the walls, floor, and roof when the outside surfaces are warmer than the inside. The quantity of heat entering through the walls may be reduced by insulation, which slows the passage of heat by resisting its flow. The resistance depends upon the character of the insulating material and its thickness. A comparison of the effectiveness of various insulating materials can be made by showing thicknesses that will pass equal quantities of heat under similar conditions.

In many apple and pear cold storages, insulation equivalent to 4 inches of cork is used for insulating the walls. The thickness of various other materials used to insulate the walls should have a heat-flow resistance equal to 4 inches of cork. When more than one material appears in the cross section of a wall, the total insulating value of the wall is the sum of the values for each of the parts.

Frequently in constructing storages, air spaces are provided between the various sections of the wall. These spaces tend to hinder the flow of heat. Unless reflecting surfaces are used to line the spaces, however, it would take three to four spaces each at least $\frac{3}{4}$ inch thick to be equivalent to a 1-inch thickness of shavings. The structural materials in a wall act as insulation, but usually some are not of much value in retarding the heat flow. A 12-inch concrete wall, for example, adds about as much insulation as $\frac{3}{10}$ inch of cork. One thickness of $\frac{25}{32}$-inch fir board is almost equivalent to $\frac{1}{2}$ inch of cork, provided the cracks are closed tight.

The quantity of heat passing through a wall with 4 inches of cork depends upon the temperature difference between the two sides. When the temperature is 65° F. outside and 32° inside, each 1,000 square feet of such a wall may be expected to permit the passage of about 48,000 B.t.u. per day. That is, 6,000 square feet of such a wall will permit the loss of about 1 ton of refrigeration per day. Approximately the same quantity would be passed by equal areas of the various materials if their total resistance were equal to 4 inches of cork. For walls twice as thick, the heat flow would be only half as great; for a wall only one-third as thick, three times as much heat would pass through.

In fill insulation, such as shavings, sawdust, and redwood-bark fiber, and rockwool blown in, the resistance is influenced by the density of packing. In vertical walls, especially, such material must be packed tight otherwise settling will occur and leave spaces unfilled after the wall is closed. In these comparisons of various materials, all the materials are assumed dry.

Moisture in any of these materials reduces their effectiveness and will cause some to rot. All should be installed so as not to accumulate moisture. Moisture condenses on surfaces cooler than the air but not on those that are warmer. The insulation material in a wall or roof is usually colder than the outside air. The insulation should be protected, therefore, against the outside air by applying a barrier on the outside of the wall insulation against water vapor. Some barriers used are asphalt, vaporproof paper, polyethylene film, or aluminum foil. A barrier is not necessary on the inside, since a wall seldom picks up moisture from the inner, or cold, side. In fact, any moisture that may be present in the insulating material tends to leave the wall and condense on the cooling coils inside the room. For this reason, a vapor barrier on the inside of an insulated wall may do more harm than good.

Floors

Many apple storages do not have insulation in the floors. For the first few days of operation, the heat transfer through the floor will be excessive. Storages without insulated floors should have the refrigeration operating for about a week or 10 days before loading starts; whereas, a storage with insulated floors can start receiving fruit after the refrigeration has operated for 3 days. The annual cost figures show that where ground water level is at least 11 to 12 feet below the floor, satisfactory performance may be expected at a lower cost than if insulation is used. In these storages, a breaker strip will pay for itself.

Tests of uninsulated floors have shown that a heat leakage rate of 1.0 to 1.68 B.t.u. per hour per square foot in the uncovered areas existed when the water table was below 11 feet and the storages had been operating for several months. When the storages are first started up in the fall, the heat leakage rate may be as high as 20 to 25 B.t.u. per hour per square foot (*26*).

Where refrigeration is supplied to maintain low air temperatures in the upper part of the room, the temperature of the fruit resting on concrete floor will be kept somewhat above optimum because of conduction from the ground through the concrete. It is as desirable to provide a space beneath the fruit as between the fruit and the outside walls. For this reason the fruit stacks should rest on floor racks or pallets to permit the cold air to circulate beneath them.

Calculating Refrigeration Requirements

In calculating the refrigeration requirements of a cold-storage plant, all sources of heat have to be considered. A typical example follows.

Desired to refrigerate 35,000 boxes of apples, to be picked and received over a period of 10 days. The fruit to be cooled from 65° to 32° F. in not more than 7 days. The storage to have a receiving capacity of 4,000 loose boxes or 153 pallet boxes per day. Average outside wall temperature is 65° F., the ground temperature 55°, and the roof temperature 75°. The storage room size is 60 x 80 feet and a ceiling height of 18 feet for a volume of 86,400 cubic feet. Walls and ceiling to be insulated sufficiently so that the heat loss will not exceed ⅔ of 3 B.t.u./hr./sq. ft. or 2 B.t.u./hr./sq. ft. Floor heat loss not to exceed 2 B.t.u./hr./sq. ft. (*26*).

Field heat (apples and pallet boxes)

Apples:	33° F. (reduction) × 0.9 specific heat (sp. ht.)	= 29.7 B.t.u./lb.
	29.7 × 40 (box wt.) × 4,000 boxes per day	= 4,752,000 B.t.u./day
Pallet boxes:	Specific heat (sp. ht.) wood is 0.50 B.t.u.	
	153 pallet boxes per day × 140 (box wt.) × 0.50 (sp. ht. of wood) × 33° F. (reduction)	= 353,430 B.t.u./day
	Total	= 5,105,430 B.t.u./day

Heat of respiration

Apples:	While cooling from 65° to 32° F. in 7 days, the apples will generate 21,000 B.t.u. per ton. 4,000 boxes daily = 80 tons of apples 80 × 21,000	= 1,680,000 B.t.u./day

Building heat loss

Floor:	4,800 sq. ft. × 0.087 × 24 × 23°	= 230,515 B.t.u./day
Walls:	5,040 sq. ft. × 0.060 × 24 × 33°	= 239,500 B.t.u./day
Roof:	5,200 sq. ft. × 0.0465 × 24 × 33°	= 191,505 B.t.u./day
	Total	= 661,520 B.t.u./day

Incidental heat

Fans: 4 hp. × 3,000 × 24	=	288,000 B.t.u./day
Infiltration, workmen, etc: 288,000 B.t.u. per 1,000 boxes received/day × 4	=	1,152,000 B.t.u./day
Forklifts: 35,000 B.t.u./hr. × 8 hr. × 2	=	560,000 B.t.u./day
Total	=	2,000,000 B.t.u./day

Summary	*B.t.u/day*	*Percent*
Field heat	5,105,430	54.0
Heat of respiration	1,680,000	17.8
Building heat loss	661,520	7.0
Incidental heat	2,000,000	21.2
Total	9,446,950	100.0

Refrigeration required $= \frac{9{,}446{,}950 \text{ B.t.u./day}}{288{,}000} = 32.8$ tons

Estimate: 35 tons required

The greatest demands for refrigeration come from field heat and heat of respiration, which are directly related to the volume of fruit being received and cooled each day during the peak of the harvesting season. To cool this fruit promptly for late keeping, it is essential to have this reserve of refrigeration for a comparatively short time. After the receiving season, when the fruit has been cooled to 32° F., the heat of respiration from 35,000 boxes of apples would require only 2.5 tons of refrigeration, and this added to building-heat leakage and heat of motors for fan and forklift trucks would demand only 7.7 tons of refrigeration. As the weather becomes cooler, the building-heat loss is reduced, resulting in still smaller refrigeration demands. In climates where day temperatures range from 55° to 75° during the harvest season, the refrigeration requirements may be roughly estimated at 8 tons for each 1,000 bushels (packed boxes) received into storage daily, in addition to refrigeration needed for building-heat loss and heat from motors. If the quantity of fruit is measured in field boxes, the requirement per 1,000 is about 6.5 tons, instead of 8, since the field boxes contain about 15 pounds less fruit than packed boxes.

COLD-STORAGE DESIGN

In planning a cold-storage plant, efficient refrigeration of the fruit should be considered first, followed by an efficient and economical method of handling the fruit. These requirements do not always permit the lowest cost in construction and operation. An insulated building in the form of a cube—dimensions equal for length, width, and height—represents the minimum requirements for materials in walls and the least outside exposure for heat transfer. Buildings of different dimensions, however, usually are necessary for the practical considerations of receiving, shipping, segregating, and stacking the fruit and for the efficient use of labor. Layout and design will be influenced also by other factors, such as precooling requirements. For a complete study of building layout and design, see reference (*14*).

Precooling

Precooling is usually spoken of as a special process for the rapid removal of heat from a commodity before transportation. The term is used also in some fruit districts to denote rapid heat removal preliminary to stacking in storage or even as a cooling before packing. The principles of rapid heat removal are the same regardless of later disposal of the fruit.

Probably the most effective present method of precooling is to stack the fruit in rooms in which a large volume of cold air is circulated. In large plants more than one coldroom is desirable, so that temperatures in one part of the storage in which fruit is being held at optimum storage temperatures may not be influenced by the temperatures being used in the precooling rooms.

