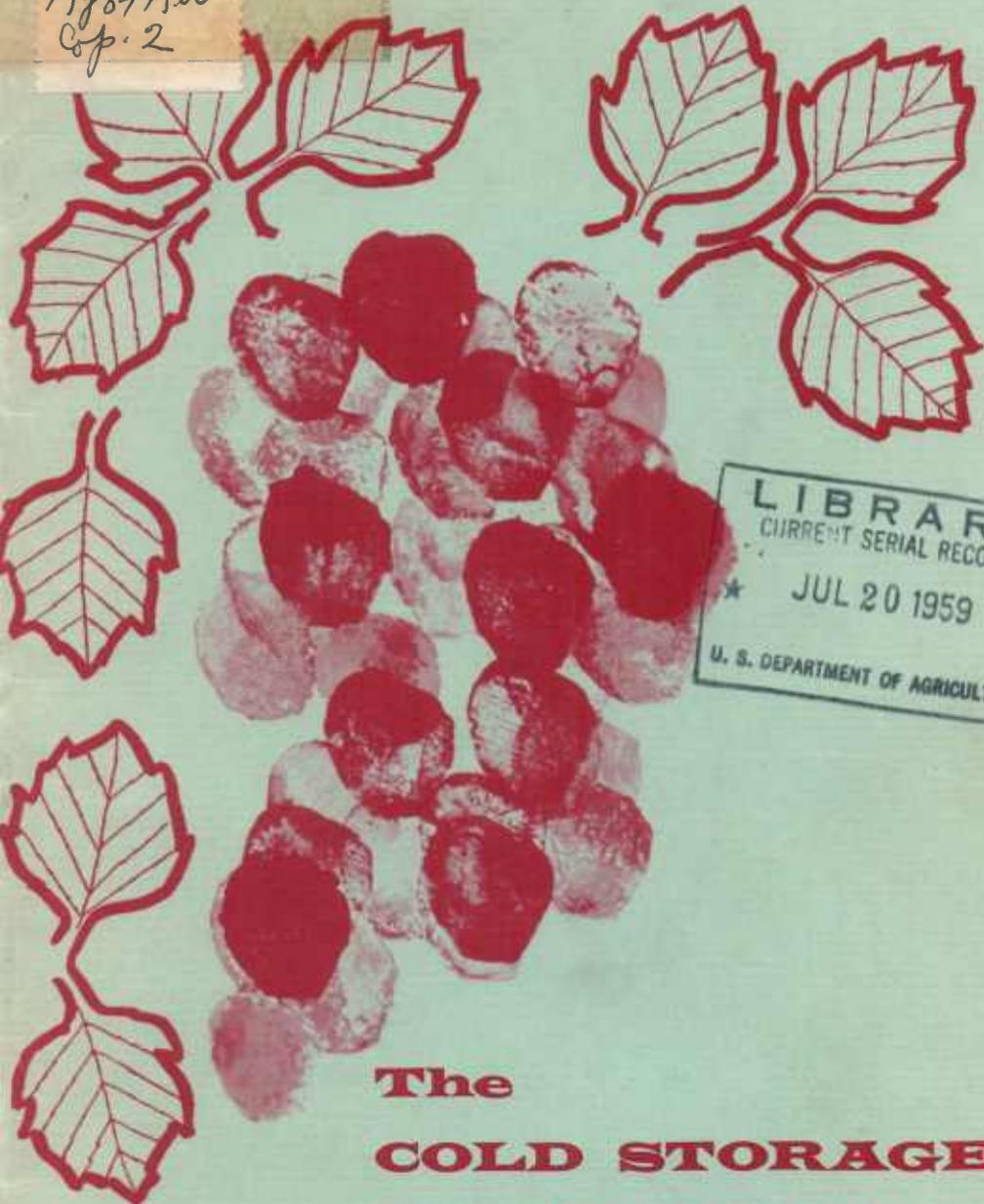


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**The
COLD STORAGE
OF VINIFERA
TABLE GRAPES**

AGRICULTURE HANDBOOK NO. 159
UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL MARKETING SERVICE



**The
COLD STORAGE
OF VINIFERA
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BY
A. LLOYD RYALL AND JOHN M. HARVEY
AGRICULTURAL MARKETING SERVICE

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THE COLD STORAGE OF VINIFERA TABLE GRAPES

A. Lloyd Ryall and John M. Harvey¹

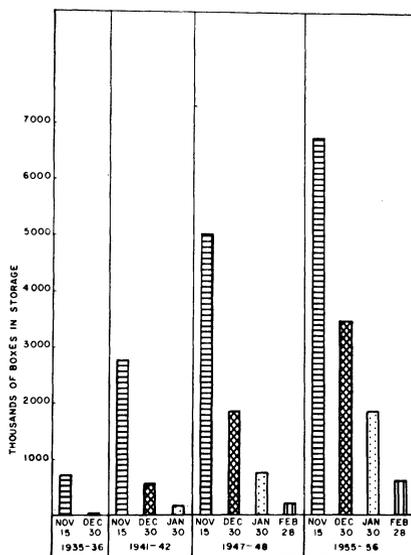
Introduction

This handbook brings together the accumulation of 30 years of research and experience in grape storage. It is written for operators of storage plants, growers, packers, and buyers of fresh grapes. The information presented on temperature, humidity, air movement, storage design, fumigation, and storage disorders, together with the sources of such information, can be used to maintain quality, reduce spoilage, and improve marketing of grapes.

Although European-type table grapes (*Vitis vinifera* L.) have been produced commercially in California since 1860, (36, 64)² prolonged storage dates back only to the late 1920's when methods for periodic fumigation with sulfur dioxide were developed. Before this some table grapes were packed in ground cork or sawdust and were stored for only 4 to 6 weeks, mostly at terminal markets (70). With further development and refinement of fumigation methods, the extensive storage of grapes in display lugs became possible and increasing quantities were stored in

the producing areas for distribution during the winter and spring months.

The holdings of table grapes in California during 4 representative storage seasons from 1935 to 1955 are shown in figure 1. During this period table grape production was fairly constant and yet, as the figure shows, both the quantity of fruit stored in California and the



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Figure 1.—Cold storage holdings of table grapes in California during four seasons. Data from annual summaries of Federal-State Market News Service.

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² Italicized numbers in parenthesis refer to items in Literature Cited, p. 41.

period during which it was stored increased materially. During 1956 grapes were stored in about 95 cold storages in California, many of which, particularly in the San

Joaquin and Sacramento Valleys, are designed principally for table grapes. On November 15, 1955, about 6,500 carlots of table grapes were in Central Valley storages.

Factors Affecting Quality of Stored Table Grapes

Each of the characters that contribute to dessert quality, such as flavor, color, and texture, is at a peak when grapes are harvested at optimum maturity. Changes that occur thereafter, even under ideal holding conditions, involve a gradual deterioration of these qualities. It is thus apparent that good quality after storage depends primarily on placing fruit of good quality into storage.

Maturity

The determination of optimum maturity of table grapes to be stored should be based on such qualities as berry and stem color, sugar content, acidity, and development of flavor characteristic of the variety. Minimum legal maturity for shipment under California law is based almost entirely on soluble solids as determined by juice readings with the Balling hydrometer or hand refractometer. However, Winkler (76) found that the ratio of soluble solids to percent acidity of the expressed juice was a better index of dessert quality than soluble solids alone and suggested Balling-acid ratios for table varieties that were above the legal minimum but below 20 percent soluble solids. Grapes with 20 percent or more soluble solids were considered to have good dessert quality at any acidity level.

As grapes mature the stems change from a leaf-green to a light green or straw color, and in some varieties a woody portion resembling the cane forms at the base of the stem. These changes are in-

dicative of good storage quality, for matured stems are less subject to desiccation, breakage, discoloration, and mold attack than immature ones. In addition, well matured stems are usually indicative of well matured and colored berries. The sturdy cap stems (pedicels) characteristic of matured stems reduce the shatter of berries from the cluster.

Handling Before and During Storage

Precooling

The value of prompt and thorough removal of field heat from grapes intended for immediate shipment or storage has been demonstrated repeatedly in both controlled tests and industry experience. Fruit should not only be promptly cooled after packing, but unnecessary delays in the vineyard and packing house before trimming and packing should be avoided. Delays at high temperature between harvest and the start of precooling are certain to result in undesirable stem drying, berry shrivel, shatter, and infection by decay organisms (42).

Relation to Moisture Loss From Fruit

Loss of water from any product is governed largely by the protective surface of the commodity, the amount of air moving over it, and the difference in vapor pressure between the commodity and the air. Grape berries have a relatively impervious skin so they do not give up water readily, and consequently

moisture is lost largely through the stems.

Air movement may vary from moderate in the vineyard to high velocity during precooling. The principal factor involved in moisture loss, however, is vapor pressure differential. For example, if we assume that air in the intercellular spaces is nearly saturated with water vapor, the tissues at 80° F. would have a vapor pressure equivalent to .99 inch of mercury. It would be somewhat less than this because of the sugar content of the fruit, but these figures are valid for comparative purposes. Air at 80° with 20 percent relative humidity (RH) would have a vapor pressure of only 0.21 inch. At 90° the tissues would have a vapor pressure of about 1.3 while air at 90° with 22 percent RH would have a vapor pressure of 0.30. These large differences in vapor pressure would result in relatively rapid movement of moisture from the tissues to the air and are representative of actual conditions that might occur in the vineyard or packing house after picking.

Differences in vapor pressure also occur during precooling because low temperature air has a much lower vapor pressure than high temperature fruit (table 1). For example, air at 31° F. and 94.3 percent RH has a vapor pressure of 0.164 inch whereas grapes at 80° have a vapor pressure of about 0.99. From these figures it is apparent that the faster grapes can be lowered to the temperature of the air in the precooling chamber the less moisture will be lost. The figures in table 1 also demonstrate that maintaining high atmospheric humidity during precooling is not as important as fast cooling. To illustrate this fact, observe that the difference in vapor pressure of 31° air at 94.3 percent RH and 79.5 percent RH is insignificant as compared with the vapor pressure of

fruit at higher temperatures. This principle was demonstrated by Dewey (15) in a study of moisture-loss from cherry and grape stems. He found that significantly more water was lost from sweet cherry stems cooled in still air at 90 percent RH than in an air blast at 70 percent RH. The amount of cooling that took place in 1 hour in an air blast required over 7 hours in still air. Consequently, the difference in moisture-loss was due primarily to the rapid decrease in vapor pressure differential when subjected to air blast cooling.

TABLE 1.—*Relation of air temperature and relative humidity to vapor pressure*

Air temperature (dry bulb)	Depression of wet bulb	Relative humidity	Vapor pressure (Hg)
°F.	°F.	Percent	Inches
31-----	0.5	94.3	0.164
31-----	2.0	79.5	.136
32-----	.5	94.4	.172
32-----	2.0	80.0	.143
33-----	.5	94.5	.180
33-----	2.0	80.5	.150
34-----	.5	94.6	.187
34-----	2.0	81.0	.157
35-----	1.0	90.0	.187
40-----	1.0	92.0	.228
50-----	.5	96.0	.347
60-----	.5	97.0	.499
70-----	.5	98.0	.707
80-----	.5	98.0	.989
80-----	23.0	20.0	.322
90-----	1.0	96.0	1.364
90-----	22.0	31.0	.432
90-----	29.0	15.0	.211

Factors Affecting Rate of Precooling

The rate of cooling of any commodity is primarily dependent upon four factors: (1) The accessibility of the product to the refrigerating medium, (2) the difference in temperature between the product and the refrigerating medium, (3) the velocity of the refrigerating me-

dium, and (4) the kind of cooling medium. Since air is the refrigerating medium used in grape cooling to obtain optimum cooling, (1) the product must be packaged and stowed in such a way that air will reach all packages of fruit uniformly, (2) the temperature of the air must be maintained continuously at a point slightly above that at which the product freezes, and (3) the air must be moved rapidly over, or preferably through, the containers.

Effect of packaging.—Accessibility of the product to the cooling medium is one of the factors governing the rate of cooling. Since the type of package and the materials used in the package affect accessibility, they become factors in the cooling rate. Pentzer (50) reported that grapes packed in sawdust cooled at about half the rate of grapes in the display lug. He also showed that cellophane curtains over the face of the pack considerably reduced the cooling rate over that in lugs without curtains. However, this difference in cooling rate occurred only when both types of pack were exposed to circulating air. In parts of the load where cooling was principally by conduction the curtains had little effect. Ryall (62) reported that, under standardized conditions of air movement, the cooling rate in standard display lugs was affected by placement of the side slats, and that either side liners or curtains reduced the cooling rate as compared with lugs packed with bottom pads only. When the grapes can be stored under ideal conditions after precooling (about 90 percent RH and minimum air movement for the maintenance of uniform temperatures), packaging materials, other than bottom pads, are of questionable value. Their elimination would reduce packing costs and speed precooling. However, when

grapes are stored under lower than recommended humidities or excessive air movement, such materials as side liners or curtains may be justified for the reduction of stem drying and berry shrivel.

Types of Precooling

Room precooling.—Many of the table grapes going into cold storage are precooling in special rooms that have more refrigerating capacity and greater air volume than the regular rooms in which the grapes are stored. These rooms are generally rather small with capacities of from 1,000 to 5,000 lugs, so that they can be filled rather rapidly and operated without interruption during the cooling period. Since it requires approximately 4 tons of refrigeration to cool 1,000 lugs of grapes 40°, a room that holds 2,000 lugs with capacity to reduce this load 40° in 12 hours must be equipped to provide 16 tons of refrigeration in 24 hours. Additionally, it should have fans or blowers capable of producing 6,000 to 8,000 cubic feet per minute (cfm) of air per 1,000 lugs of fruit and air directing or distributing devices that will provide an even flow of air in all parts of the room.

Figure 2 shows a dry-coil bunker precooling room with 2 of the baffles removed to show the coils. The 2 fans pull air over the refrigerating coils (7,900 feet of 1¼-inch ammonia coil) and move it through a duct on the ceiling to the back of the room where it is released. The air returns through the palletized stacks to the bottom opening of the coil bunker. The room has a capacity of 5,200 standard display lugs (28 pounds net) and the 2 blowers move air at 34,600 c.f.m. This is an excellent type of precooling room with ample refrigeration and good air volume and distribution.

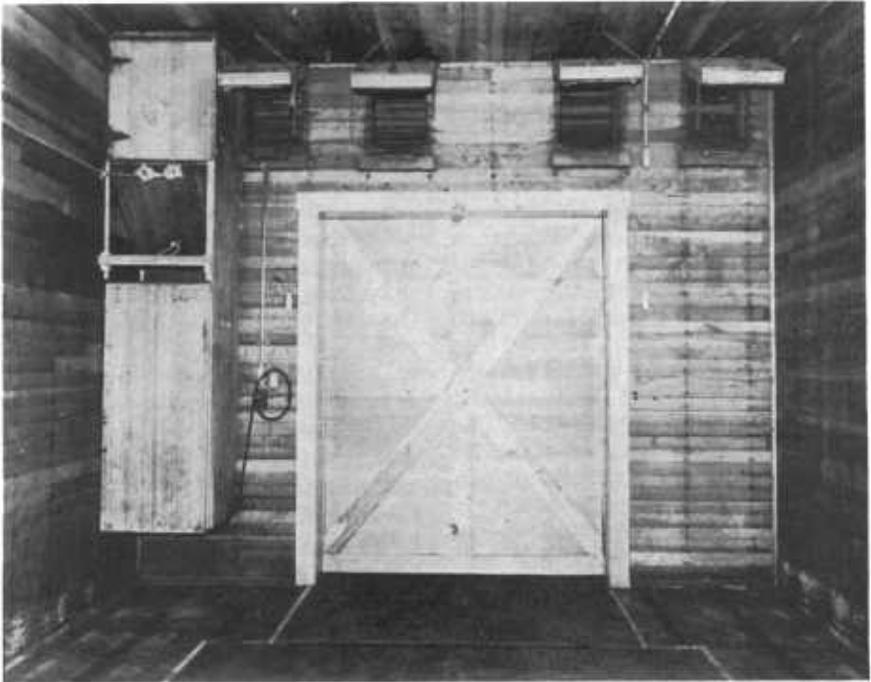


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Figure 2.—Face of dry coil bunker (2 panels removed) and ducts from two fans. Five-car precooling room.