For efficient precooling, the rooms should be so designed that the cold air will have a positive flow between the stacked containers. The more rapid the circulation and the colder the air, the faster the heat will be removed from the contents of each container. For these reasons the circulation system should be planned for the free movement of air in large volume through the fruit stacks, rather than having it dispersed about the room from circuitous ducts and from small duct openings that tend to greatly restrict the air flow and to prevent it from having the fullest sweep over the surface of the containers.

Capacity and Height of Rooms

Although many small rooms are advantageous for precooling, large rooms may be used to good advantage for the storage period. Usually, cooperatives and large shippers have their storage space divided into at least four rooms for flexibility and expediency of operation. For instance, for apple and pear storage one room may be held at 36° F. for apples susceptible to soft scald or for fruit intended for early markets, and one room may be held at a constant temperature of 30° to 32° for the long storage of both fruits. The other two rooms, then, can be used for rapid cooling or for storage at different times in the season.

Storage rooms are generally one story to facilitate lift truck handling of fruit. The trusses and walls should be high enough to allow stacking pallet boxes eight high. A clearance of 21 feet under the trusses allows ample room for stacking. In the larger storages more height is required as pallet boxes are occasionally stacked 10 to 11 high.

The doors are usually 8 feet wide by 10 feet high to accommodate lift trucks.

To prevent excessive loss of cold air from the rooms, air-curtain doors are provided. These doors operate automatically when the main refrigeration doors are left open. For a discussion of air-curtain doors, see reference (*21*).

Layout of Rooms

The plant should be so laid out that facilities can be expanded if needed. The position and shape of the rooms for receiving and shipping should be carefully designed so as to avoid congestion. Where a packing plant is constructed in conjunction with the cold storage, its position must be such that loose fruit can be brought to it direct either from the orchard or from storage rooms. The packing room should not occupy space that otherwise could be used for cold storage nor obstruct fruit deliveries to the cold-storage plant.

Since the compressor room is a source of heat, placing it at one side of the cold-storage building (*14*) eliminates the cause of a warm spot. This location also makes machinery more accessible if it has to be replaced and lessens the risk of loss of machinery if a fire should occur, or of damage to the fruit if ammonia leaks occur in the compressor room.

Fans and Ducts

The efficiency of a refrigeration system depends to a great extent on the effective movement of heat from the fruit to the evaporation coils. The fans should move the greatest possible volume of air at the smallest possible cost of power. Two reasons for keeping the fan-power requirements at a minimum are that (1) the fans operate over a long period in the year, so that any reduction in the cost of power to drive them is an important item and (2) the power used on the fans add heat to the circulated air, thus adding to the refrigeration load and reducing the useful capacity of the refrigerating machinery. Each horsepower used on the fan puts a load of 0.2 to 0.3 hp. on the compressor motor.

Having a fan of lower capacity than necessary to circulate the required volume of air is false economy, whereas true economy is having fans and ducts so designed as to move the required volume of air with the least possible power. Many plants are handicapped by having a fan too small or ducts with too much air resistance which increases the power required. For this reason installing an efficient fan having the required capacity at a moderate speed pays off. Where one fan is used, the fan motor should have more than one pulley, so that the speed of the fan may be reduced after the fruit has been cooled, provided the split between the delivered and returned air can be kept down to 1.5° F. at the slower speed.

Fans are rated at free delivery and at a definite static head pressure. To avoid overloading fan motors, the fan load at the speed it will run should be thoroughly investigated. If the speed of a fan is doubled, the quantity of air that it will deliver will also be doubled. The static pressure at which the fan will operate will be four times as great. But the horsepower required to drive the fan will be eight times as great.

If we let hp. = horsepower, N = speed, Q = volume of air, and P_s = static pressure then we have the following equations:

$$\frac{Q_2}{Q_1} = \frac{N_2}{N_1} \qquad (1)$$

$$\frac{\text{Fan } P_{s_2}}{\text{Fan } P_{s_1}} = \frac{N_2}{N_1} \qquad (2)$$

$$\frac{hp_2}{hp_1} = \left(\frac{N_2}{N_1}\right)^3 \qquad (3)$$

Increasing the speed of a fan to get more air circulation is at the cost of more power for every cubic foot of air circulated. For best efficiency, fans should be run at their rated load and speed.

Resistance in Air Ducts

The design of air ducts has an important bearing on the volume of air that can be circulated by a blower, the volume circulated becoming less as the resistance in the ducts increases. The resistance to airflow is greatest in parts where the velocity is high and where the air changes velocity or direction. Air ducts are little used in present day cold storages except in reversed airflow systems and in some older installations. Therefore, ducts will be discussed from this point of view.

Air flows like water, and abrupt changes induce turbulence and eddies that increase the resistance. Abrupt changes in the area of ducts and unrounded turns should be avoided. Even in rounded turns the flow of air is accelerated by curved splitters (figs. 8 and 9) that aid the air in making the turn with a more equal velocity over the entire face of the duct. Thus, dividing the air stream at turns prevents piling up pressure against the outside face of the turn and reduces turbulence.

The inside of the ducts should be free of obstructions and as smooth as possible. Large ducts are preferable, because they permit delivery of the required volume of air without excessive velocities. Ducts that are too small in cross section or cause abrupt turns in the air streams build up a resistance that results in high power consumption and inefficient circulation.

Unless the air passes through the body of the stacked fruit, the maximum quantity of heat is not being removed.

Spacing Air Ducts

The distance between the delivery and the return openings is dependent upon several conditions. The temperature of the air leaving a storage room is necessarily warmer than that entering it from the delivery ducts, although this temperature difference should be small. The larger the volume of air circulated, the less this temperature difference will be. In fact, in a given room from which a certain quantity of heat is being removed, the temperature difference is determined almost entirely by the rate of air circulation, in cubic feet per minute or in air changes per hour.

The method of distributing the circulation has no direct effect on the temperature rise in the air unless it affects the volume circulated or the quantity of heat picked up. Since the temperature of the air leaving the room is dependent upon the volume circulated, the distribution within the room or the relation between discharge and return openings can be adjusted to the requirements of the specific room, bearing in mind the necessity for having the warmest air in the room enter the return and the desirability of having relatively high velocities to keep the fruit temperature down as nearly as possible to that of the air.

The greater the distance of air travel between delivery and return openings the greater must be the velocity.[6] One advantage of higher velocities within a room is that locations that might have been high-temperature pockets are swept by moving air, and warm air that tends to accumulate in these pockets is carried away to the cooling coils. These higher velocities also take the field heat out of warm fruit faster than relatively still air.

When the distance between delivery and return is great, it is particularly important to leave an unobstructed space over the packages and under the ceiling at all points. Otherwise, the air will tend to move along the aisles or other open spaces instead of over the fruit, and the advantage of high velocities will be lost. As in shorter air travel, airflow should be equalized over the length of the ducts and directed for equal distribution throughout the stacks of fruit.

In the design of an air-distribution system for a storage room, a few points should be considered that, if the air volume is adequate, will determine how well a uniform temperature in all parts of the room can be maintained. The air should be both discharged into the room and taken from it at or near the ceiling. The discharge and return openings should be so located that the air is forced to move past all the stored fruit. Installations in which the air is discharged along a center aisle and returned at the floor at one end of the aisle usually do not provide for ample circulation along the sides of the room, and any point in the upper part of the room not directly supplied with cold air from the discharge openings is likely to remain too warm. Complicated duct systems with numerous laterals and small openings are to be avoided. They add to the initial expense, build up high resistance to airflow, and tend to result in local warm spots.

Reversing Directions of Airflow

Since it is impossible to avoid having the temperature of the air rise as it passes through the room, the fruit near the openings of return ducts is warmer than that near the openings of delivery ducts. If all duct openings can act alternately as deliveries and returns, the warmest fruit will not be so warm and the coldest not so cold. This can be done by reversing the direction of air circulation every few hours by a simple set of dampers and special duct arrangement near the fan (figs. 10 and 11). If the dampers are arranged to operate automatically, they require a minimum of attention (fig. 12). To take full advantage of air reversals, ample volume and good distribution are necessary. If such distribution and volume are provided, periodic reversal of the air will