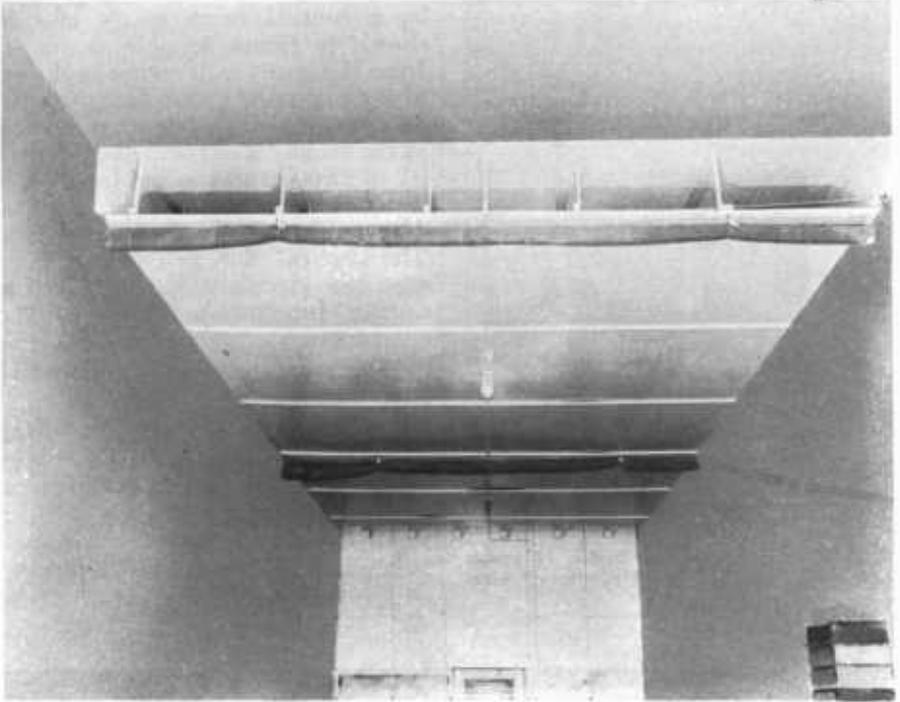
A precooling room refrigerated by a central brine spray unit is shown in figure 3. Air is ducted from the spray unit to the back end of the room and passes into a return duct through the openings shown at the front. The room has a capacity of 2,200 hand-stacked lugs. Additional air as needed can be diverted from the main supply duct. The vertical flue in one corner is used to circulate sulfur dioxide during fumigation which, at the completion of gassing, can be cleared from the room by manipulation of the louver.

An ice-refrigerated precooling room with a capacity of 6,600 lugs in one layer of pallets is shown in figure 4. Six fans, each with a rated capacity of 8,000 c.f.m., are located at the top of the bulkhead in the far end of the room. These



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Figure 3.—A 2,000-lug precooling room with air ducted from central brine spray chamber—opening to return duct and SO₂ circulating flue shown.



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Figure 4.—Ice-refrigerated precooling room showing false ceiling for ducting air from six fans and canvas baffles for directing air through palletized stacks of fruit.

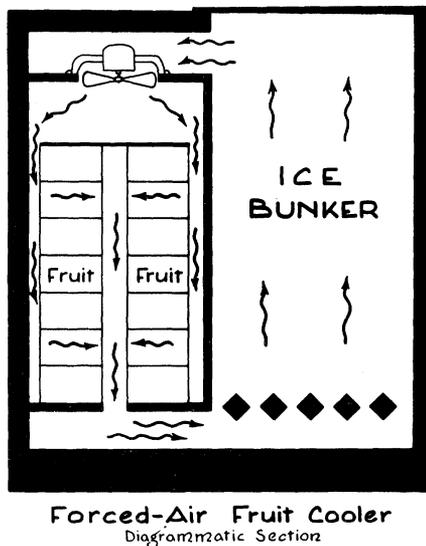
pull air from an ice bunker located below the loading platform outside the building, move the air through the false ceiling duct, and discharge it near the rear of the room. When the room is operating, the canvas baffles suspended from the duct are lowered to the top of the load to assure movement of the return air through the stacked fruit rather than over the top of the load. The bunker has a capacity of about 30 tons of chunk ice to which salt can be added if a lower temperature air blast is desired. In actual operation the generous air volume and large ice capacity of this system have provided a satisfactory rate of cooling without the use of salt.

Car precooling.—Grapes intended for storage are not ordinarily pre-cooled in refrigerator cars. However, when grapes move some distance to a cold storage

plant from points where other pre-cooling facilities are not available, very satisfactory removal of field heat can be accomplished in a refrigerator car. In this case the refrigeration is supplied by ice in the car bunkers and the air movement is provided by either the built-in car fans or portable bulkhead fans. The refrigerator car thus becomes essentially a precooling room and the same principles of air volume, air direction, and temperature differential apply. The fruit must be loaded to provide free air access to all parts of the load, the bunkers must be kept adequately supplied with ice, and salt must be added to the ice in sufficient amount to maintain a consistently low air blast temperature.

Forced air precooling.—A method of rapid cooling, based on forc-

ing air through vented containers by creating a pressure differential, has been developed by the Department of Agricultural Engineering at the University of California (25). It has been reported that commodities packed in containers that allow free air flow through the package, and in stacks spaced and baffled so that air supplied by the fans must pass through the packages, can be cooled in one-eighth the time required by the conventional method of passing air over the outer surfaces of the packages (fig. 5).



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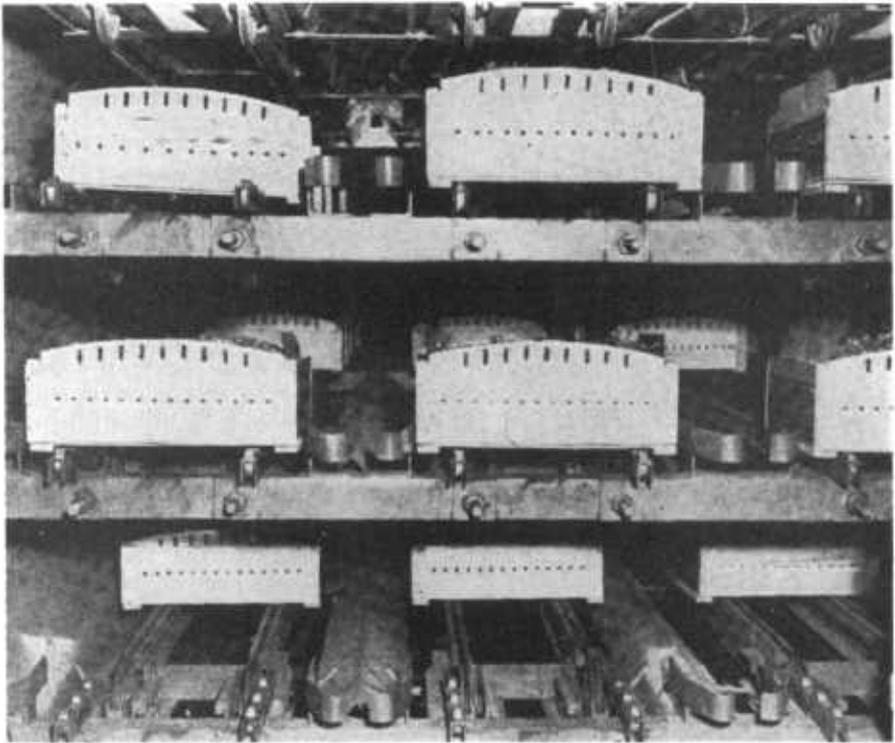
Figure 5.—Principle of forced-air cooling. (Photograph courtesy of Rene Guillou, Department of Agricultural Engineering, University of California, Davis, Calif.)

Other adaptations of this principle can and have been successfully made in existing precooling rooms and in refrigerator cars. However, it should be remembered that the system is ineffective with any pack that does not permit air passage, such as a wrap pack or sawdust pack, and it becomes less effective as resistance within the package is increased by packaging materials

such as side liners, curtains, trays, or cups.

Tunnel cooling.—Tunnel cooling has been used for several years in the early grape districts (1) for the rapid removal of field heat from packed grapes. The method allows the loading and shipment of pre-cooled grapes on the day of harvest whereas conventional cooling methods require holding the fruit over a day to accomplish comparable cooling. However, tunnel cooling also has been used for rapid pre-cooling prior to refrigerated storage. The cooling is accomplished by moving the packed, unlidded lugs on a continuous conveyor under a plenum chamber from which high-velocity, refrigerated air is directed at the face of the lugs from slots on the lower face of the plenum. The refrigeration source through which the air circulates is either ice or a mechanically refrigerated evaporator coil. Some of the units are designed to move a single layer of lugs directly under the plenum whereas others use multiple layer conveyors with baffles beneath each row of lugs to redirect the air at the face of the lugs below. The single layer coolers have produced somewhat more rapid and uniform cooling than the multiple layer coolers. Figure 6 illustrates the loading end of a multiple layer cooler operated in the Coachella Valley.

Vacuum cooling.—The cooling of certain kinds of fresh produce by evaporation of moisture at reduced pressures obtainable in a vacuum chamber has developed into extensive commercial use within the last 8 years. However, the process is adapted principally to those commodities, such as leafy vegetables, that have a relatively large surface area in proportion to volume. The amount of heat that can be removed by this process is limited by the amount of water than can be vaporized from the tissues without



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Figure 6.—Multiple-layer tunnel cooler. (Photograph courtesy of California Fruit Exchange, Sacramento, Calif.)

damage to the texture or appearance of the product.

Tests conducted at Fresno and New York (24) have shown individual grape berry temperature reductions of only 6° to 10° by the standard treatment used for leafy vegetables. W. R. Barger of the U.S. Department of Agriculture (unpublished data) determined that moisture loss from grape clusters was only 0.4 to 0.5 percent when pressure in the chamber was reduced to 4.5 mm. of mercury and maintained for 10 minutes. Cooling from 70° to 35° F. would require evaporation of water equivalent to approximately 2.5 percent of the original fresh weight of the fruit. If it were possible to withdraw this amount of moisture the appearance of the clusters would probably be adversely affected. It

seems apparent, therefore, that grapes are not adapted to vacuum cooling.

Storage Environment

After sound, mature grapes have been properly packaged and pre-cooled, the factor which then determines success or failure in their preservation is the storage environment. Factors in the environment that affect grape quality are temperature, atmospheric humidity, air movement, and fumigation with sulfur dioxide.

Temperature

Although one study (12) indicated that Emperor grapes could be stored at temperatures as low as 28.4° F., present recommendations are generally for air temperatures

of 30° to 31°. The freezing point of seven varieties of California-grown vinifera grapes has been reported to vary from an average of 23.6° and a range of from 22.9° to 24.7° for mature Thompson Seedless, to an average of 25.6° and a range of from 25.2° to 26.1° for mature Almeria (78). Since the freezing point is largely determined by sugar content, certain lots that are harvested at minimum maturity may have freezing points as high as 27°. While there appears to be no evidence on the freezing point of grape stems, it seems probable that they may freeze at a slightly higher temperature than the berries. To provide a margin of safety in relation to freezing, allowance must be made for temperature variation because of the lag in response to refrigeration controls and the temperature spread between incoming and return air.

Relative Humidity

A numerical figure for relative humidity represents the percent of saturation of air with water vapor at a given temperature. The water holding capacity of air increases as the temperature rises so air of 90 percent relative humidity at 70° F. contains much more water by weight than air of the same relative humidity at 32°. As the relative humidity of air increases the vapor pressure also increases and the capacity of the air for removing water from other sources decreases.

It is thus apparent that to reduce moisture loss from stored fruit to a minimum, the relative humidity of the storage air must approach that of the air within the intercellular spaces of the individual fruits. Assuming that air in the intercellular spaces is saturated and that the fruit and storage air temperatures are identical, moisture loss from the fruit could be entirely stopped only

by maintaining the storage air at a relative humidity of 100 percent. However, this is not possible under commercial conditions and would not be desirable if it could be accomplished because saturated air would favor the rapid development of decay organisms. Actually, the relatively small vapor pressure differential between fruit at 32° F. and air at 31° with 90 percent RH results in only slight moisture loss from the product. Such slight losses are within the limits of commercial acceptability during a normal storage period, particularly if air movement is not excessive. It has been determined that grapes can lose as much as 1.2 percent water by weight without affecting their appearance and that moisture losses as high as 5 to 6 percent were required to cause severe shriveling (46).

The best and currently recommended relative humidity for the cold storage of vinifera grapes is 87 to 92 percent (3). Earlier recommendations were usually in the range of 85 to 90 percent, but as methods of decay control have been improved the use of higher humidities, as a means of maintaining better appearance, has been recommended and rather generally accepted.

Accurate control of refrigerant temperature provides the only satisfactory method for maintaining high humidities in mechanically refrigerated storages. As the difference between the temperature of the refrigerating surface (coil or spray) and the temperature of the air in contact with the refrigerating surface increases, the humidity decreases. If the temperature of the refrigerating surface is below the dew point at a given air temperature and relative humidity, then moisture will condense on this surface and the air will lose moisture equivalent to the amount condensed.

The data in table 2 indicate the relative humidity that could be expected with certain air and refrigerating surface temperatures. For example, if the air moving over the refrigerating surface is cooled to 30° F. and the surface temperature is 25°, the relative humidity of this air will be about 79 percent because any water vapor above this amount will condense on the coil or spray. However, if air at the same temperature moves over a refrigerating surface maintained at 27° the relative humidity will be almost 89 percent and if the difference between air and refrigerant temperature were only 1° (air 30°, refrigerant 29°) then a relative humidity of over 94 percent could be expected. Actual humidities obtained under the above conditions of refrigerant and air temperatures will usually be somewhat higher than indicated because all of the air will not come in contact with the refrigerating surface. Thus air leaving the chamber will be a blend of that which has dropped moisture and that which has retained its original moisture content.

It is, of course, apparent that as the split between refrigerant temperature and air temperature becomes narrower, a greater refrigerating surface is necessary. If air is cooled from 32° to 30° F. during passage through a dry coil bunker, considerably more surface will be required to accomplish this temperature reduction when the coil is operated at 29° than when it is operated at 25°. This principle has been recognized in most of the newer grape storage plants. With an adequate refrigerating surface and with the temperature of that surface controlled by automatic devices, there is no humidity problem. Where refrigerant surface is not adequate to maintain the desired atmospheric humidity, pressure-atomized or heat-vaporized water can be added to the air. However,

this is a makeshift which will materially add to coil frosting or brine dilution problems.

TABLE 2.—*Relation of dew point to air temperature and relative humidity*

Dew point	Air temperature (dry bulb)	Depression of wet bulb	Relative humidity
° F.	° F.	° F.	Percent
28-----	29	0.5	94.1
26-----	29	1.0	88.3
23-----	29	2.0	78.5
29-----	30	0.5	94.2
27-----	30	1.0	88.6
25-----	30	2.0	79.0
30-----	31	0.5	94.3
28-----	31	1.0	89.0
26-----	31	2.0	79.5
31-----	32	0.5	94.4
30-----	32	1.0	89.2
27-----	32	2.0	80.0
31-----	33	1.0	89.5
32-----	34	1.0	89.7
33-----	35	1.0	90.0

In ice-refrigerated storage rooms the temperature of the refrigerant is 32° F. unless salt is added to the ice. Air temperatures in well designed ice-refrigerated storages usually can be maintained at about 34° after the fruit is thoroughly cooled. With a refrigerant temperature of 32° this would indicate a relative humidity of about 90 percent which is well within the desirable range. As with mechanically refrigerated rooms the amount of refrigerating surface is important and if 34° air is to be maintained, with melting ice at 32° as the refrigerant, an ice bunker large enough to permit a large ice surface must be provided.

Air Movement

As indicated in an earlier section, to provide uniform high velocity air through the stacks, a minimum air volume of 6,000 c.f.m. per 1,000 lugs is essential for the rapid re-

removal of field heat. This is best accomplished in a separate precooling room that has more refrigerating and air moving capacity than that required in a regular holding room.

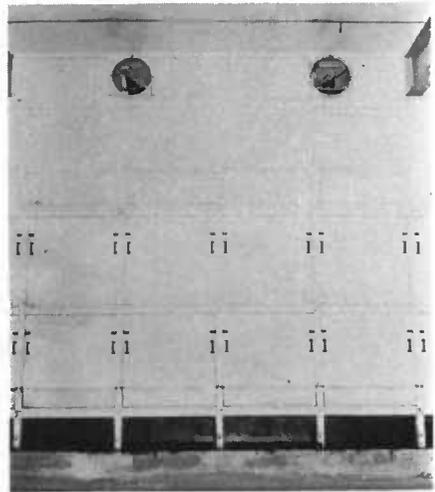
After the field heat has been removed from the fruit, a high air velocity is unnecessary and undesirable. Only enough air movement should be provided to remove respiratory heat and heat entering the room through exterior surfaces and doorways. Usually 50 to 75 linear feet per minute (lfm) through the stacks is sufficient to accomplish this, but it is very important that the air is directed in such a way that it moves uniformly through all parts of the room. Allen and Pentzer (2) found that doubling the air movement in fruit storage rooms increased moisture loss by about one-third and was equivalent to about a 5 percent drop in relative humidity.

Methods of controlling air movement.—All modern grape storage rooms have fans or blowers to provide forced air circulation. The rooms, with individual dry-coil, spray-coil, or ice bunkers, provide air movement by means of blade fans mounted along the upper part of the bunker. These may move air directly across the upper part of the room from open fans (fig. 7) or through ducts which extend part way or entirely across the ceiling to discharge air against or down the opposite wall (fig. 8). Somewhat more positive and uniform air movement is obtained when the air is ducted across the room to return through the stacked fruit than when open fans are used. With the latter there is a tendency for part of the air to short-circuit back to the bunker.

Many methods of air circulation are used within rooms which are cooled by a ducted system from a central brine-spray chamber. A common system for distributing air in the narrower rooms is shown in

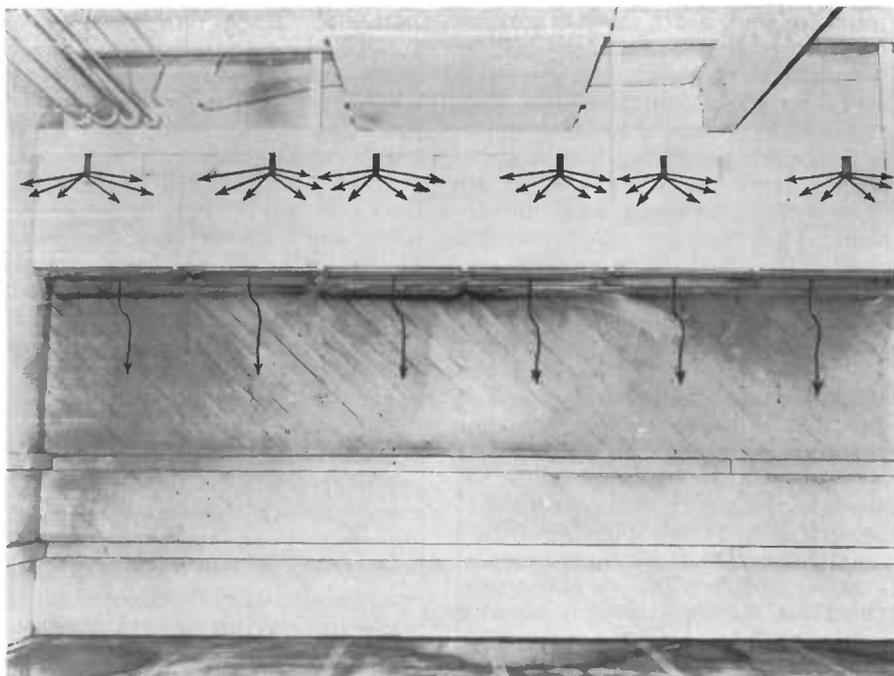
figure 9. Each long wall of the room contains an air duct. The air from the brine spray chamber is discharged through the louvered openings at the lower part of the right wall, moves through the stacked fruit and enters the return duct through openings located along the wall and near the ceiling at the left. If the openings are properly adjusted to effect uniform air flow from the discharge side, this system provides very uniform and satisfactory air movement.

In wider rooms multiple ducts are often used. The air is discharged from several ducts and moves in a predetermined pattern to one or more return ducts. Figure 10 shows a grape storage room in which the air from the central brine spray chamber is discharged downward from a duct on each side wall, moves through the stacks to the center of the room, and enters the return duct through openings at the bottom and upper sides. This provides excellent air distribution as determined by the uniformity of air velocity and temperature through the room.



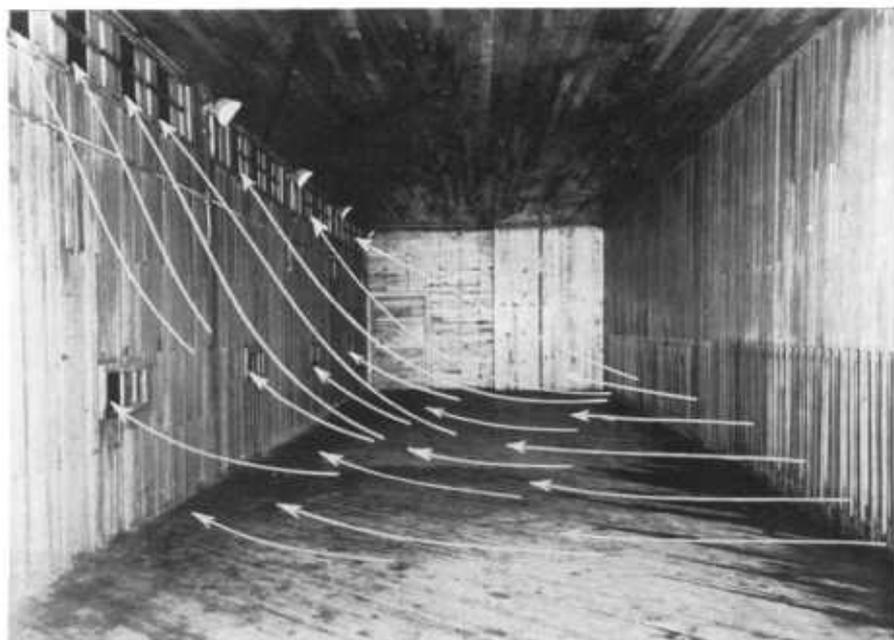
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Figure 7.—Open fan at the top of a dry-coil bunker.



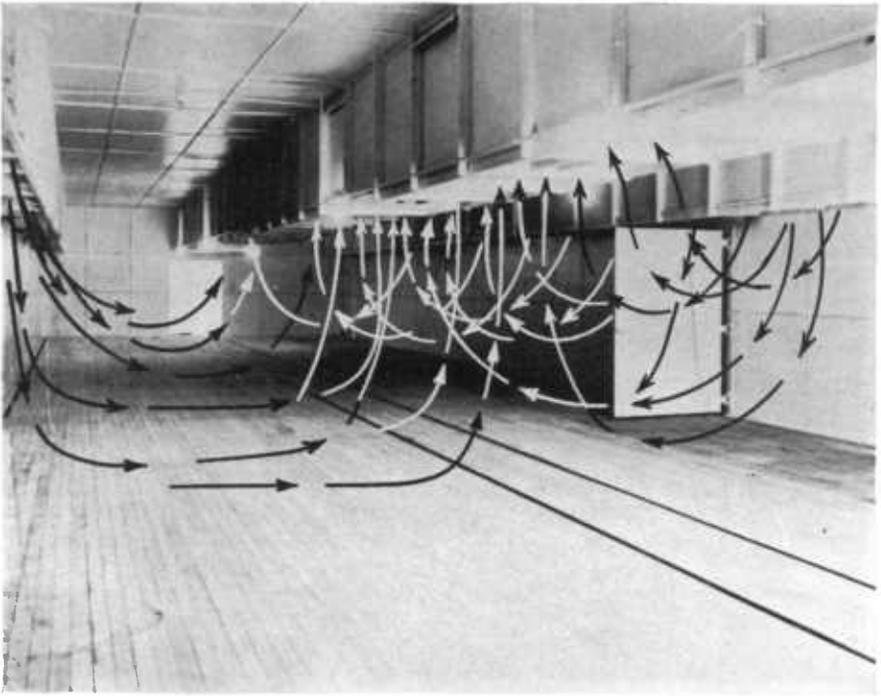
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Figure 8.—Rear wall discharge of air from ceiling ducts in room dry-coil bunker system. Air moves straight down from bottom duct openings and straight out from front duct openings.



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Figure 9.—Cross-room air movement from wall ducts supplied by central brine-spray chamber. Air moves across room from louvered openings at right to upper and lower openings at left.

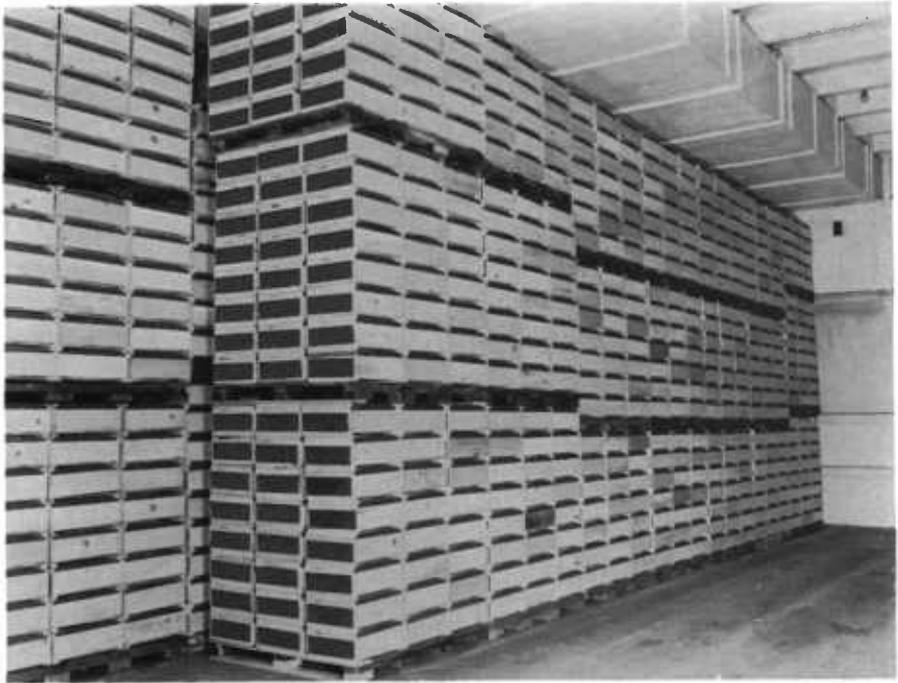


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Figure 10.—Storage room with air discharge ducts at side walls and return duct in center. Air moves down from bottom of side wall ducts and up into bottom and sides of ducts down center of room.

Effect of stacking method on air movement.—Air distribution and fruit temperature are both materially affected by placement and alignment of the stacked packages of fruit. Most of the newer plants stack on pallets with the pallet loads placed 3 high in the storage rooms. Whether the containers are palletized or hand stacked in the rooms, 2 principles should be observed: (1) The side of the display lugs should be in the direction of air movement; and (2) uniform spacing should be maintained between rows and between pallets. Heat transfer is accomplished much more easily from the lightweight, partially open side of the lug than from the thick, solid end pieces; and uniform spacing of rows and pallets is essential for good air distribution.

A cardinal principle of air movement is that air will follow the path of least resistance and, if spacing is irregular, the wider spaces will get a greater volume of air than the narrower ones. If some spaces are partially blocked, dead air zones will occur with resultant temperature rises or localized failure of sulfur dioxide to reach these spots during fumigation. Wide aisles in the direction of air movement are undesirable since most of the air will move through the aisle and will by-pass the stacked fruit. If two-way pallets are used the pallets can be stacked in either direction, but when one-way pallets are used the open ends should always be in the direction of air movement. Figures 11 and 12 illustrate excellent stacking arrangements for



BN-7113

Figure 11.—Palletized stacks on two-way pallets with sides of lugs in direction of air movement.

palletized fruit. Figure 11 shows fruit on two-way pallets with good spacing between rows on the pallets and between pallets. Air is discharged from the duct at the back of the room and moves forward to the coil-bunker through the stacks. This room was being emptied when the photograph was made, but is completely filled during most of the storage season with an aisle only along the coil-bunker side of the end crosswise of the air movement. Figure 12 shows the face of palletized stacks in a coil-bunker room with open fans. Air from the fans moves over the top of the stacks and returns through the stacks to the bottom bunker opening. These are one-way pallets with the open ends in the direction of air movement. Note the uniform spacing of lugs and pallets and the excellent alignment.

Types of Refrigeration Systems

Many cold storage plants in Central California were designed and built specifically for the storage of table grapes. In these plants, four general types of refrigerating systems exist: (1) Individual room dry-coil bunkers; (2) individual room unit coolers; (3) central brine-spray chambers with ducted-air systems; and (4) individual room ice bunkers. There are however, many minor variations within these basic types.

Dry-Coil Bunkers

Most cold storages built in recent years and intended primarily for table grapes are of the individual room, dry-coil bunker type. Direct-expansion coils of smooth pipe

(usually 1½ to 2 inch) are mounted on one wall of the room and a wooden baffle is constructed between the bank of coils and the room. Openings at the top and bottom of the baffle allow air to circulate over the coils. Fans in the upper openings draw the air in at the bottom opening; the air moves over the refrigerating surface on the coil bank and through the fans to ceiling ducts or directly into the space above the stacked produce.