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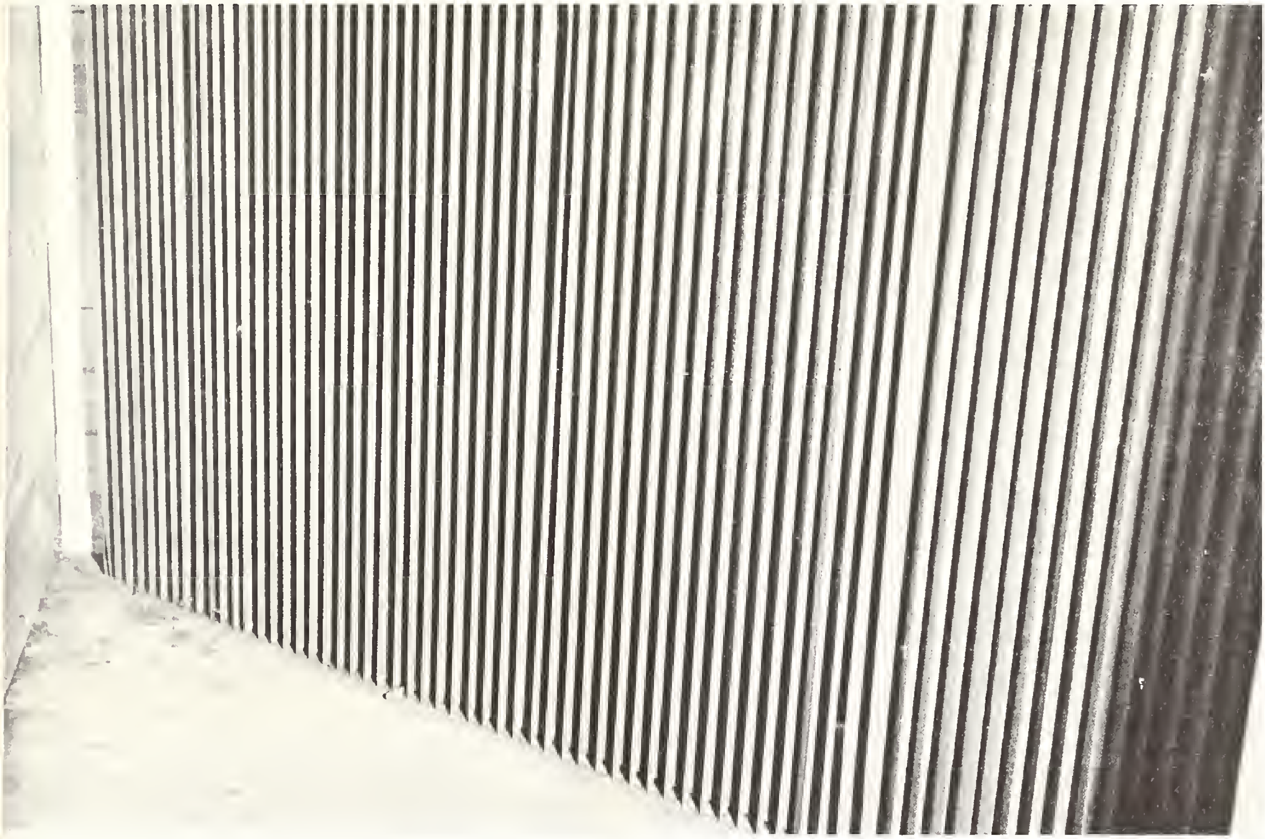
[6] Air velocity and air volume although sometimes considered different expressions of the same thing are not. In an extreme case, for example, a long, narrow room, about 10 × 100 feet, consider two arrangements of ducts—in one, the ducts are along the sidewalls, so that the air discharged is returned 10 feet away at the other side; in the other, the air is delivered at one end and picked up 100 feet away in a duct at the other. Now assume that a given volume of air is to be circulated through this room, which is 10 feet high and has a volume of 10,000 cu. ft. If 1,000 c.f.m. of air is to be circulated through this room and it moves from one side to the other, its average velocity will be 1 ft. p.m. If, on the other hand, it moves from one end to the other, the same volume will move through the room at 10 ft.p.m. In this example, the velocity in one case is 10 times as great as in the other, the volume of air being the same in both cases.

This is an extreme example of a situation in a storage room. The volume of air required depends upon the quantity of heat to be removed and the tolerable difference in temperature between delivery and exhaust air. It is uneconomical to deliver to a larger volume than these considerations require. The velocity at which the required volume of air moves through the room depends upon the length of the path it must traverse. Increasing the distance between delivery and return openings requires that the velocity for a given volume be correspondingly increased. For this reason, velocity and volume are not necessarily dependent upon each other. Volume can be adjusted to the heat load, and velocity can be controlled by the distance between openings.



PN–2378

FIGURE 8.—Curved vanes or splitters inside a rectangular duct.

result in a minimum difference in fruit temperature throughout the room. The method is particularly adapted to rooms in which air below the freezing point of the fruit is used for the rapid removal of heat in precooling. Reversing the air periodically lessens the danger of freezing the fruit near the discharge openings.

Air traveling along a delivery duct with plain openings along the side or bottom tends to move past the first openings, and the openings farthest from the fan tend to discharge more air than those nearest the fan. In a return duct the reverse is true; more air tends to enter the openings nearer the fan. These effects may be compensated by adjusting the size of the openings. In a delivery duct the openings nearest the fan may be made largest and those at the far end smallest. In a return duct, openings near the fan may be small and larger as the distance from the fan increases. If the same duct is to be used alternately for delivery and return, however, this gradation in size of openings will obviously not be satisfactory. When the duct is used for delivery, the desired

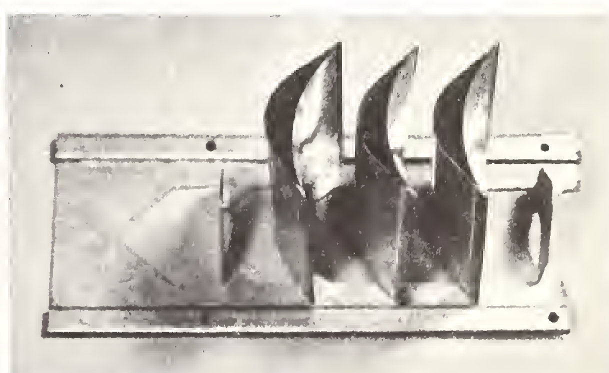


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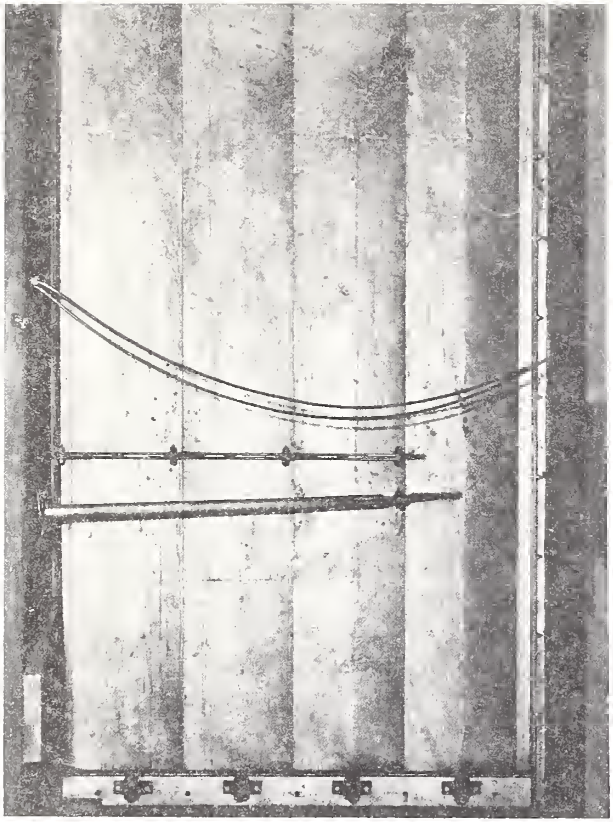
FIGURE 9.—Looking down on a small section of the splitters shown in figure 8.



PN-2380
FIGURE 10.—Closed reversing dampers in a large air duct.

equality of volume discharged at various openings may also be had by installing a deflector vane at each to turn the air outward through the opening. These deflectors, or scoops, are illustrated in figure 13, which is from a photograph of such a deflector inside a duct.

When the air direction is reversed periodically, the ducts should be laid out somewhat as illustrated in figure 14. The ducts are at the ceiling, one along each side of the room. The figure shows a pair of ducts, either one of which may be used as a delivery while the other acts as a return. The arrangement permits reversing the direction of air movement without throwing the quantity of air entering or leaving such openings out of balance. The openings and deflectors extend the full width of the duct and their size is progressively larger as the distance from the fan end of the duct increases. The reason for this is to provide uniform air volumes when the duct acts as a return. The scoops are adjusted to distribute the air uniformly when acting as a delivery. The size of openings and adjustment of the deflectors should be fixed for uniform distribution without provision for readjustment from time to time. Openings 10 to 25 feet apart are spaced equally along the duct. It is sometimes convenient to have one opening in each bay.

Attempts to regulate the temperature of a room by merely choking down the duct openings delivering cold air inevitably results in failure. There are two reasons for this, first, some fruit adjacent to the delivery ducts will be subjected to low temperature, and, second, choking down the volume of air necessary to remove the field heat, and later the storage heat of respiration, results in a wide range of temperatures in different parts of the room. To avoid these conditions, sufficient air needs to be recirculated to raise the temperature of the in-

PN-2381
FIGURE 11.—Open reversing dampers in a large air duct.

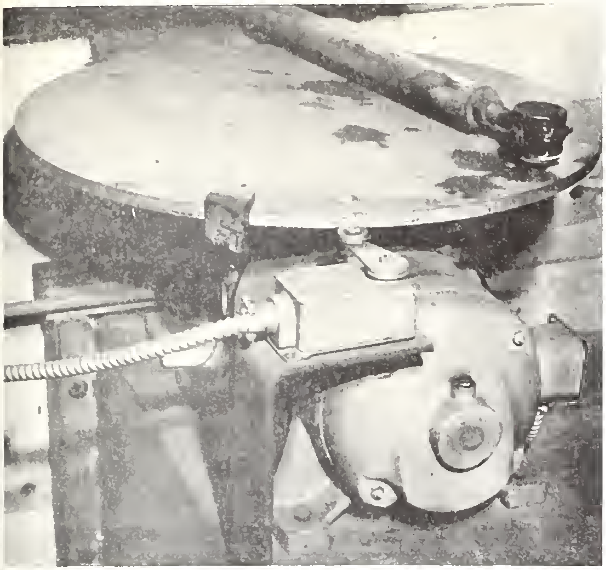


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FIGURE 12.—Automatic reversing mechanism for dampers shown in figures 10 and 11.

coming air and to provide adequate air movement through the stored fruit.

Where refrigerating one room at 30° F. and another at 36° from the same cooling unit is desirable, the 36° room must be provided with a damper in the main supply duct and a recirculating duct installed within the room with a small fan between delivery and return ducts. This arrangement will choke down the supply of air at 30° and mix it with the warmer air that is recirculated by the auxiliary duct and fan. Thus, the air is tempered to 36° before leaving the delivery duct and an adequate volume is circulated.

Planning for Economy

When a new plant is to be installed or additional equipment is considered, excessive costs should be avoided. At such times the first cost is frequently deciding what equipment to purchase. Usually when the cost of a proposed job is learned, it seems excessive and there is a tendency to look for items that can be eliminated or reduced. *It is not wise to cut down the first cost by unduly limiting the cooling surface, the condenser capacity, the sizes of fans or ducts, or the efficiency of the insulation.* Savings in these items will be small compared with reduced returns from overripe fruit or added power costs projected over many years of operation. When looking for possible economies in cold-storage construction, do not lose sight of the following essentials:

1. Sufficient refrigeration must be available to cool the fruit as fast as it comes in. For long-period storage this should be done in the shortest possible time. For each 1,000 boxes of apples received into storage daily at 65° F., approximately 8 tons of refrigeration are required.

2. The air movement must be sufficient to distribute the refrigeration efficiently. In blower-circulating systems, at least 1,500 cubic feet of air per minute is needed for each ton of refrigeration.

3. The return air must be taken from the room at the points of highest temperature. In general, these points are in the upper parts of the room.

Safety

All measures for the safety and health of workmen must be considered in cold-storage plants and safety guards used to cover exposed moving parts of machinery. All due precautions should be provided against fire hazards and accidents recognized by industrial safety rules, including well-lighted rooms, gas masks for ammonia fumes, and ammonia pressure releases that are exhausted outdoors. Employees should not be required to work in blasts of cold air for long periods without being adequately protected by proper clothing.

The engine room should have doors and windows opening to the outside so that, in an emergency, ventilation would be possible by opening or breaking them. The outside doors should be kept locked if there is any possibility of children or other persons entering and exposing themselves to danger from the machinery.

A high-pressure release valve should be installed in the refrigerating equipment and connection made to the outside with a vent pipe so that if the pressure release operates, the refrigerant will not be discharged within the building. A gas mask designed for the refrigerant in use should be hung just inside the

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FIGURE 13.—View of air deflector inside a rectangular duct, directing air out through a slot in the top of the duct.

outside door so that it can be reached without entering the engine room. To be effective, this mask must be kept in operating condition, and employees must be familiar with its use.

The fire-insurance inspector should be consulted and the recommendations for avoiding and fighting fire should be followed. The electric installation should be made in accordance with prevailing codes. If no legal code applies in the locality, the insurance inspector should be consulted about the appropriate provisions of the National Electric Code that should be followed in making the installation.

To avoid the possibility of persons being locked inside the storage room, one or more doors should be operable from inside the room.

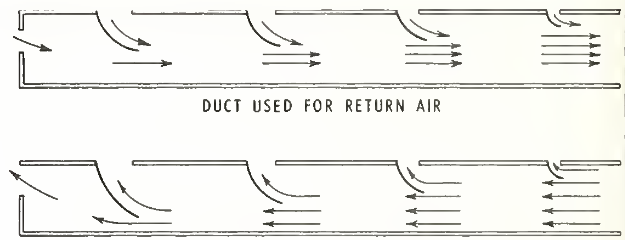

FIGURE 14.—Diagram of delivery and return ducts that may be used interchangeably with a reverse air system. Deflector vanes are used to equalize the quantity of air delivered from the varisized duct openings. As the distance from the fan room increases, these openings are made larger to equalize the flow of returning air. The number of openings is adjusted to the length of the duct.

COLD-STORAGE MANAGEMENT AND PLANT OPERATION

Many cold-storage plants are not utilized to best advantage, either because of shortsightedness in management or not operating at maximum efficiency. During the cooling period many plants take in fruit faster than their equipment can cool it. As a result the fruit is not cooled to the holding temperatures until ripening is well advanced. Several managerial steps can be taken to improve conditions. Compressors and auxiliary apparatus need to be in good shape. Condensers must be clean and all available condenser surface used. Evaporating coils should be kept as free as possible from frost and the blowers used should circulate the maximum volume of air. Good management includes such handling of the fruit as will utilize the plant to best advantage and such control over the operation of the plant and over the care of the equipment as will keep both at top operating efficiency.

Handling the Fruit

Reducing the Initial Fruit Temperature

The quantity of heat that must be removed from a package of fruit depends largely upon how warm it is when put into storage. If its average temperature can be reduced before storage, it will lessen the load imposed on the plant by each box. Fruit picked in the afternoon is ordinarily warmer than that picked in the morning. Picked fruit left in boxes under the tree is considerably cooler in the morning than at evening. In some districts fruit left under the trees overnight or picked in the morning may be at a temperature of 55° F. as against 80° late in the afternoon. To cool 1 ton of fruit from 55° to 32° requires removal of 41,400 B.t.u. of field heat, as compared with 86,400 B.t.u. for the warmer fruit. The cooling capacity of the cold storage would be more than doubled if the operator of the plant could have the cooler fruit delivered.

Leaving fruit out in the orchard to cool overnight frequently results in its cooling faster than it would in a cold-storage plant that is being crowded beyond its capacity. It also results in the fruit already in storage having a chance to cool faster and represents an exceptional situation where a few hours' delay in the orchard increases its storage life. These advantages warrant curtailing afternoon deliveries with such fruits as apples and pears and correspondingly increasing early morning deliveries, especially in plants with limited cooling capacity, even at the expense of some difficulty and inconvenience in handling and hauling.

Hydrocooling

Hydrocooling, or cooling by the use of cold water, has been used for many years for rapidly cooling perishable vegetables and some fruit, especially peaches grown in the Eastern and Southern States (*4*). It has not been used extensively for long-keeping fruits like apples and pears.

Tests results reported by Blanpied (*5*) showed a discernible difference for the first 3 months in lots of McIntosh apples that were hydrocooled or air cooled in 3 days and 1, 2, or 3 weeks. However, after 4 or 5 months in storage the hydrocooled, 3-day air cooled, and 7-day air cooled apples were about equal in quality.

Recent research by Schomer and Patchen (*28*) produced similar results for Golden Delicious and Red Delicious apples. For these varieties when hydocooled or air cooled in 3 and 7 days, their storage life and quality were essentially the same. However, when air cooled in 14 and 28 days, their quality was inferior and storage life shortened.

The same tests on Winesap apples did not indicate any quality change or length of storage life. The slow-cooling rate improved the quality for the test panel.

Segregation of Long-Storage Fruit

The Delicious variety causes the most serious storage problem in western apple districts because of its storage-temperature requirements, its large tonnage, and its relatively short harvest period. If the cooling capacity of the plant is sufficient to cool all these apples as fast as harvested, all the fruit should be cooled as quickly as possible. Since this is usually not possible, an attempt to cool all the fruit with equal promptness means that none of it is cooled quickly. In general, the longer a box of apples is to be held, the more important it is to cool it quickly. This is illustrated graphically in figure 15. Long-storage lots of fruit, then, should get more than an equal share of refrigeration at harvesttime and short-storage lots less. Those lots for long storage should be put into rooms where the receipts would be limited to a quantity that could be cooled rapidly. Fruit for shipment during the harvest season or shortly thereafter would be deliberately withheld from any of the cold-storage rooms to save the refrigeration for long-storage lots.