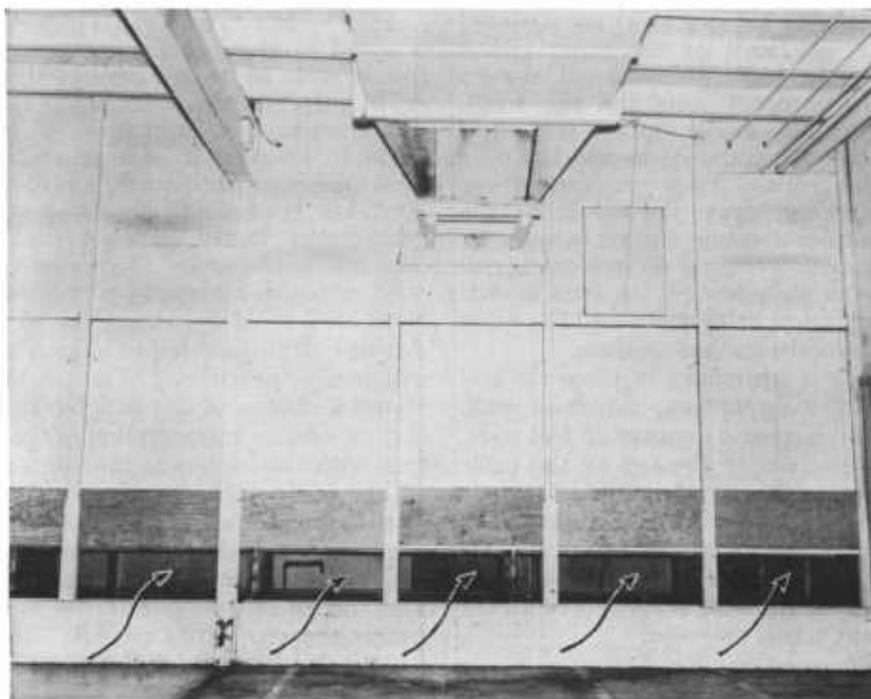
It is customary to place the coil bunker on the long-dimension wall. If the room is not over 40 feet wide, open fans at the top of the baffle generally provide satisfactory air distribution. If the air must be moved more than 40 feet, better air distribution is obtained by moving the air through ducts part or all the way across the room.

This system is particularly well adapted to grape storages because grapes must be treated periodically with sulfur dioxide and the individual room bunker permits each room to be treated as a separate unit. Since sulfur dioxide is rather corrosive to metals, smooth pipe rather than finned coils are used. The coil surfaces are often coated with corrosion-resistant paints, and some method of bypassing the coil during sulfur dioxide fumigation is commonly provided. Figure 13 shows a section of dry-coil bunker during normal refrigeration operation with the louvers at the bottom of the baffle open for air circulation through the coil bank. The same section is shown in figure 14, but with the bottom louvers closed and the hinged door near the fan housing open. This permits cir-



BN-7114

Figure 12.—Palletized stacks on one-way pallets. Air movement along sides of lugs and open pallets.



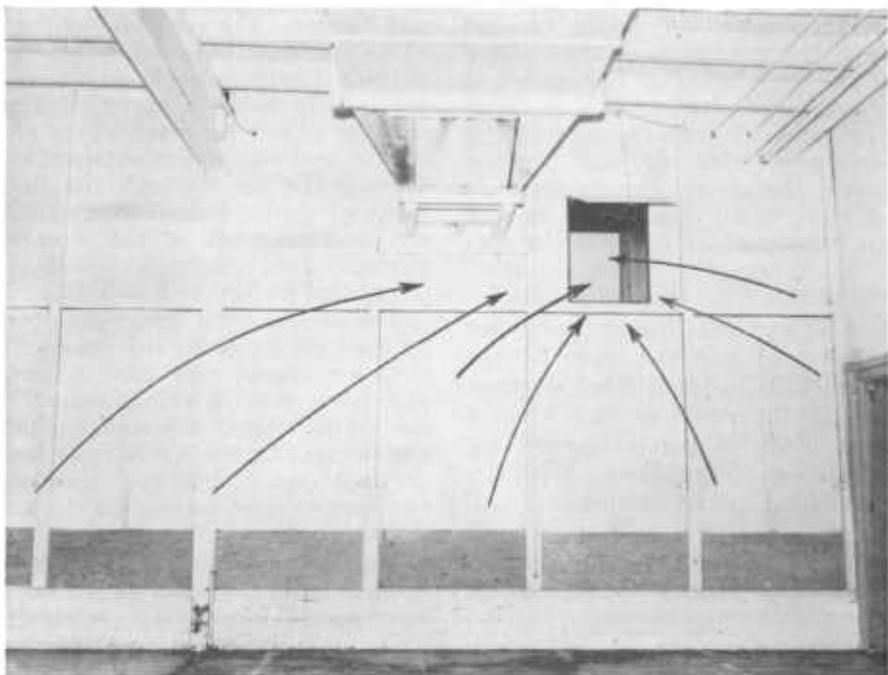
BN-7117

Figure 13.—Section of dry-coil bunker with fan above and bottom louvers open for air circulation through the coil bank.

ulation of sulfur dioxide within the room, while avoiding direct contact of the circulating gas with the coils. However, some of the gas reaches the coils by diffusion and even after the room atmosphere is cleared and normal air circulation is resumed, some sulfur dioxide will be present in the air as a result of a gradual release of the fumigant from the fruit and containers.

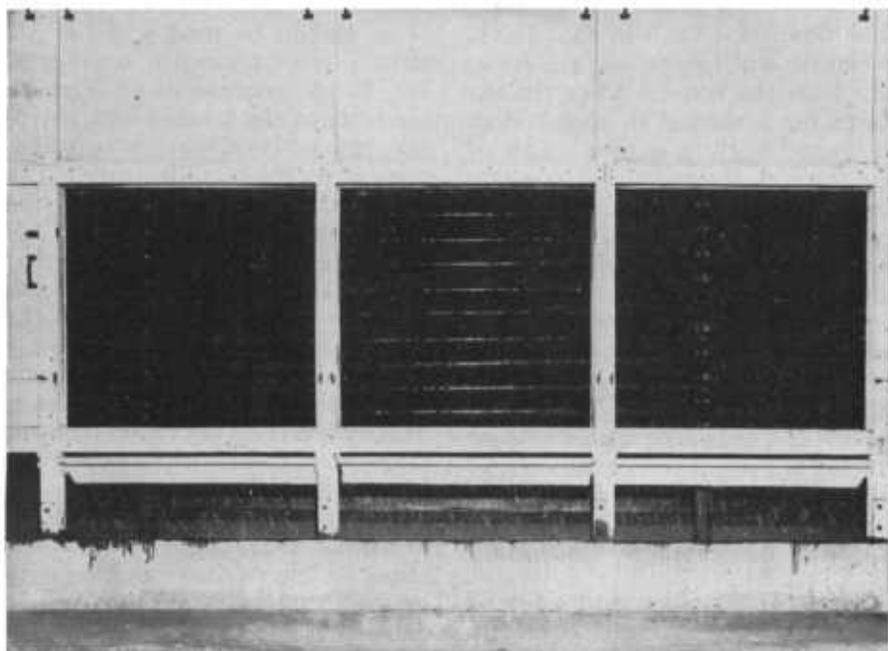
Unless the coils and supports are thoroughly protected by an acid-resistant coating, it is desirable to provide some means of washing the coils after each fumigation. This can be done by means of a water line placed above the coils with spray nozzles at suitable intervals. At the completion of gassing, the ammonia supply to the coil is shut off and the water valve is opened. Since sulfur dioxide is rather soluble in water

the room atmosphere can be cleared rather effectively, with the fans in operation, while the water is flooding down over the coils. At the same time the coils are defrosted and any residual sulfurous acid on the coils is washed away. Figure 15 shows a section of coil bunker with three panels removed to reveal water from overhead nozzles flooding over the coils during the degassing and defrosting period. Usually, somewhat less than 1 hour is required for satisfactory removal of sulfur dioxide from the atmosphere and thorough washing of the coils. Because grapes are usually stored at temperatures slightly below the freezing point of water it is essential that means be provided for draining all water lines in the bunkers at the completion of the washing process.



BN-7118

Figure 14.—Section of dry-coil bunker with bottom louvers closed and door above coils open for bypass during sulfur dioxide fumigation.



BN-7119

Figure 15.—Section of dry-coil bunker with three panels removed to show water from overhead nozzles during degassing and defrosting.

The removal of sulfur dioxide from the storage room atmosphere at the completion of fumigation is accomplished by aeration in those plants that do not have coil washing equipment. In dry-coil bunker rooms the usual arrangement involves a small door at the end of the bunker which opens to the outside. When fumigation is completed this door is opened and outside air is pulled through the bunker and forced into the room by the fans. This builds up some air pressure in the room so that when a room door is partly opened air rushes out of the room. With the usual fan capacity this method will effectively clear a room in 30 to 40 minutes. Of course, some refrigeration is lost by moving outside air into and through the room, but the air does move over the coil before it goes into the room.

Another method sometimes used involves exhausting the air from the room through a flue in the roof. The flue has a built-in fan which, when the flue louver is open, draws air from the room. After the exhaust fan is started an outside door is opened slightly so that a flow of air through the room can be established. With an adequate fan capacity the clearing can be accomplished rapidly, but moving outside air over the fruit during warm weather often causes some condensation of moisture on the fruit and containers. When either method of aeration clearing is used the fumigation and degassing should be done during the night to take advantage of the lower outside temperatures.

Central Brine-Spray Chambers

Many of the older, and a few of the newer cold storages in central California are built with a centrally located brine-spray chamber

and blower. The chamber consists of an enclosed bank of direct-expansion ammonia coils which are continually being sprayed with a solution of salt in water. Very effective heat transfer is obtained by moving the air through the fine spray of chilled brine. The cooled air is distributed to the storage rooms by duct systems such as those illustrated in figures 9 and 10.

The central brine-spray chamber requires substantially less ammonia coil, less liquid and suction line, and fewer control valves than the individual room dry-coil bunker system, resulting in a relatively low original cost. However, effective eliminators must be used on the air discharge side of the brine chamber to prevent particles of brine from being carried in the air to the storage rooms. In grape storage rooms it is necessary to neutralize the brine with sodium hydroxide after each sulfur dioxide fumigation. Equipment for determining the hydrogen-ion concentration of the brine should be used and the pH should be maintained in a range of 7.5 to 8 continuously. Usually the brine is also treated with corrosion-preventive chemicals as recommended by the manufacturer. The principal disadvantages of the ducted brine-spray system as applied to grape storages are (1) that it is usually impossible to fumigate a single room because all of the rooms are served by one main air supply duct and one return air duct; (2) that total air volume is usually less from the central blower than from the multiple fans used in the individual room systems; and (3) that uniform air distribution is difficult to attain because of variations in air pressure and velocity in different parts of the supply duct.

It is a commonly held, but erroneous, belief that a brine spray,

when used for cooling, adds humidity to the air. On the contrary, the brine spray picks up moisture from the air to an even greater extent than a frosted coil due to the somewhat lower vapor pressure of brine at comparable temperatures. Wile and Halls (74) state that if a brine-spray and dry-coil system operate at the same surface temperature the humidity must be lower with the brine system. Thus, it is essential for maintenance of proper humidity that sufficient coil and brine surface be supplied to maintain a minimum split between refrigerant and air temperature.

As mentioned previously, it is usually impractical to fumigate a single room in a multiple-room plant with a central brine-spray system. Therefore, the whole plant must be fumigated as a unit, using the central blower to circulate the sulfur dioxide. The brine spray is turned off during the fumigation and clearing period, but even with the spray off the brine and coils become acidified if circulation is through the spray chamber. Accordingly, it is desirable to bypass the air around the brine-spray chamber during the gassing and aeration periods. This can be accomplished with a special tunnel around the spray chamber which has suitable louvers for diversion of the air through it when needed. Clearing sulfur dioxide from the storage air is often difficult in the central brine-spray system. If an outside door into the return air duct is provided and an outside storage room door opened at the other extreme of the system, clearing can be accomplished reasonably well.

Unit-Coolers

The unit-cooler is a modification of the brine-spray or dry-coil

bunker systems in which the unit contains expansion coils and blowers for moving the air through the coils and discharging it into the room. These may be in the form of relatively small units suspended from the ceiling or large units placed along one wall. These generally have finned coils for extended refrigerating surface and move the air from open fans without ducts. They are usually dry-coil units although some of the larger wall units have built-in brine spray systems. Unit-coolers are not commonly used in grape storage rooms, principally because finned-coils have a limited life when exposed periodically to sulfur dioxide. When such units are used there is a tendency to use too few of them for the maintenance of adequate humidity and air movement. However, there seems to be no reason why unit-coolers should not provide satisfactory conditions for grape storage if the installation is designed to provide adequate refrigerating surface and air volume.

Ice-Refrigerated Storages

Where the storage need is limited to one or two seasonal commodities, with a storage period of only a few months, there has been an increasing tendency to use ice as a source of refrigeration rather than mechanical systems. This is particularly true of storage plants owned by growers who are interested in having precooling facilities available during the harvest season and in storing a limited quantity of fruit for sale during the fall or early winter.

A number of ice-refrigerated storages are in operation in central California. Capacities vary from 4,000 to more than 100,000 lugs of grapes and construction varies from

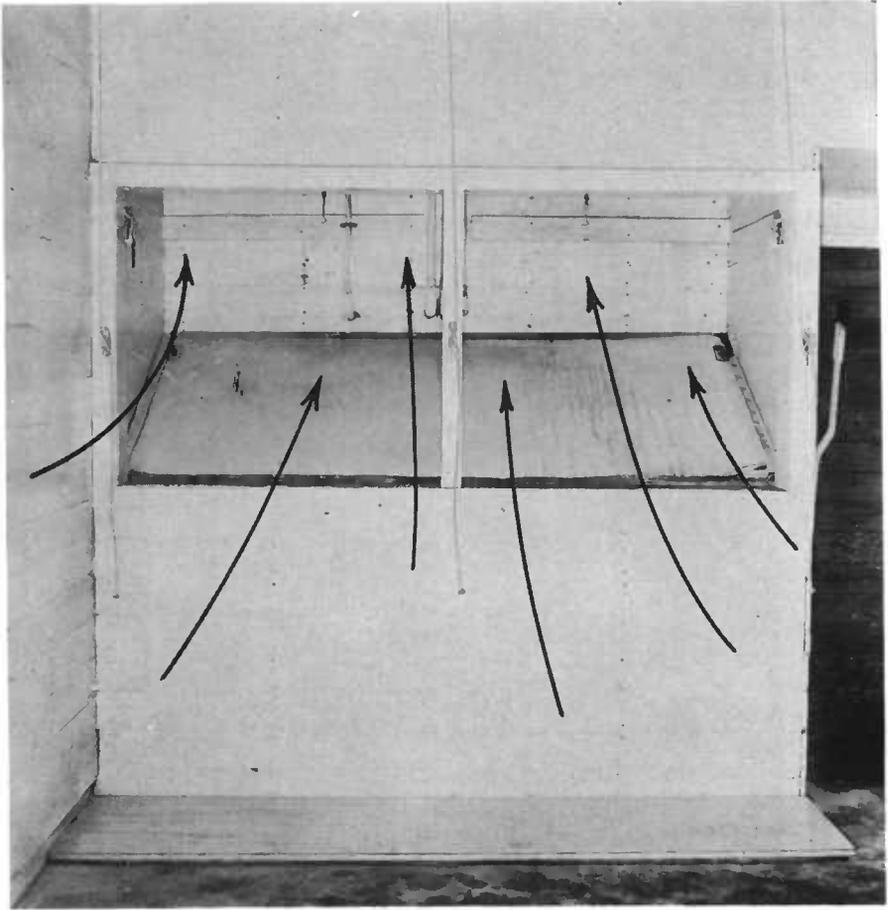
those in which the lugs are hand-trucked and stacked to those with mechanized handling operations and ceiling heights which permit stacking three pallets high. The usual design is similar to that of the individual room dry-coil bunker system, with an ice bunker extending the full length of one wall and fans at the top of the bunker or bunker duct for discharging air into the room. In some cases the bunker is above ground and against the outside of the room. More commonly the bunker is under ground with the loading platform outside the building at its upper surface. This simplifies icing of the bunker, for hatches in the platform are readily accessible and the ice can be handled at truck-bed level. Figure 16 shows the hatches (some open with plugs removed) along the loading platform of an ice-refrigerated storage plant which has underground bunkers.