The procedure of segregating apples for long-, intermediate-, and short-storage periods places demands upon the management for more planning before harvest than a procedure whereby all the apples are treated alike. This planning should include selection of apples that are of optimum maturity and freest from in-

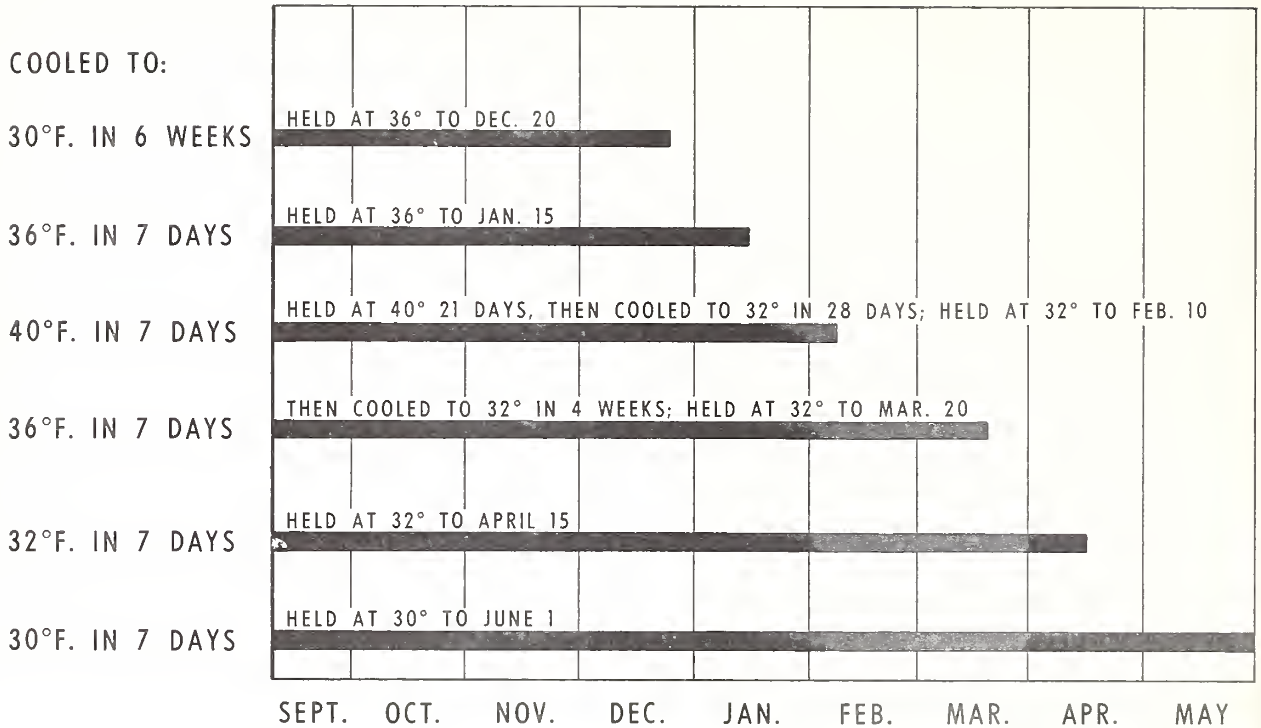

FIGURE 15.—Normal storage life expectancy of Delicious apples when cooled at different rates and stored at different temperatures. For each week of exposure at 70° F. before storage, deduct 9 weeks of storage life at 32°; for each week's delay at 58°, deduct 1 month of storage life at 32°.

herent defects for preferential refrigeration over the long period on the one hand and the early marketing of weak, overmature fruit on the other. It may necessitate the use of cold-storage-in-transit privileges and shipping the fruit under the standard refrigeration service provided by the railroads for a part of the tonnage scheduled for intermediate and early marketing, to conserve local refrigeration for promptly and adequately cooling the tonnage intended for marketing after December. Such a sacrifice in cooling early shipments is an expedient and is desirable only when limited capacity prevents prompt cooling of the entire crop.

Segregating to Avoid Soft Scald

Development of soft scald in Jonathans and other varieties of apples, including Winesaps, is erratic and unpredictable. It usually can be traced to a quick reduction in fruit temperature to 30° to 32° F. when the fruit is somewhat advanced in maturity or is delayed at relatively high temperatures after picking before going into storage. When such delays are unavoidable, the disorder may be prevented by holding the fruit at 36°, or slightly above, for the first few weeks of storage. When it is impossible to get susceptible varieties into cold storage promptly, they should not be cooled to the 30° to 32° range generally recommended for apples but only to a moderate temperature (36°) and segregated for early sale. Therefore, avoid putting them in the same room with a variety like Delicious, which should be held at 30° to 32°. Storage in separate rooms in which the temperature can be controlled independently is desirable. Although the fruit will not keep as long at this higher temperature, the risk from soft scald will be avoided.

Stacking Packages

Lines are ordinarily painted on the floor of storage rooms (fig. 16) to indicate the spaces for placing rows of boxes on pallets or pallet boxes and to facilitate even stacking. Maintain-

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FIGURE 16.—Lines painted on floor will facilitate placing pallet loads or pallet boxes of fruit and help in providing uniform spaces for the movement of cold air through the stored fruit.

ing an air space between rows at all points is important. A uniform spacing of 4 to 5 inches between rows is practically as effective in permitting cooling as wider spacing, provided headroom between the top of the boxes and the ceiling is sufficient. Careless stacking, however, in which some boxes in one row touch or approach those in another, restricts air movement and retards cooling. A spacing of 4 or 5 inches is also needed to facilitate forklift truck maneuverability between rows. This convenience in trucking has regulated spacing in most storage houses. To overcome slight irregularities in stacking, 4 inches may be considered a satisfactory spacing for the bottom pallets. The rows should be so laid out that the general direction of air movement is along the rows instead of across them.

Stacking packages in contact with outside walls or floors should be avoided, as there is some heat transfer through conduction that affects the temperature of fruit in outside or bottom packages. When pallet loads of fruit are being stacked, spacing between the walls and the pallets may be insured by using side rails, as illustrated in figure 17, or by fastening 2- by 6-inch planks to the floor around the outside of the room. On concrete floors an air space should be provided beneath fruit by stacking the fruit on pallets.

To prevent the lower fiberboard boxes from crushing when pallet loads of packed fruit are stacked three or more high, 1- by 4-inch boards are placed on end at the four corners or between the first and second boxes on each corner of the pallet (fig. 18). The boards are cut about 1 inch shorter than the height of the stacked boxes on the pallet. As the boxes are compressed a small amount by the pallet load above, the boards take up the load. The use of these boards eliminates crushing and improves the stability of the stack.

In large rooms warm fruit may be brought in over a long period; this means that fruit that has been in the room for some time and has cooled is sometimes warmed by incoming fruit. This effect in unavoidable in some rooms, but by judicious stacking it can be kept at a minimum. Sometimes, the first fruit brought in can be stacked near the air-discharge ports so that after it is cooled it is not exposed to air coming from warm fruit brought in later.

Overhead Space

In most storage rooms air circulation is planned so as to have the primary movement over the tops of the boxes and through aisle

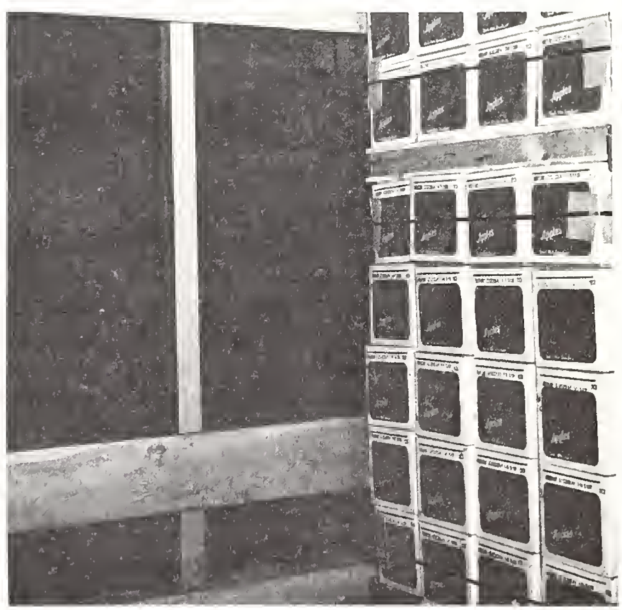

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FIGURE 17.—View showing side rails along wall to prevent stacking fruit too close to wall and preventing air circulation.

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FIGURE 18.—Pallet load of fiberboard boxes of fruit spaced with 1- by 4-inch boards placed on end and other pallet loads with 1- by 4-inch corner boards to take load of pallet above.

spaces. The cooling in the interior of the stacks is accomplished partly by secondary, or convection, currents up and down the spaces between pallet boxes. This cooling is effective only insofar as the warm air that rises to the ceiling is moved away and replaced by colder air. Leaving reasonable space overhead permits sufficient circulation for carrying off the heated air. If the space is limited, the air tends to move along aisles or unfilled channels in preference to the ceiling space. When fruit is stacked too close to the ceiling, air movement is restricted and cooling is retarded and uneven. No rule has been established on the minimum space required over the boxes to permit good circulation, but leaving the truss space open for this is a good practice.

If the primary air circulation can be forced to move over the top of the stacks and through the spaces between stacks, cooling will be more rapid. Moving the cooling air to the outside walls and then down and back through the stack spaces will greatly assist in cooling the fruit.

If natural convection is sacrificed by reducing the ceiling space, forced circulation must take its place, otherwise the effectiveness of cooling will be reduced instead of increased. For this reason, if air is forced through the box spaces by cutting down circulation over the fruit, the boxes must be arranged carefully. Uniform spacing becomes even more important, and air channels that will permit diversion of air around the stacks of boxes must be avoided. Precooling rooms in which these conditions are met provide much faster cooling than rooms in which natural convection is depended upon for cooling the interior of the stacks.