Figure 16.—Icing hatches for bunkers of ice-refrigerated storage. Bunkers below platform have capacity for about 184 tons of chunk ice.

The first essential of an ice-refrigerated plant is adequate bunker capacity. There must be enough ice surface to provide air near 32° F at the discharge points and the volume of the bunkers must be such that the air will not be restricted during passage through the ice. A good rule of thumb seems to be 1 cubic foot of bunker volume for each 10 cubic feet of room space, although several ice-refrigerated rooms are performing satisfactorily with a somewhat lower proportion of bunker capacity to room volume. In cases where the rooms are used primarily for precooling, and for storage only at the end of the harvest season, at least enough ice bunker capacity should be provided so that 1 reicing each day would maintain the refrigeration capacity during the peak load period. Since a much greater air volume is needed during precooling than during storage, some method of reducing air flow should be provided. This can be accomplished most easily by the use of two-speed fan motors.

As stated previously, sulfur dioxide is fairly soluble in water and the surface of melting ice provides a considerable quantity of water. Therefore it is desirable, so that a reasonably constant concentration of gas can be maintained during the fumigation period, for the air to bypass the ice while the sulfur dioxide is being circulated. A satisfactory method of accomplishing this is illustrated in figure 17. The floor grid through which air normally enters the bunker is closed and a hinged panel in the bunker duct is opened. With this arrangement air is pulled directly from the room and discharged again at the top of the bunker duct. Figure 18 shows the same bunker duct section with the grid cover removed and the duct baffle closed for normal air circulation through the ice bunker.

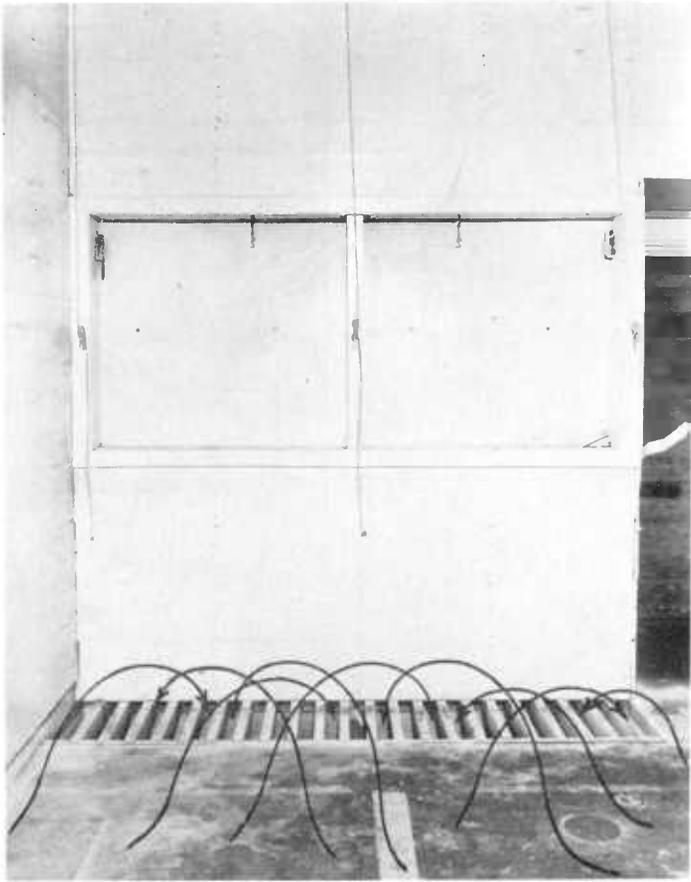


BN-7121

Figure 17.—Section of ice bunker duct with air return grid covered and bypass panel open as used for circulation of SO_2 in the room.

Comparative cost figures between ice-refrigerated and mechanically-refrigerated storages are not available, but it is apparent that the original cost of a mechanically-refrigerated plant would be materially higher than that of an ice-refrigerated plant of the same capacity. On the other hand the cost of operation, on a per-ton of refrigeration basis, would certainly be higher for the ice-refrigerated plant. Even under volume usage, ice probably cannot be purchased on a delivered

basis for less than \$5.50 per ton, whereas an efficient mechanical plant should provide refrigeration at \$2 or less per ton. The decision on whether to use ice or mechanical refrigeration must be based on such factors as annual period of operation, available capital, delivered cost of ice, and need for the lower temperatures obtainable with the mechanical plant. The decision must be made on an individual basis, according to prevailing circumstances and need.



BN-7122

Figure 18.—Section of ice bunker duct with air return grid open and bypass panel closed for normal air circulation through the ice bunker.

Factors Affecting Refrigeration Capacity Requirements

The refrigeration requirement of any storage plant must be based on peak refrigeration load. This peak usually occurs when outside temperatures are relatively high and warm fruit is being moved into the plant for precooling and storage. The refrigeration load during the peak of the harvest season will, of course, depend upon the amount of fruit received each day, the temperature of the fruit at the time it is placed under refrigeration, the specific heat of the product and the final temperature attained. Other

factors affecting the total heat load include vital heat or heat of respiration, heat leakage through room surfaces and open doors, and heat produced by electric motors, lights, mechanical handling equipment, and workmen.

Field Heat

Field heat, or sensible heat as it is sometimes called, is the heat that must be removed from the product to cool it to a given storage temperature. Any measures that can



A



B



C

Plate 1.—A, Stages in the development of gray mold rot. B, Stages in the development of Cladosporium rot. C, Alternaria rot in Emperor grape.



A



B



C



D



E



F

Plate 2.—A, Sound (left) and freezing injury (right) to Emperor grapes. B, Sulfur dioxide injury to Emperor grapes. C, Sulfur dioxide injury to Tokay grapes. D, Ammonia injury to Emperor grapes. E, Box bruising of Emperor grapes. F, Nest rot stage of gray mold rot.

be taken to avoid high fruit temperatures at delivery, such as harvesting early in the morning or shading the fruit from the sun, will naturally reduce the refrigeration load. The amount of refrigeration required to lower the temperature of a known amount of fruit a given number of degrees can be calculated according to the following formula: $R = TR \times P \times S$ in which

Fruit

$$40 (\text{°TR}) \times 28,000 (\text{P fruit}) \times 0.82 (\text{S}) = 918,400 \text{ B.t.u.}$$

Boxes

$$40 (\text{°TR}) \times 4,000 (\text{P wood}) \times 0.33 (\text{S}) = 52,800 \text{ B.t.u.}$$

Total—971,200 B.t.u.

Since 144 B.t.u. are required to melt 1 pound of ice, the removal of 971,200 B.t.u. would require an amount of refrigeration equivalent to that provided by the meltage of 6,744 pounds of ice or by 3.37 tons of refrigeration. If a reduction in temperature of more or less than 40° is required to bring the fruit to storage temperature, the heat load, of course, will be correspondingly greater or less than the figure shown.

Vital Heat

Vital heat is that produced by fruits and vegetables as a result of the respiratory process. As mentioned previously, grapes have a relatively low rate of respiration as compared with other fresh fruits and vegetables. However, a certain amount of heat is produced and it must be considered in the calculation of total refrigeration requirements. Vital heat production by several varieties of vinifera grapes (as calculated from the average rate of carbon dioxide evolution at different holding temperatures) has been published (79). At temperatures from near 30° to about 100° F., the rate at which this heat is generated increases as the temperature of the fruit increases. In fact, the vital heat produced by grapes

R is the B.t.u.³ to be removed, TR is the temperature reduction required in degrees F., P equals the pounds of fruit or containers, and S is the specific heat⁴ of the commodity.

According to this formula, the refrigeration requirement for reducing the temperature of 1,000 standard display lugs of grapes by 40° F. would be as follows:

almost doubles for each 10° rise in temperature between 32° and 80°.

During precooling, the rate of heat evolution decreases as the temperature is lowered and, consequently, a median fruit temperature should be used to calculate the refrigeration load from evolved heat. For example, in calculating the heat evolved by grapes during cooling from 75° to 35° F., the rate of heat evolution at 53° could be used. For the Thompson Seedless variety this figure is given as 1,690 B.t.u. per ton of fruit per 24 hours. On this basis, 1,000 lugs (14 tons of fruit) of this variety would produce 23,600 B.t.u. and would require about 165 pounds of ice, or its equivalent in mechanical refrigeration, to remove the vital heat alone during a 24-hour precooling period.

After the grapes are down to storage temperature the vital heat production is substantially lower than during the cooling period. Thompson Seedless grapes produce only about 430 B.t.u. per ton per

³ British thermal unit, the amount of heat required to raise the temperature of 1 pound of water 1° F.

⁴ Calculated on the basis of moisture content according to the formula $S = 0.008 a + 0.2$ in which S is specific heat, and a is the percentage of water in the product.

24 hours at 32° F., so the vital heat evolved from 1,000 lugs of grapes at this temperature would increase the load by only about 42 pounds of refrigeration per day.

Heat Leakage

A substantial part of the refrigeration load in a cold storage plant is due to heat leakage through exterior walls, the roof, and the floor. The rate of such heat leakage will depend upon the type of insulation used, the thickness of the insulation, the moisture content of the insulation, and the temperature differential existing between the outside temperature and the temperature maintained in the storage room. Shredded redwood bark is commonly used as wall and roof insulating material in California cold storages. The heat conductivity of this insulation has been given (4) as 0.26 B.t.u. per hour per 1° F. of temperature difference per square foot of surface of a

1-inch-thick material having a density of 5 pounds per cubic foot. Corkboard has approximately the same insulating value as redwood bark, but such materials as planer shavings and crushed pumice have considerably less insulating value per inch of thickness (5). A wall of cinder concrete with a density of 97 pounds per cubic foot permits the passage of approximately 19 times as much heat as redwood bark of similar thickness.

A storage room 25 by 40 feet with a 9-foot ceiling would have 1,170 square feet of wall surface and 1,000 square feet each of ceiling and floor surface. If the walls and ceiling of the room were insulated with 8 inches of redwood bark and the floor with 4 inches of corkboard and if the temperature differential averages were 40° F. on the walls, 50° on the roof and 30° on the floor, approximate heat leakage into the room could be calculated as follows:

<i>Exterior walls</i>		<i>B.t.u.</i>
	$\frac{1,170 \text{ (sq. ft.)} \times 0.26 \text{ (B.t.u./hr.)} \times 24 \text{ (hrs.)} \times 40 \text{ (°TD)}}{8 \text{ (in. of RW bark)}} = 36,504$	
<i>Roof</i>		
	$\frac{1,000 \text{ (sq. ft.)} \times 0.26 \text{ (B.t.u./hr.)} \times 24 \text{ (hrs.)} \times 50 \text{ (°TD)}}{8 \text{ (in. of RW bark)}} = 39,000$	
<i>Floor</i>		
	$\frac{1,000 \text{ (sq. ft.)} \times 0.27 \text{ (B.t.u./hr.)} \times 24 \text{ (hrs.)} \times 30 \text{ (°TD)}}{4 \text{ (in. of cork)}} = 48,600$	
	Total heat leakage per day -----	124,104

Thus, under the conditions specified, the refrigeration requirement for heat leakage through exterior surfaces would be almost one-half ton per day.

Air Infiltration

Storage room doors are open for substantial periods each day for placement of fruit in the rooms and removal of fruit for shipment. The air entering the room, during the

exchange which occurs as a result of temperature differential, may carry large quantities of heat along with it, particularly if outside doors are open. Hukill and Smith (31) state that 100,000 B.t.u. per hour can enter a room through a 4- by 7-foot outside door when a temperature differential of 30° F. exists between room air and outside air. It is apparent that any means of reducing this air exchange, such as using light-weight swinging doors

or automatic door-opening and closing devices, will result in a material reduction of total heat load.

Other Heat Sources

Heat is produced by electric motors, electric lights, and the combustion-type motors used on some fruit-handling equipment. All of these sources add to the total heat load in the cold storage plant. The amount of heat evolved from an electric motor can be estimated at 3,000 B.t.u. per hour for each horsepower. Each kilowatt of incandescent light adds about 3,500 B.t.u. per hour. In addition to these mechanical sources of heat, the vital heat produced by workmen accounts for 1,000 B.t.u. per man-hour. A calculation of these factors for a 40-carlot room with six 1-horsepower fan motors operating contin-

uously, six 200-watt lights burning 8 hours each day, and 2 men working in the room for 8 hours each day, will show the heat load in the room from these sources as follows:

<i>Electric motors</i>	<i>B.t.u.</i>
6 (motors) × 3,000 (B.t.u./hr.) × 24 (hrs.)	= 432, 000
<i>Electric lights</i>	
1.2 (KW) × 3,500 (B.t.u./hr.) × 8 (hrs.)	= 33, 600
<i>Workmen</i>	
2 (men) × 1,000 (B.t.u./hr.) × 8 (hrs.)	= 16, 000
Total heat load-----	481, 600

Thus the heat produced from incidental sources in this 1 room would require about 13¼ tons of refrigeration per day.

Disorders of Grapes in Storage

During storage grapes are subject to a variety of disorders, some of which result from conditions that exist during storage, some from conditions that already existed when the fruit was placed in storage, and others that result from a combination of postharvest and preharvest factors. Deterioration of fruit in storage can be the result of attack by decay-causing organisms, of natural aging processes, or of chemical, physical, or mechanical injuries. A thorough understanding of each of these factors is necessary to determine the most effective way of controlling them.

Decay

Gray Mold Rot

The fungus *Botrytis cinerea* pers. ex Fr. (gray mold), is widespread in nature and causes decay in many kinds of fruit, vegetables, and ornamentals. Since this organism is

capable of growth at low temperatures, it is one of the principal causes of spoilage in grapes held in cold storage. Gray mold is particularly prevalent in varieties such as Emperor, Ribier, or Flame Tokay when they are harvested late in the season after exposure to high moisture conditions.

Symptoms.—Several common names are used to describe the various stages of gray mold rot. The early stage of the disease commonly is called "slip skin" since, after infection, the tissue just beneath the surface of the berry is attacked first, loosening the skin from the underlying flesh. A slight pressure applied to the berry causes the skin to break loose and separate from the firmer underlying tissue, hence the name, "slip skin." There may be a slight browning of the affected areas of the berry, but at this stage, the decay is not readily discernible by appearance alone (plate 1, A).

Later, the causal fungus grows through the entire inner flesh of the berry, resulting in a soft, watery mass of decayed tissue enclosed in a still, somewhat intact, but browned skin. Under moist conditions the fungus sporulates on the surface of the berry, producing the typical gray mold stage of the disease. However, when grapes are fumigated in storage, surface growth and spore formation are usually prevented. Fumigation does not prevent development of the fungus within previously infected berries. Diseased berries gradually lose moisture, shrivel, become a darker brown color, and form the mummy stage of decay. In storage the fungus may spread by contact from a diseased berry to adjoining berries, in which case the "nest rot" stage of the disease is formed. When nest rot occurs there is usually a rather well-developed growth of grayish-white mycelium over the surface of the affected berries (plate 2, *F*) (18, 43).

Control measures.—There are four primary measures that may be employed to reduce postharvest losses from gray mold rot. Each of these is related to and serves to supplement the others:

1. Grapes that are to be shipped directly to market after harvest should be rapidly cooled to at least 40° F. and those that are to be stored before marketing should be rapidly cooled to 31° to 32° F. Holding grapes at low temperature slows the development of gray mold, but does not in itself provide complete control.

2. Soon after harvest, and at intervals during storage, Vinifera grapes should be fumigated with sulfur dioxide (see section on sulfur dioxide for details). American, or eastern, varieties of grapes are not fumigated because of their susceptibility to injury.

3. Vineyard applications of fungicides to prevent field infections

have been effective in reducing decay in storage (18, 20, 21, 22, 26, 44, 65, 66). One of the most effective materials tested for this purpose has been captan. This fungicide is usually applied as a dust in a formulation containing 10 percent captan, 50 percent sulfur, and 40 percent inert carrier. Application is made at the rate of 20 pounds per acre with the duster directed toward the clusters. For Emperor grapes grown in California the first application should be made about the middle of July and should be followed by additional dustings at 3- to 4-week intervals with the last one applied not later than 2 weeks before harvest. This is a rather expensive treatment and, though it has been effective in years in which the fruit is exposed to high moisture conditions, it is of no particular benefit in dry years. The grower must consider the economic aspects of the control measure, therefore, before deciding upon its use.

4. Selective marketing to minimize decay losses has been shown to be effective (see separate section on this subject for details). The use of a decay forecast allows the storage operator to market early those lots of grapes in which a high percentage of decay is indicated and to retain in storage only those lots likely to remain sound.

Certain cultural practices have been found to affect the incidence of gray mold rot. The control of insects in the vineyard, for example, indirectly affects decay by reducing wounds in the fruit (39, 75). Dense foliage around the fruit and weeds around the base of the vines tend to slow the time required to dry the grapes after exposure to rainfall and thus favor the development of decay (11, 63).

Additional references on gray mold rot are: (19, 40, 41, 53, 55, 56, 60, 67, 68, 69).

Cladosporium Rot

Cladosporium rot, (*Cladosporium herbarum Pers.*), is an important cause of spoilage in grapes held in cold storage, particularly in the Emperor and Flame Tokay varieties. Like gray mold rot, the causal fungus is capable of growth at and even below storage temperatures.

Symptoms. — Cladosporium causes a black, firm decay that is usually localized on one side of the berry. The decay is not definitely sunken, but the grape is flat or wrinkled on the affected side. The decay is shallow and usually does not extend to the seeds. The affected tissue is firmly attached to the skin and can be easily removed with it. In storage, signs of the fungus are usually not present on the surface of the affected berries (Plate 1, B), but when the fruit is removed from storage and placed at room temperature, a sparse surface growth of gray-green fungus may be produced (18). Cladosporium rot is easily distinguished from gray mold rot by its black color and the fact that it usually remains localized rather than affecting the entire berry.

Control measures.—Fumigation of vinifera grapes with sulfur dioxide reduces postharvest infections of grapes by Cladosporium and other fungi and reduces spread of decay from affected to sound berries in storage and transit (see section on sulfur dioxide). Applications of fungicides in the vineyard have reduced the development of Cladosporium rot in stored grapes but the disease is usually not serious enough to warrant the expense of applying fungicides in the field (26). Additional references on Cladosporium rot are: (7, 13, 17).

Alternaria Rot

During the storage of Emperor and some other varieties of grapes,

decay caused by species of *Alternaria* and *Stemphylium* may develop. Infections by these organisms seem to occur quite early in the harvest season, even in the absence of rainfall (26, 27). The causal fungi often gain entrance into the berry through the capstem, causing a localized tan to dark brown decayed area in the berry (plate 1, C). Since the fibrous conductive tissue ("brush") that leads into the berry from the capstem is attacked, affected berries are easily shaken from the cluster. Species of *Alternaria* and *Stemphylium* may occasionally be isolated from other parts of the berry where they cause symptoms quite similar to those caused by *Cladosporium*, but which are not as dark in color.

Other Types of Decay

Although table grapes are subject to many types of decay in the field, only the above-mentioned organisms commonly cause decay at low storage temperatures under California conditions. Decay caused in the field by organisms that are active only at high temperatures is usually culled out at harvest or during packing and, consequently, is not a serious disorder in storage. For information regarding these disorders refer to U.S. Department of Agriculture Miscellaneous Publication No. 340, Market Diseases of Fruits and Vegetables: Grapes and Other Small Fruits (60).

Physiologic Aging

Unlike certain other fruits, grapes do not ripen after harvest or improve in flavor or texture during storage. Since there is no starch reserve in the grape, there is no increase in sugar content after harvest. Grapes, therefore, are at prime quality at harvest, and subsequently suffer a gradual decline in quality.

As grapes approach the end of their storage life the berries become somewhat dull in color, losing the brightness they had at harvest. Red varieties assume a gray-purple color and green varieties turn a gray-green to brown color. The texture becomes soft and flaccid and the flavor resembles that found in raisins.

Though picked from the vine, the grape is still a living organism in which a considerable amount of sugar (carbohydrate) is stored. The vital processes (respiration) that go on in the fruit after harvest gradually use up the stored carbohydrates, taking up oxygen and releasing carbon dioxide, water, and a certain amount of heat in the process (see section on vital heat). The evolution of heat, which is a measure of respiratory activity, is lower in vinifera grapes at 32° F. than in any other fruit except the Winesap apple (79). Factors that affect the rate of respiration and consequently the aging of grapes in storage are temperature, fruit maturity at harvest, variety, and sulfur dioxide fumigation.

Temperature.—Temperature is the most important factor affecting the rate of respiration. Within certain limits, the respiration rate decreases with a lowering of the temperature. De Villiers (14) demonstrated that the respiration rate in Red Muscat grapes was about 2½ times as great at 50° as at 32° F., 7 times as great at 68° as at 32° F., and 18 times as great at 86° as at 32° F. The importance of rapid cooling in relation to the storage life of the fruit is apparent from these results.

Maturity.—Immature grapes have a higher rate of respiration than mature ones. De Villiers found that in Mataro grapes the respiration rate was about 1½ times as great in green as in firm ripe fruit. Differences in respiration rates due to maturity were greatest immedi-

ately after harvest and became less pronounced toward the end of the holding period. Grapes to be stored for long periods, therefore, should be of prime maturity, but not over-ripe. Since over-ripe fruit is more susceptible to infection by the gray mold fungus than less mature fruit, this factor should also be considered when selecting fruit for long-term storage. Fruit having green, immature stems appears to age more rapidly in storage than fruit with strong, amber-colored, mature stems.

Variety.—The rate of respiration differs considerably among different varieties of grapes. In general, poor keeping varieties have a higher rate of respiration than varieties that keep well in storage (14). Thompson Seedless grapes, for example, which have a maximum storage life of about 100 days, respire more rapidly and evolve more heat at 32° F. than Emperor or Almeria, both of which can be successfully stored for periods as long as 6 or 7 months. The normal storage life of several grape varieties is shown below. Certain lots of each of these varieties may keep for longer or shorter periods, depending upon the quality at harvest.

Variety:	Months in storage
Muscat (Alexandria)-----	1 to 1½
Flame Tokay-----	1½ to 2½
Thompson Seedless (Sul- tanina)-----	2 to 3
Red Malaga (Castiza)-----	2 to 3
Malaga (White Malaga)---	2 to 3
Almeria (Ohanez)-----	3 to 5
Ribier (Alphonse Lavallee)-----	3 to 5
Emperor-----	4 to 6

Sulfur dioxide fumigation.—Several workers have found evidence that fumigation with sulfur dioxide slows the rate of respiration and thereby contributes to a lengthening of the storage life of the fruit by physiologic means as well as through decay control (see section on fumigation with sulfur dioxide).

Chemical Injury

The principal chemicals to which grapes may be exposed in storage are sulfur dioxide and ammonia gas.

For information concerning injury with sulfur dioxide, see section on fumigation with this chemical and plate 2, *B, C*.

In plants using a direct expansion refrigeration system, grapes are sometimes exposed to ammonia gas that has escaped into the atmosphere of the storage room. Red-colored grapes turn blue and green-colored fruit assumes a slightly bluish cast in the presence of ammonia (plate 2, *D*). The change in color is caused by the reaction of ammonia with the sap in the cells near the surface of the fruit. When exposed to the gas the sap becomes less acid and the acid-sensitive pigments (anthocyanins) in these cells change color.

Most of the gas enters the berries around the capstem attachment, and the adjacent tissues develop the greatest discoloration. Similar discolored areas may form around wounds in the skin. When exposed to ammonia the capstems turn dark blue or black and portions of the stems become blue (*16*).

When an ammonia leak is detected, the gas should be cleared from the room as soon as possible because slight discolorations from the gas disappear when the fruit is removed from the ammonia atmosphere. The fruit will not recover from severe injury resulting from long exposures to the gas. The best way to remove ammonia from the room is with water. In rooms equipped with a spray system for clearing the room of sulfur dioxide this can easily be done.

Another way of minimizing damage from ammonia is to neutralize it with sulfur dioxide. Sulfur dioxide reacts with ammonia to form ammonium bisulfite, a whitish

crystalline substance. Approximately 4 pounds of sulfur dioxide are required to neutralize 1 pound of ammonia. No more than a 1 percent concentration of sulfur dioxide should be used, as higher concentrations might cause injury to the fruit. If commodities other than grapes are stored in the room, sulfur dioxide cannot be applied.

Freezing Injury

Vinifera grape varieties when injured by freezing have a dull appearance and are soft and flabby. After severe freezings they turn brown and become wet and sticky (plate 2, *A*). The berries of most varieties will not freeze at temperatures as low as 28° F. because of the high sugar content. However, the stems and capstems are often injured by temperatures that apparently have no effect on the berries. The frozen stems are at first limp and pliable, with a water-soaked or dark-green appearance; but they soon dry, become dark colored, and are more susceptible to mold invasion than sound stems. However, if grapes are frozen after having been fumigated with sulfur dioxide in storage, the stems may not turn dark, but retain their former green or straw-yellow color. When berries, injured by freezing, are pulled off the capstem, the brush (the small bundle of fibres that extends from the capstem into the berry) is usually found to be shorter than normal and somewhat browned (*60, 79*).

Desiccation

Desiccation in storage is evidenced by dry stems, shriveling of the berries near the capstems, and by loss of weight. There are several factors that affect desiccation in storage grapes:

Temperature.—High temperatures in the field at harvest and ex-

posure to high temperatures after harvest result in a rapid drying of the stems and shriveling of the berries. Stems dry and turn brown almost four times as fast at 100° as at 70° F. and the berries lose weight six times as fast at 100° as at 70° F. (42). The importance of careful handling to prevent exposure to high temperature is obvious. There is evidence that picking grapes in the cool part of the day lessens drying of the stems (23, 8, 9). Fruit should not stand in the field or in the sun for long periods and should be precooled to storage temperatures as rapidly as possible. The longer it takes to bring the temperature of the fruit down to the air temperature of the precooling or storage room, the greater the loss of moisture from the fruit (see section on precooling).

Humidity studies in South Africa have shown that picking fruit during periods of high humidity lessens drying of the stems (23). It should be pointed out, however, that such conditions also favor the development of gray mold rot. The maintenance of relative humidity at approximately 90 percent in storage will aid in preventing excessive drying of the stems (see section on relative humidity). The relative humidity of the air surrounding the fruit within the package is affected by air movement around the package in the storage room. Once the fruit is cooled, it is desirable to provide only enough air movement to maintain the 31° F. temperature of the fruit. In rooms where favorable levels of relative humidity or air velocity cannot be maintained, curtains and package liners of various types may be helpful in preventing desiccation. However, these are a disadvantage during precooling.

Maturity.—In California storage varieties, such as Emperor, there is less desiccation in mature than in immature fruit. As the fruit ma-

tures the skin becomes more lignified and more resistant to water loss (14). Many growers do not harvest the Emperor until the stems have developed a woody texture and have begun to turn yellow or amber. When the vines are over-cropped the stems remain green and weak, the fruit fails to mature properly or there is a delay in reaching maturity. Cultural practices that favor early maturity of the grapes, therefore, provide fruit that is less susceptible to desiccation and less likely to be exposed to conditions favoring gray mold rot.

Mechanical Injury

Shatter

One of the most common forms of mechanical injury in California table grapes is shatter (the separation of the berries from the cluster). Varieties differ greatly in their susceptibility to this disorder. The Flame Tokay and Thompson Seedless (Sultanina) varieties are especially subject to shatter while the Emperor and Ribier are relatively resistant. In most vinifera varieties shatter results from a pulling of the "brush" from the flesh of the berry while in certain labrusca types an abscission layer develops at the junction of the capstem (pedicel) and the berry (47). This latter type of shatter is also characteristic of certain vinifera varieties grown in South Africa (8, 9).

Rough handling during picking, packing, and transit is responsible for a large part of the shatter that occurs in storage grapes. W. T. Pentzer of the U.S. Department of Agriculture (unpublished data) found that shatter caused by transit impacts could be materially reduced by eliminating all slack from the load in the refrigerator car. This was done by compressing the load with a mechanical "car-squeeze" and bracing the center space so that

load tightness is retained during transit. Cultural practices such as thinning help to strengthen the stems and reduce shatter. There is also evidence that hot, dry weather and a deficiency of soil moisture during the period of ripening contribute to shatter (8, 9). Girdling Thompson Seedless vines to increase the size of the berries also strengthens the attachment of the berries to the stems, thereby reducing shatter (33). Pentzer (47) found that naphthalene acetic acid (NAA) did not affect the adherence of the berries in vinifera grapes, although this material was found to reduce drop in other fruits. He attributed the ineffectiveness of NAA applications to vinifera grapes to the lack of a definite abscission layer. Grapes that firmly adhere to the stems at harvest sometimes develop shatter after prolonged storage. If grapes are allowed to become over-mature before harvesting, more shatter occurs than when the fruit is harvested at prime maturity (14).

Postharvest conditions that favor desiccation also favor shatter. Shatter is reduced by rapidly cooling the fruit as soon after harvest as possible.

Bruising

Bruising commonly occurs in berries that are in contact with the sides or bottom of the packed container (plate 2, E). Affected berries are somewhat flattened, show a brown discoloration, and are situated on one side of the bunch.

When grapes are fumigated in storage or transit, the bruised areas may become bleached as sulfur dioxide penetrates the berry readily at points where the skin is weakened. The small, dried undeveloped "shot berries" that drop off the cluster and collect in the bottom of the box sometimes puncture or bruise the skin. Severe bruising may predispose the fruit to infection by decay organisms.

Protective liners to prevent the fruit from touching the wooden sides of the box and adequate padding in the bottom of the box help to reduce bruising.