Control of the Plant

In a cold-storage plant the relatively large investment in machinery and construction can be justified only if it increases the value of the fruit stored. The value of a plant in maintaining this condition is largely determined by the way it is operated. Even the best designed plant with automatic equipment needs more or less continuous attention to insure the best results.

Core Temperature

To make the best use of a plant, it is essential to know what temperatures are being maintained. One or two thermometers for showing aisle-air temperatures do not indicate the performance of a plant. An operator needs to know core temperatures of the fruit, especially in parts of the room where cooling is difficult. Periodic observations of fruit temperatures will indicate what methods of stacking and air distribution will give best results and what parts of the room need special attention. Reliable thermometers or thermocouples are necessary for this purpose. An investment in equipment for obtaining accurate records of temperature in all parts of a storage is worthwhile.

Frequently, when actual fruit temperatures are measured, the results are disappointing. If they are, conditions sometimes may be markedly improved with little cost or inconvenience.

It is to an operator's advantage to know just how quickly he can cool the fruit and how uniformly he can hold the temperatures after it is cooled.

In addition to the management's responsibility to ascertain whether core temperatures are what they should be in all parts of the cold-storage plant, management has the further responsibility of checking on fluctuations in temperature during the operating season. This is best done by the continuous operation of a recording thermometer, or thermograph, at a central point in each room. One type of such an instrument is shown in figure 19. A file of temperature records affords the management a protection against complaints of grossly irregular temperatures but does not insure optimum core temperatures at all positions throughout the stored fruit.

Maintaining Humidity

The relative humidity in storage rooms should be determined periodically to avoid atmospheres that are relatively dry and likely to cause subsequent shriveling of the fruit. Several types of instruments are available for this purpose (fig. 20). If type *A* or *C* psychrometers are used, the relative humidity may be found in table 8.

Maximum use of Equipment

If during the cooling period some of the compressors must be shut off to avoid localized freezing at some points while fruit temperatures are too high at others, the capacity of the equipment is not being used to full advantage and some means for better distribution of the refrigeration should be found. This usually may be done either by improving the air circulation or increasing its volume. While ample circulation cannot compensate for inadequate refrigeration, it does permit maximum use of the refrigeration available.

Pending the time when the air-circulation system can be overhauled to give maximum use of the compressors, the management may take temporary steps to prevent freezing at local points during the cooling period. They usually involve removing the fruit or covering it where air is introduced and using portable fans to accelerate the movement of air away from the cold spots towards points where fruit temperatures are high.

Operating Efficiency

Keeping Equipment Balanced

To get the best results from a plant, the various steps in the mechanical removal of heat must be balanced. That is, the heat picked up in the room must be transferred in succession from the fruit to the air, from the air to the cooling coils, from the coils to the compressor, and from the compressor to the condenser, where it is discharged to the cooling water. If in one or more of these steps, the quantity of heat that can be transferred is unduly restricted, the equipment performing the other steps cannot be worked to its greatest capacity. The condenser is doing its part if the head pressure is not excessive; and the cooling coils are not unduly limiting the capacity of the plant if the suction pressure is well up. Whether the air-circulation system is in balance with the rest of the equipment, however, is not as easily known.

During the cooling period, when the refrigerating equipment is operating to full capacity,

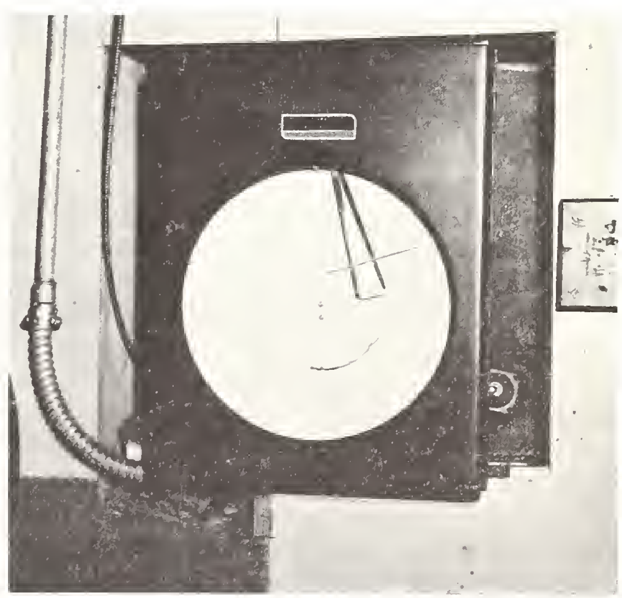

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FIGURE 19.—Recording thermometers are useful for giving temperature fluctuations and providing a permanent file on cold-storage performance.

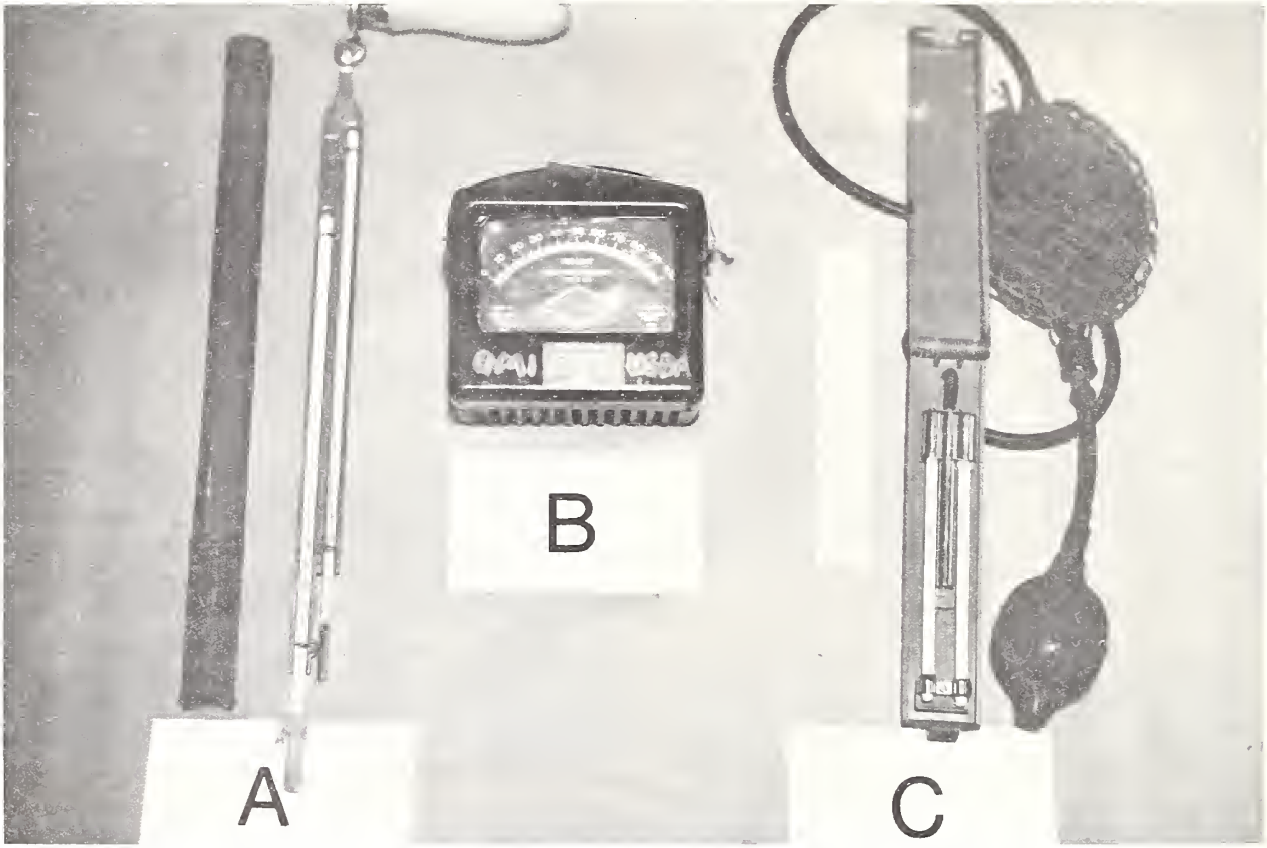

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FIGURE 20.—Psychrometers consisting of wet- and dry-bulb thermometers that can be used for determining the relative humidity of storage rooms: *A*, Sling type; *B*, wall type; and *C*, hand-aspirated type.

the volume of air circulation may be considered in balance if the temperature difference between delivery and return air does not exceed 10° F. A lower split is desirable, but if it is greater than 10°, increasing the volume of air circulation is beneficial. As the load is cooled and as less warm fruit is brought into the storage, the split will decrease and should reach 1° to 2°. After fruit temperatures become about stationary, a split exceeding 1.5° is an indication of insufficient air volume. During this period further cooling is not required, but temperatures must be maintained uniformly throughout the room.

Uniformity of temperature depends first on an adequate volume of air. If the volume is sufficient, as indicated by the split between delivery and return, and if temperatures in some part of the room are still too high, the air is not being distributed to the best advantage.

Ammonia Pressures

The gage pressures on the refrigeration equipment should be routinely observed. Too low suction pressures or too high head pressures are signs that the system needs attention. Ordinarily suction pressures below 20 to 25 pounds indicate that the cooling coils are not picking up heat as rapidly as they should. Head pressures of over 160 to 170 pounds indicate lack of sufficient cooling in the condenser. These limits depend upon the kind of system used, but the cause of any unexpected changes in pressure should be found and corrected. If pressures are normally outside these limits, the possibility of making adjustments or changes in the installation should be investigated to reduce power consumption and to get more refrigeration. Table 9 shows how power consumption increases as the head pressures increase and the suction pressures decrease with ammonia compressors. Suction pressures as high as 35 to 40 pounds and head pressures as low as 100 to 120 pounds can be obtained under favorable conditions. Pressure gages should be checked occasionally for accuracy, since they may get out of adjustment after long use.

The temperature of liquid ammonia at various gage pressures is as follows:

Gage pressure (pounds)[1]	*Temperature (° F.)*
Suction pressure:	
Below normal:	
0	−28
5	−17
Normal:	
10	−8
15	−1
20	5
25	11
30	17
35	21
Head pressure:	
Below normal:	
40	26
50	34
75	50
Normal:	
100	63
125	75
150	84
175	93
200	101

[1] Suction pressures seldom occur below 10 or above 35 pounds; head pressures seldom below 100 or above 200 pounds.

Frosted Coils

Accumulation of heavy layers of frost on cooling coils retards the passage of heat. Pipes or finned coils need to be defrosted frequently to get the most from a cooling system. Disposal of the ice and water from defrosting may be a problem in direct-expansion plants, but removal of the frost during the cooling period is essential.

Brine Treatment

In brine-spray plants the frost is washed off with brine, which is continually being diluted by the condensed water, making it necessary to drain off some of the solution at intervals and add more salt. The brine should not be any stronger than necessary to prevent accumulation of ice. One objection to brine-spray systems is that upon exposure to air the brine tend to become acid. Unless this tendency is checked, the particles of brine carried by the air are very corrosive and may damage any metal with which they come in contact. The brine may be treated with a chemical to retard this corrosive effect. The instructions regarding such treatment, which are furnished by the company installing the equipment, should be followed carefully. If they become lost or forgotten, new instructions should be requested.

Care of Condenser

The water used in the condensers leaves a deposit on the pipes that, if allowed to accumulate, interferes with the transfer of heat. The water tubes of a condenser should be examined at least once each year, preferably before the harvest season, to make certain they are in good condition. If dirty, they should be given a thorough cleaning.

Care of Compressor

The compressor and other machines, including motors and pumps, need careful attention. Instructions furnished by the machinery manufacturers should cover operation of the particular machines in the plant and should be kept in the engine room and referred to frequently. Carelessness in operation or failure to observe the recommended routine may prove expensive in repairs. A well planned and cared for compressor room is shown in figure 21.

Controls

Automatic parts of the numerous types of control equipment used in various plants usually depend upon changes in temperature or pressure or are controlled by clocks. It will pay to become familiar with the principle of operation of each item involved in automatic control.

Ducts and Dampers

The dampers and openings in ducts should be set open wide enough to permit the desired air distribution. In making adjustments the ports requiring more air should be opened to full capacity in preference to closing down dampers or openings at other points. When the temperature of the delivery air is too low, the ports should not be closed down to prevent

TABLE 8.—*Relative humidity of atmosphere by wet- and dry-bulb thermometers*

Air temperature (° F.)	Relative humidity when depression (° F.) of wet-bulb thermometer[1] is—									
	0.5°	1.0°	1.5°	2.0°	2.5°	3.0°	3.5°	4.0°	4.5°	5.0°
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
20°	92	85	77	70	62	55	48	40	33	26
25°	94	87	81	74	68	62	55	49	43	37
29°	94	88	83	77	72	66	60	55	50	44
30°	94	89	83	78	73	67	62	56	51	46
31°	94	89	84	78	73	68	63	58	52	47
32°	95	90	84	79	74	69	64	59	54	49
33°	95	90	85	80	75	70	65	60	56	51
34°	95	90	86	81	76	71	66	62	57	52
35°	95	91	86	81	77	72	67	63	58	54
36°	95	91	86	82	77	73	68	64	60	55
40°	96	92	87	83	79	75	71	68	64	60
45°	96	93	89	86	82	78	74	71	67	64
50°	96	93	90	87	83	80	77	74	71	67

[1] Difference between dry- and wet-bulb readings. Water should not be freezing on the wet bulb while a reading is made. The humidities shown in this table apply only when the air is moving rapidly past the thermometers, as with the sling or aspirating psychrometer.

TABLE 9.—*Relation of head or condensing and suction pressures to horsepower requirements per ton for typical ammonia compressors*

Condensing pressure (pounds)	Suction pressure of—				
	10 pounds	20 pounds	25 pounds	30 pounds	35 pounds
6-BY 6-INCH COMPRESSOR					
	Hp.	*Hp.*	*Hp.*	*Hp.*	*Hp.*
85	1.30	0.90	0.77	0.66	0.56
105	1.42	1.04	.90	.79	.68
125	1.62	1.18	1.03	.91	.82
145	1.75	1.33	1.17	1.03	.93
165	1.94	1.47	1.31	1.17	1.05
185	2.12	1.60	1.44	1.30	1.17
205	2.29	1.76	1.57	1.42	1.29
9- BY 9-INCH COMPRESSOR					
85	1.20	0.84	0.71	0.61	0.52
105	1.32	.97	.84	.73	.64
125	1.50	1.11	.97	.86	.77
145	1.67	1.25	1.10	.98	.88
165	1.83	1.39	1.23	1.11	1.00
185	2.00	1.53	1.36	1.23	1.11
205	2.17	1.67	1.50	1.36	1.24

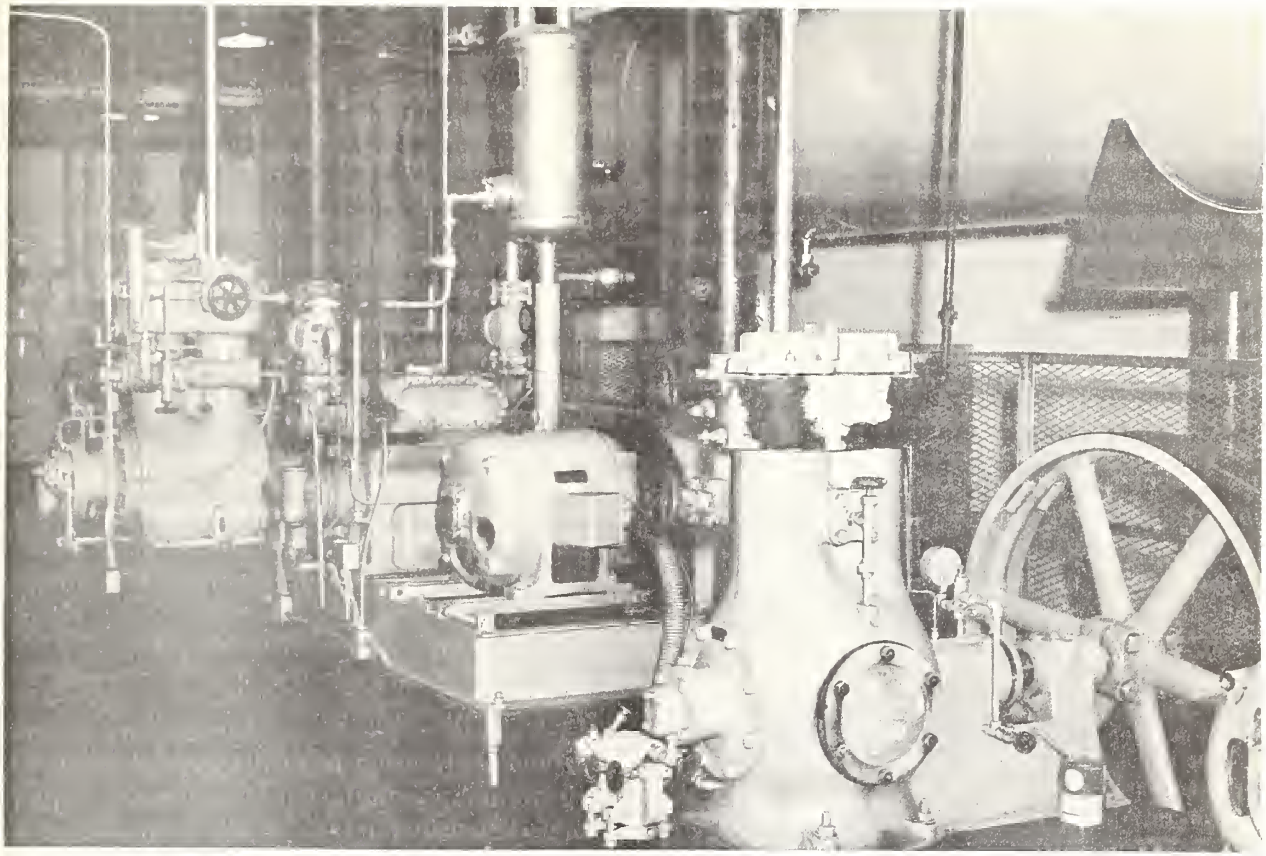

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FIGURE 21.—Arrangement of multiple compressors in engine room.

freezing; instead the temperature of the air should be raised and as much volume as possible permitted to circulate through the room. Many plants have too little air circulation, resulting in high temperatures in parts of the room. Sometimes the delivery-air temperature is lowered in an attempt to correct this. If this temperature becomes too low for safety, closing down the openings to prevent freezing aggravates the condition instead of improving it.