Berry Cracking

As the temperature of fruits is lowered, the turgidity generally increases. Varieties in which the berries have thin skins, such as Thompson Seedless, will sometimes crack during precooling or in the early stages of cold storage. Cracks in the skin can frequently be found in the Flame Tokay at harvest and may be infected with the *Cladosporium* fungus. These cracks are crescent-shaped, usually occur at the blossom end of the berry, and are rarely over one-fourth inch long and one-eighth inch deep. The disorder apparently occurs more extensively in grapes that are very turgid at harvest as a result of exposure to wet weather or other high moisture conditions. No effective control measures have been developed for cracking. Fortunately it affects a relatively small proportion of the crop.

Fumigation With Sulfur Dioxide

The effectiveness of sulfur dioxide in retarding the activity of spoilage organisms in fresh grapes was demonstrated in 1925 by Winkler and Jacob (77). Shortly thereafter, methods of applying the gas to commercial shipments of grapes

were developed (32) and the various factors related to decay control and fumigation injury were determined (6, 30, 32, 48, 49, 77).

Sulfur dioxide is used primarily to control grey mold rot in storage. Grey mold (*Botrytis cinerea*) is

one of the few organisms causing grape decay that is capable of growth at the low temperatures at which grapes are stored. If the berries are infected with this organism before storage, fumigation with sulfur dioxide is ineffective in killing such infections and the decay continues to develop. However, the gas kills fungus spores present on the surface of the fruit and consequently prevents post-harvest infections. When properly applied it also prevents the spread of decay by contact from previously infected berries to sound ones, thus eliminating "nest-rot."

Decay caused by the other low temperature organisms, *Cladosporium herbarum* and species of *Alternaria*, is also reduced by sulfur dioxide fumigation. As in grey mold, fumigation kills spores on the surface, but does not control infections that have occurred before storage (27).

In addition to reducing decay, sulfur dioxide is effective in setting the light green or straw yellow color of the stems. Without fumigation grape stems turn a dark brown or black color in storage. Fumigation also tends to prevent the berries from becoming separated from the cluster ("shattering") (34, 35, 58). Wounds that would otherwise act as entrance ports for decay organisms are cauterized by the fumigation.

Grapes treated with sulfur dioxide have a slower rate of respiration than untreated ones (52, 77) and this lowered rate of respiration tends to lengthen the storage life of the fruit. Pentzer *et al* (52) found that when Emperor grape tissue contained 87 p.p.m. sulfur dioxide, respiration was reduced to 8 percent of normal at 32° F. However, at this concentration the gas caused serious injury to the fruit. At a concentration of 22 p.p.m. no injury occurred and the respiration rate

was reduced to 82 percent of that in an untreated check lot. Although the effect of sulfur dioxide on the respiration rate is slight at the concentrations employed commercially, there is a small reduction in the loss of stored carbohydrates from the fruit. The sensitivity of the relationship between the respiration rate and the concentration of sulfur dioxide in the tissues is demonstrated by the fact that the respiration rate increases during the intervals between fumigations in storage (37).

Methods of Applying Sulfur Dioxide

Sulfur dioxide may be applied either by releasing the compressed gas from steel cylinders, or by adding potassium or sodium bisulfite to the package. At one time the gas was generated by burning sulfur in the fumigation chamber, but this method is no longer in common usage.

Fumigation With the Liquefied Gas

Fumigation may be accomplished in special fumigation rooms, in precooling rooms, in refrigerated storage rooms, or in railway refrigerator cars. Initially a 1 percent concentration of gas is applied to the fruit for 20 minutes. This is often done in a special gassing room at prevailing outside air temperatures. During cold storage the fruit is fumigated at weekly or 10-day intervals with $\frac{1}{4}$ percent concentrations of sulfur dioxide for 20 minutes (29, 61).

The concentration of gas can be calculated on the basis of free air space in the chamber used for the fumigation (2). First, determine the volume of the chamber in cubic feet; next subtract 0.5 cubic foot for each lug of grapes to be fumigated. The fruit in each lug occupies ap-

proximately 0.5 cubic foot of space, when air voids between the berries are taken into account. Since 1 pound of sulfur dioxide is equivalent to 5.5 cubic feet of gas at 32° F., the free space (cubic feet) in the chamber multiplied by the percent concentration desired, divided by 5.5 will give the pounds of gas needed. For example, the amount of sulfur dioxide required to make a 0.25 percent concentration of the gas in a 3,200 cubic foot storage room containing 500 lugs of grapes is calculated as follows:

$$\frac{[3,200 - (500 \times 0.5)] \times 0.0025}{5.5} = 1.34 \text{ lbs.}$$

Cylinders containing the correct weight of gas for specific storage rooms or other fumigation chambers are provided by various service companies to the storage operator. The cylinder is connected to a pipe leading into the fumigation chamber, the valve is opened and the cylinder is heated in a water bath to drive all the gas into the chamber. The sulfur dioxide is rapidly mixed with the atmosphere inside the chamber by fans or blowers to insure uniform distribution of the fumigant.

After a 20-minute exposure of the fruit to the fumigant, the sulfur dioxide is removed either by opening room doors, by ceiling exhaust fans or by a water spray system (see section on refrigeration systems). Sulfur dioxide is usually cleared from fumigated refrigerator cars by circulating the air through the ice bunkers. The gas is dissolved in the film of water on the melting ice surfaces.

For fumigating grapes in a refrigerator car a fan with canvas baffles should be used in the brace to distribute the sulfur dioxide uniformly in the load. Without a brace fan, injurious concentrations of gas

accumulate in the space above the load and in the open brace, and relatively little fumigant reaches the fruit within the load, providing poor control of decay (72).

A method sometimes used to estimate the amount of gas needed for a 0.25 percent concentration is to use $\frac{3}{4}$ to 1 pound of gas for each 1,000 lugs of grapes. Until the room is half filled with grapes an additional $\frac{1}{4}$ pound of sulfur dioxide is used for each carload unit of empty space. Thereafter, no gas is added for the unoccupied space (2).

Under experimental conditions it has been found that continuous exposures to very low concentrations of sulfur dioxide (30 p.p.m.) were effective in controlling decay and resulted in less injury to certain grape varieties than did short exposures of higher concentrations of gas (35, 37, 58). To utilize this method of fumigation a device to automatically control the concentration of sulfur dioxide in the storage room was developed in South Africa. Although this method of fumigating grapes may be adaptable to certain types of small storages, the maintenance of a constant concentration of sulfur dioxide in large storage rooms would be difficult as it would preclude normal handling operations to remove fruit at intervals for marketing. In rooms using ice as a refrigerant, low concentrations of sulfur dioxide could not be maintained as the gas would be absorbed by the ice. The same difficulty would be encountered in rooms refrigerated by a brine-spray system.

Fumigation With Bisulfite

Sodium or potassium bisulfite is utilized as a source of sulfur dioxide under conditions that preclude fumigation of grapes in the storage

room or refrigerator car. Such conditions exist in fruit that is exported in the sawdust pack and which cannot be "room fumigated" during transit aboard ship. Prior to shipment, grapes destined for export are usually fumigated in the usual way at intervals during storage and the sawdust and bisulfite are not added until the grapes are ready to be shipped. The sawdust acts as a dispersing agent for the bisulfite as well as a cushion for the fruit against mechanical injury.

Sodium bisulfite can also be used in the standard display lug by distributing the powder evenly in the excelsior pad placed in the bottom of the box. The pad is slit to add the bisulfite and the paper cover is then replaced so that the fruit is not in direct contact with the powder. Not over 5 grams of bisulfite should be used in either the standard 28-pound display lug or in the sawdust pack as larger amounts may cause injury to the fruit (6, 45, 48, 49).

Sulfur dioxide is produced as a result of the reaction of bisulfite with moisture in the atmosphere. If there is not too much moisture in the package, the release of gas is quite slow and the fruit, therefore, is exposed to low concentrations of sulfur dioxide over a long period of time. Care must be taken, however, never to use bisulfite under abnormally high moisture conditions as this would result in such a rapid release of gas that chemical injury to the fruit would occur. Such high moisture conditions would exist, for example, if wet sawdust were used or if wet fruit were packed.

The rate at which bisulfite releases sulfur dioxide gas can be regulated to a degree by mixing it with various hygroscopic materials, such as dehydrated alum or silica gel (33, 57, 59, 71, 73). Such ma-

terials reduce the amount of moisture available for reaction with the bisulfite and consequently slow the release of gas. However, these methods have only been used under experimental conditions and have not gained wide commercial application in the United States.

Symptoms of Sulfur Dioxide Injury

One of the most common types of injury that may occur in grapes fumigated with sulfur dioxide gas is a bleaching or discoloration of the fruit. This is most pronounced at breaks in the skin or at the attachment of the capstem to the berry. Although the gas can enter the berry through the vascular tissue of the capstem, it penetrates more readily through tears that occur in the skin near the capstem attachment during handling. As a result, the tissue underlying such wounds tends to dry out and collapse, forming a pit or depression that is a well-known symptom of sulfur dioxide injury. This type of injury is particularly prevalent in the Emperor variety when stored for long periods (plate 2, *B*).

In certain varieties, such as Flame Tokay, injury may occur as small, bleached, and slightly sunken pits scattered over the entire surface of the berry (plate 2, *C*). These detract from the normal bright color of the fruit and can make the fruit unmarketable.

When sulfur dioxide injury occurs in red varieties, the color of affected areas of the berries may change to pink or white; with blue or black varieties, the color becomes a lighter blue or pink; and with white varieties, affected areas sometimes assume a greyish cast. Injury is more apparent after the grapes have been exposed to warm temperatures for several hours than

it is immediately after the fruit is removed from cold storage. Injured berries may turn brown at warm temperatures due to oxidation reactions in the affected tissues.

Immediately after fumigation, grapes may have a slightly sulfurous taste and badly injured fruit may have a distinctly disagreeable, astringent flavor. However, it has been found that 50 percent of the sulfur dioxide residue in the fruit disappears within 2 days after treatment and the fruit is almost entirely free of sulfur dioxide within 5 days after treatment (48). Consequently, fruit treated when shipped from California is almost entirely free from sulfur dioxide by the time it reaches eastern markets.

Factors Affecting Sulfur Dioxide Injury

The amount of sulfur dioxide injury that develops in fumigated grapes is directly related to the amount of the fumigant absorbed by the fruit. Absorption of sulfur dioxide is dependent upon the particular variety, the maturity of the fruit, the fruit temperature, the presence of wounds and the concentration, frequency, and length of exposure to the gas.

Variety

Certain varieties of table grapes such as Malaga, Thompson Seedless (Sultanina), and Castiza (Red Malaga) absorb sulfur dioxide more rapidly than Ribier (Alphonse Lavallee) and Alicante Buschet. The rate of SO_2 absorption by the Emperor variety is slightly greater than that of Ribier, but considerably lower than that of Thompson Seedless (48, 51). Flame Tokay is quite susceptible to injury as evidenced by the pitting that frequently is found over the surface of this variety after fumiga-

tion (54). Many of the varieties of grapes grown in South Africa are particularly subject to injury from sulfur dioxide. Consequently, when the fumigant is employed, it is administered in much lower concentrations than are used commonly under commercial conditions in the United States (18, 58).

Maturity

Immature fruit absorbs gas more rapidly than mature fruit (48). Winkler and Jacob (32, 77) found that ripe Muscat grapes (27° Balling) absorbed about one-half as much sulfur dioxide as green ones (18° Balling) and about one-sixth as much as very green ones (13° Balling). Since very mature grapes are more subject to infection by decay organisms and absorb sulfur dioxide less readily than immature grapes, it may sometimes be desirable to fumigate them with slightly higher concentrations of gas than are ordinarily used.

Fruit Temperature

Warm grapes absorb more sulfur dioxide than cold grapes (32, 48, 77). Pentzer and Asbury (48) found that Thompson Seedless grapes absorbed more than twice as much gas at 72° than at 39° F. Malaga grapes absorbed almost three times as much gas at 75° than at 48° F. Temperature is a particularly important factor in sulfur dioxide injury when varieties that absorb sulfur dioxide rapidly are being fumigated (58).

Wounding

The intact skin of most varieties of vinifera table grapes grown commercially in California possesses a high degree of resistance to penetration by sulfur dioxide gas. However, the gas is able to penetrate the berry through the vascular tissue of the cistern and readily

penetrates through any type of perforation of the skin caused by physical wounding, the activity of decay-causing organisms, or other weakening factors. These characteristics are desirable to a certain degree since the fumigant tends to concentrate in the tissue at points that are most susceptible to invasion by spoilage organisms. The fact that grapes are to be fumigated, however, is no excuse for rough or careless handling, as the bleached, pitted areas that form at points of wounding lower the quality of the fruit (32, 77).

Concentration and Length of Exposure to Fumigant

The higher the concentration and the longer the exposure, the more sulfur dioxide grapes absorb. Of all the factors considered, these are the most important in relation to fumigation injury. The use of circulating fans or blowers is essential to distribute the gas uniformly in the fumigation chamber and to prevent injurious concentrations from building up near the gas inlet. It is also important that an efficient method of exhausting the room of fumigant is used to prevent over-exposure to the gas. When refrigerator cars are fumigated, allowance must be made for the ice in the bunkers since sulfur dioxide is rapidly absorbed by the melting ice.

To determine the concentration and length of exposure that will control spoilage organisms without injury to the fruit, all the above factors as well as those related to infection by decay organisms must be considered. The concentrations and exposures cited under "Methods of Applying Sulfur Dioxide" meet the needs for fumigation under average conditions. Commercial operators sometimes vary the concentration and exposure to

meet the needs of specific situations. Obviously, since a given storage room may contain grapes of several varieties, maturities, and with different decay potentials, one treatment cannot fit the optimum requirements for each factor. To cite an extreme example, the fumigation requirements of an immature, warm, injury-susceptible variety, not exposed to conditions favoring infection would be quite different from those of a mature, cooled, injury-resistant variety that had been exposed to rainfall.

Workers in South Africa have found that certain of their varieties can absorb about 20 p.p.m. SO₂ without injury. This concentration of sulfur dioxide in the tissue was obtained if the grapes were fumigated with 0.25 to 0.3 percent of the gas for 20 minutes (58). Consequently, the 1 percent concentration of SO₂ commonly used for the initial fumigation of grapes in the United States would not at all be suitable for fumigation of these South African varieties.

Frequency of Fumigation During Storage

Another factor affecting the amount of sulfur dioxide absorbed by grapes is the frequency at which fumigations are made during the storage period. The common commercial practice is to fumigate at 7- or 10-day intervals with a 0.25 percent concentration of gas for 20 minutes. Under laboratory conditions grapes were fumigated at intervals of 7, 14, or 21 days to determine the effect of frequency of SO₂ fumigation on injury and decay development. No consistent relation between frequency of fumigation and injury could be demonstrated in these studies. There was some evidence that mechanical injuries, which allowed the gas to penetrate the berries more readily,

and the high initial concentration of gas (1 percent) were more important as causes of injury than was frequency of fumigation during storage. When grapes were stored for long periods (5 months), more decay developed in those that received the less frequent fumigations than in those that were fumigated more often. The frequencies of fumigation used in this study had no significant effect on decay in grapes stored for short periods (3 months) (29).