Freezing Near Coils

In direct-expansion rooms the packages nearest the coils sometimes become too cold even though other fruit in the room may be too warm. This localized low temperature is caused by the radiation of heat directly from the packages to the coils, even though the air next to them may be above the freezing point. Here, the air circulation may be increased to keep the packages from getting too cold or, if necessary, a shield may be put between the boxes and the pipes. This shield is not to deflect the air but to prevent direct radiation; that is, to stop the "shining," or radiation, of heat from the boxes to the cold surface of the pipes. This radiation takes place regardless of the temperature of the air between boxes and pipes.

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APPENDIX

How To Make a Thermocouple

The following suggestions on how to construct a thermocouple are not necessarily complete for all methods of making thermocouples. Each presents its own problems and experience will provide the best procedures to use. The procedures outlined here must be regarded as general enough to cover the requirements for constructing thermocouples to be used in indicating the temperatures in a cold-storage room for apples.

Materials

Two dissimilar metals such as two dissimilar metallic wires when joined together constitute a thermocouple. Some thermocouples are more sensitive than others. Since the instruments used in the Pacific Northwest are calibrated for copper-constantan thermocouples the following types of wire are used:

No. 29 Copper wire, enameled single-cotton covered

No. 24 Constantan wire, enameled single-cotton covered

The smaller the wire used the less cost per foot and the greater the sensitivity of the thermocouple. However, too small a wire will break easily and must be handled with care.

Cutting Wire

Cut both wires to length of the finished thermocouple. Remove the insulation and enamel for a distance of about one-half inch from one end of each wire by scraping with a knife to insure a good connection with the circuit.

Twisting Wire

With both wires extending the same distance, twist these two ends together.

Fusing or Soldering the Thermocouple

The twisted ends should be soldered with a resin core solder, then clip the end so that it is not over 1/4 to 3/8 in. long. *Do not use acid core solder as it is conducive to corrosion and will shorten the life of the thermocouple.*

For better and longer lasting thermocouples the wires can be fused with a small electric arc or gas torch.

Electric arc.—The construction of an apparatus for fusing thermocouples junctions electrically is illustrated in figure 22.

Assemble parts by nailing or screwing wood base together, fasten porcelain sockets to base, and fasten metal carbon holder securely to support block. Porcelain sockets should be connected in parallel, connect one lead wire to 110 volt plug, another wire from sockets to metal carbon holder. Other lead wire is connected to alligator clamp. Tape or insulate all exposed metal connections. In using the electric arc, bare and scrape ½ inch of thermocouple wire, twist bare ends together, insert in alligator clamp with clamp gripping bare wire. Thermocouple wire should protude ¼ to ⅜ inch from clamp. Plug in extension cord to 110 volt outlet. By use of wooden handle press the wire into contact with carbon and slowly break contact, drawing an electric arc which fuses thermocouple wire. A 1/16 fused ball should be formed on the end of the thermocouple wire. If arc is too hot for size of thermocouple wire, unscrew one resistor to cut the current down.

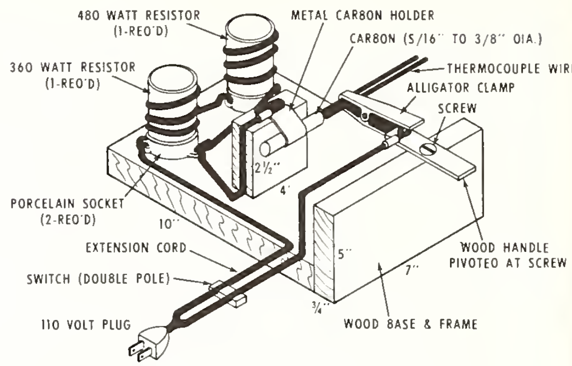
CAUTION

An electric arc will burn the eyes so protect eyes with dark glasses or place a piece of smoked glass over the arc area.

Do not plug in unit until ready to fuse thermocouple and unplug unit before removing thermocouple wire. Remember when unit is plugged in there is 110 volts on all exposed places. Avoid touching a grounded circuit while using the apparatus to prevent being severely shocked.

Gas torch.—When using a gas torch, use the following procedure:

When welding, use an acetylene torch, and select a torch tip in proportion to the size of wire to be welded. (For the smallest gage wires use a No. 1 torch tip and for the largest gages use a No. 10 tip.) Fasten the torch in a vise so that the flame will be horizontal. Adjust the torch so as to get a neutral flame, about 4 in. long, with the white cone—surrounding the small blue cone—almost ¾ in. long. Hold the twisted junction of the wires in the flame—at



APPARATUS FOR FUSING THERMOCOUPLE JUNCTIONS

FIGURE 22.—Apparatus for fusing thermocouple junctions.

the tip of the white cone—until both wires are a bright red, then dip in a fluxing mixture consisting of 6 parts of fluorspar to 1 of borax. (If fluorspar is not available, borax alone may be used.) Place the flux-covered twisted ends, immediately in the flame. Since one wire melts at a lower temperature than the other, manipulate the weld in the flame until both wires reach their melting points at about the same time. This can be done by keeping the wire that melts first in the cooler part of the flame until the other wire is about to melt.

As soon as both wires reach the melting point, revolve the weld in the flame until both metals flow together forming a ball weld at the tip.

Use a moderately hot flame to avoid burning. After fluxing the metal, the weld should be made, if possible, on the first attempt. Continued heating at welding temperatures will result in a poor weld. If a good weld is not made promptly, and a shorter thermocouple can be used, cut off the ends, make a new twist, and repeat the procedure.

Inexpensive Paint for Concrete Walls

The following is an inexpensive and durable paint for concrete walls:

50 pounds slack lime
15 pounds granulated salt
15 gallons of water

Mix the water with the ingredients to a thick slurry consistency for painting on concrete structures.

Harvesting Maturity of Apples

Because of the importance in harvesting apples at the proper time for storage, the following research information on picking dates for apples in the Pacific Northwest is quoted in its entirety (*2*).

> *Before 135 days from full bloom.* Red Delicious apples are immature. They never develop high quality, are so disposed to scald that scald inhibitors may not control the disorder, and—except for some Super Red Sports—they normally have inadequate color.
>
> *Between 137 to 150 days from full bloom,* Red Delicious can be stored for over six months and retain high quality providing they are free from water core.
>
> > *At 137 to 144 days,* Red Delicious are generally very susceptible to storage scald. They should be treated with a scald inhibitor as soon as possible after harvest. Delays should not be more than 10 days.
> >
> > *By 145 days,* most Red Sports have developed their maximum color and have reached their peak of maturity for flavor, texture, and late storage potential. At this stage, Red Delicious have had significant water core in four years out of eight (1959 through 1966). In seasons when water core develops early, water-cored fruit should be segregated in the orchard and kept in separate lots at the warehouse for earlier marketing.
> >
> > *At 145 to 150 days,* Red Delicious have long storage potential in seasons when water core is not significant. They have superior flavor and are nearly as firm in the late storage period as apples harvested at 137 to 144 days. They are less susceptible to storage scald than apples harvested earlier, but should still be treated with a scald inhibitor.
>
> *After 150 days from full bloom,* Red Delicious have excellent quality for the early marketing period, but do not have good potential for the late storage season.
>
> *By 155 days from full bloom,* Red Delicious have had significant water core in six years out of eight (1959 through 1966). In these years, from 40 to 70 per cent of the apples were affected and more than half of these had water core in the severe range. Even with excellent storage conditions, severely water-cored fruit begins to show internal browning in late January and early February. Fruit harvested in this late period loses firmness more rapidly than that harvested before 150 days.

Pressure Testing

The use of pressure testing to determine the maturity of apples at harvest time is not reliable.

A Magness-Taylor pressure tester can be used in the storage house to test the rate at which apple firmness is being lost during the storage season and is a method used to predict the future storage life of apples.

Harvest Maturity for Pears

In contrast to apples the flesh firmness of pears is the most satisfactory way of determining their maturity.

The picking maturity of pears varies slightly from district to district because of different growing conditions.

Table 10 shows the recommended pressure for picking pears as determined by L. P. Batjer and others (*3*).

TABLE 10.—*Flesh-firmness recommendations for harvesting pear varieties*

Variety	Firmness [1]		
	Maximum	Optimum	Minimum
	Pounds	*Pounds*	*Pounds*
Anjou	15	13	10–11
Bartlett	19	17	15
Bosc	16	13	11
Comice	13	11	9
Hardy	11	10	9
Kieffer	15	13–14	12
Seckel	18	16	14
Winter Nelis	15	12.5	11

[1] Magness-Taylor pressure tester with 5/16-inch-diameter plunger.

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