Precautions To Follow When Using Sulfur Dioxide

Human Toxicity

The pungent odor of sulfur dioxide is easily recognized and can be detected in concentrations as low as 30 to 40 parts per million (p.p.m.). At 400 p.p.m. the gas becomes extremely irritating and can cause injury to the mucous membranes of the eyes, nose, and mouth. At 2,500 p.p.m. (0.25 percent, the concentration commonly used to fumigate grapes in storage), the gas can cause respiratory spasms and death if the victim cannot escape from the fumes (3).

If exposed to irritating concentrations of the gas, affected areas should be flushed with large quantities of water. A few drops of dilute ephedrine sulfate will give relief when applied to the nose. Goggles and a gas mask effective against acid type gases should be worn in the presence of even weak concentrations of the gas.

Injury to Other Commodities

Grapes are almost unique in their ability to withstand sulfur dioxide fumigation. Concentrations of the gas commonly applied to grapes cause severe injury to almost all other fresh fruits and vegetables. For this reason grapes must not be

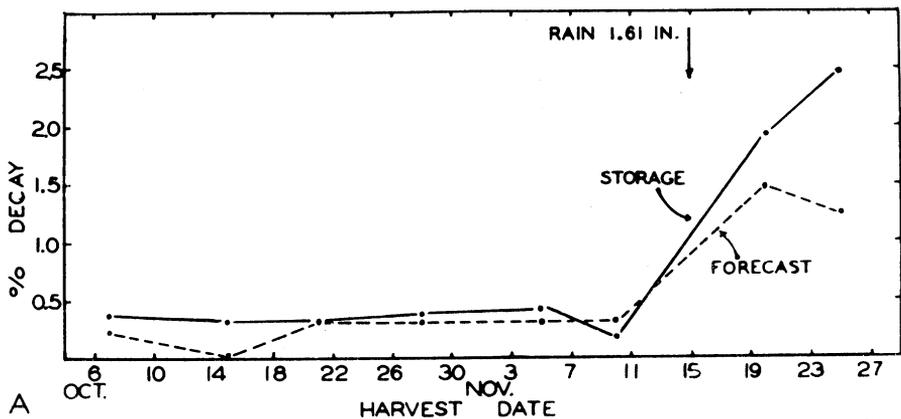
stored in the same room with other produce and during fumigation the gas must not be allowed to move through leaks in walls, or through hallways or ductwork into adjoining rooms where other commodities are stored. If grapes are shipped in mixed loads with other fruit in a refrigerator car, the car must not be fumigated. Severe injury to peaches, nectarines, plums, and other commodities has been observed when these fruits have been shipped with grapes in fumigated cars.

Corrosive Effect on Equipment

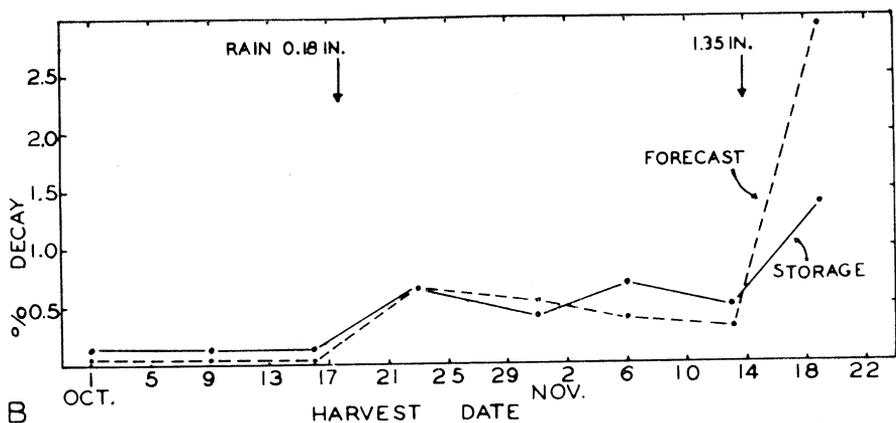
Sulfur dioxide forms sulfurous acid when dissolved in water. Metal surfaces upon which moisture collects in cold storage rooms therefore become covered with sulfurous acid during and after fumigation. The acid is extremely corrosive to both iron and zinc, causing the deterioration of coils, brine-spray chambers, and other equipment made of these metals. Some protection is afforded by treating exposed metals with acid resistant paints. A minimum of electrical wiring should be used inside grape storage rooms and switches and other control equipment should be located outside the room if possible.

Other Precautions

Certain precautions already noted under "Factors affecting sulfur dioxide injury" should be stressed. When bisulfite is being used as a fumigant no more than 5 grams per lug or chest should be applied. It should be evenly dispersed in the package and not in contact with the fruit and it should not be used with wet grapes or wet sawdust. Grapes treated with bisulfite should not be refumigated with sulfur dioxide in storage because bleaching may result from the combined treatment (45).



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Figure 19.—Interrelation of decay forecast and decay actually developing in stored Emperor grapes. A, Fresno vineyard, 1952. B, Fresno vineyard, 1953.

Selective Marketing of Storage Lots

Since decay and other disorders vary considerably from one lot of stored grapes to another, it is desirable to arrange and identify the lots in storage in a way that will enable the shipper to market poor keeping lots early and retain only sound, high-quality fruit for late marketing. To determine the keeping quality of different lots of grapes, the shipper may rely on his knowledge of the storage history of fruit harvested in past years from various vineyards, on the gen-

eral appearance of the fruit at harvest, on the weather to which the fruit had been exposed before harvest, on periodic inspections made during the storage period, or on a laboratory forecast of the potential storage decay present in specific lots of fruit at harvest. A rating of lots based on all but the last two of these factors requires a considerable amount of experience and reliable storage records over a period of years. Such may not be available in a new storage plant, in one in which the personnel are new, or in one storing fruit that may come from a different source each year. Neither can fac-

tors related to the effect of exposure to weather before harvest always be accurately evaluated. Inspection and forecasting, therefore, offer a more precise way of measuring and estimating storage disorders.

Inspection in Storage

Stowage of grapes in storage should allow ready access to each lot and inspections of randomly selected boxes from each lot should be made at regular intervals. Lots in which decay begins to appear are marketed immediately but if too much decay is present, the fruit may have to be trimmed and re-packed. If a lot is not inspected frequently enough, decay may develop to the point where the whole lot becomes unsalvageable. The frequency at which grapes are inspected in storage varies with the time of year and the opinion of the storage operator about the keeping quality of the particular lot. If a lot was suspected of being particularly subject to decay, it would probably be inspected at weekly intervals or before each fumigation. Fruit thought to be sound would be inspected less frequently. At the beginning of the storage period inspections are usually less frequent than they are toward the end of storage.

Forecasting Decay in Storage Grapes

Most of the decay that develops during storage in the Emperor and other late-harvested storage varieties is caused by the gray mold fungus, *Botrytis cinerea*. A method of measuring the potential amount of decay in storage caused by this organism has been developed and found to be exceptionally accurate under laboratory conditions. The method has also been

adapted to several commercial storage operations and has been used as a guide to marketing individual lots of storage grapes (28).

The forecast is based on the premise that (1) decay in stored grapes is caused primarily by infections that occur in the vineyard before harvest, but which have not developed far enough to be detected and removed during packing, and (2) that fumigation kills only fungus spores on the surface of the berries and not the fungi that have entered the berries before harvest. These fungi continue to grow within individual berries during storage despite fumigation. The fumigation does, however, reduce the occurrence of new infections due to spread of decay from diseased to sound berries.

Method

Applying these principles to measuring infections present in grapes at harvest, the amount of decay that will develop in storage can be predicted. It is important, however, that only field infections be measured and not infections that might occur after harvest, which are largely controlled by sulfur dioxide fumigation.

The forecast is made by taking a sample of individual berries from each lot of grapes to be tested. The sample is placed in glass jars and is fumigated with sulfur dioxide to kill all surface contamination. After fumigation, the jars are covered and the fruit is held under sterile conditions at high humidity and at room temperature. Under these conditions, decay develops within 10 days that would require several months to develop in cold storage. By calculating the percentage decay occurring in the test sample, the amount of decay that will develop during storage in corresponding lots can be predicted.

Unless the sample is representative, the forecast would provide an erroneous idea about decay in the particular lot being tested. Under experimental conditions samples are taken from marked vines randomly situated in each of the vineyards being tested. Fruit from these vines is picked at weekly intervals through the normal harvest season and taken to the laboratory. A portion of the fruit from each lot is used for the forecasting test and the remainder is placed in cold storage for approximately 3 months. With this method of sampling there is a correlation between the percentage decay that develops in the forecasting test and that which subsequently develops in corresponding lots in storage (Figure 19, *A, B*).

Under commercial conditions samples can be taken by clipping individual berries from the packed lugs of grapes as they pass along the conveyor toward the lidding machine. This method of sampling provides a good measure of the potential decay present in specific lots of grapes going into storage and requires less time and labor than collecting the samples in the vineyard. However, when grapes are packed in the field, it may be more practical to collect samples in the vineyard as is done experimentally.

Effect of Harvest Date

Since field infections normally increase as the season progresses, the forecast indicates the harvest date after which grapes should not be held for long-term storage. In years when heavy rains occur during the harvest, this date is fairly

obvious. However, in other years when light rains, periods of high humidity, or heavy morning dew or fogs occur, their effect on infection may not be recognized. The forecast measures infections due to all these factors.

Effect of Source of Storage Lot

The amount of decay in storage varies with lots harvested from different vineyards or districts. In years when no rain occurs during the harvest season, this factor may be the principal source of variation in decay between lots. However, variation in decay between vineyards is also important in seasons when the fruit is exposed to heavy rains. Grapes in certain vineyards are capable of withstanding adverse weather conditions without severe decay losses, while others suffer decay after exposure to only mildly unfavorable weather conditions. To detect these variations the forecasting test is particularly useful (see section on decay for discussion of the factors related to infection).

Application of Forecast

The forecasting test provides a relatively precise method for the selective marketing of storage lots according to their decay potential. If a high percentage of decay in a given lot is indicated by the forecast, the shipper can market this lot early, before decay has a chance to develop. If the forecast indicates that a particular lot is sound, that lot can be held safely in storage to take advantage of favorable markets late in the storage season (27, 28).

LITERATURE CITED

- (1) ANONYMOUS.
1949. TUNNEL METHOD OF PRECOOLING GRAPES. *Blue Anchor* 26(3) : 6-7, 21, 29, illus.
- (2) ALLEN, F. W. and PENTZER, W. T.
1936. STUDIES ON THE EFFECT OF HUMIDITY IN THE COLD STORAGE OF FRUITS. *Amer. Soc. Hort. Sci. Proc.* (1935) 33 : 215-223.
- (3) ——— and PENTZER, W. T.
1955. (COLD STORAGE OF) APPLES, PEARS, AND GRAPES. REFRIGERATING DATA BOOK. The American Society of Refrigerating Engineers, pp. 19-01 to 19-16. New York.
- (4) AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS.
1945. HEATING, VENTILATING, AIR CONDITIONING GUIDE. 808 pp., illus. New York.
- (5) AMERICAN SOCIETY OF REFRIGERATING ENGINEERS.
1942. REFRIGERATING DATA BOOK. Ed. 5, 515 pp., illus., New York.
- (6) ASBURY, C. E., BRATLEY, C. O., and PENTZER, W. T.
1936. FURTHER OBSERVATIONS ON MOLD CONTROL IN GRAPES DURING TRANSIT AND STORAGE—1935 SEASON. *Blue Anchor* 8(6) : 8-9.
- (7) BERRY, J. A. and MAGOON, C. A.
1934. GROWTH OF MICROORGANISMS AT AND BELOW 0° C. *Phytopathology* 24 : 780-796.
- (8) BEYERS, E.
1938. DROP BERRY AND DESICCATION OF STALKS IN WALTHAM CROSS GRAPES. Union South Africa, Dept. Agr. and Forestry, Low Temp. Research Lab. Ann. Rpt. 1936-37 : 91-101. Capetown.
- (9) ———
1939. FURTHER INVESTIGATIONS OF FACTORS AFFECTING "DROP" AND DESICCATION OF STALKS OF WALTHAM CROSS IN STORAGE. Union South Africa, Dept. Agr. and Forestry, Low Temp. Research Lab. Ann. Rpt. 1937-38 : 79-87. Capetown.
- (10) BLUMER, S.
1947. VERSUCHE ZUR BEKÄMPFUNG DER GRAUFÄULE (*botrytis cinerea*). *Schweiz. Z. Obst- u. Weinbau.* 56 : 51-61.
- (11) ———
1951. DIE BEKÄMPFUNG DER KRANKHEITEN UND SCHÄDLINGE IM REBBAU. *Schweiz. Z. Obst- u. Weinbau.* 60 : 173-179.
- (12) CARRICK, D. B.
1930. SOME COLD-STORAGE AND FREEZING STUDIES ON THE FRUIT OF THE VINIFERA GRAPE. *Cornell Agr. Expt. Sta. Mem.* 131, 37 pp., illus.
- (13) DELP, C. J., HEWITT, W. B. and NELSON, K. E.
1951. CLADOSPORIUM ROT OF GRAPES IN STORAGE. (Abstract.) *Phytopathology* 41 : 937-938.
- (14) DE VILLIERS, F. J.
1926. PHYSIOLOGICAL STUDIES OF THE GRAPE. Union South Africa, Dept. Agr. Sci. Bul. 45, 97 pp., illus.
- (15) DEWEY, D. H.
1950. THE EFFECTS OF AIR BLAST PRECOOLING ON THE MOISTURE CONTENT OF THE STEMS OF CHERRIES AND GRAPES. *Am. Soc. Hort. Sci. Proc.* 56 : 111-115.
- (16) ———
1952. AMMONIA DAMAGE TO STORED FRUITS AND NUTS; SULFUR DIOXIDE AS A CORRECTIVE TREATMENT. *Ice and Refrig.* 123(3) : 19-22.
- (17) DUFRENOY, J. and GENEVOIS, L.
1935. DÉVELOPPEMENT DU CLADOSPORIUM HERBARIUM SUR DES RAISINS À BASSE TEMPÉRATURE. *Compt. rend. soc. biol.*, 118 : 708-710, illus. Paris.
- (18) du PLESSIS, S. J.
1936. STUDIES ON THE WASTAGE OF EXPORT GRAPES WITH SPECIAL REFERENCE TO THAT CAUSED BY BOTRYTIS CINEREA, PERS. Union South Africa, Dept. Agr. and Forestry Sci. Bull. 151, 163 pp., illus.
- (19) ———
1937. STUDIES ON THE PHYSIOLOGY AND PARASITISM OF BOTRYTIS CINEREA PERS. *Ann. Appl. Biol.* 24 : 733-746.
- (20) ———
1938. FURTHER STUDIES ON THE CONTROL OF BOTRYTIS ROT IN GRAPES. Union South Africa, Dept. Agr. and Forestry Sci. Bul. 166, 32 pp.

- (21) _____
1939. COMPARISON OF THE EFFECTIVENESS OF VARIOUS FUNGICIDES AND THE METHODS OF THEIR APPLICATION FOR THE CONTROL OF BOTRYTIS ROT OF GRAPES. Union South Africa, Dept. Agr. and Forestry Sci. Bul. 199, 31 pp.
- (22) _____
1943. SWAWEL VIR DIE BESTRYDING VAN WINGERDSIEKTES (SULFUR FOR THE CONTROL OF VINEYARD DISEASES). Farming in South Africa 43: 472-474, 477.
- (23) _____ and REYNEKE, J.
1939. EXPERIMENTS ON THE CONTROL OF DRY STALK AND WASTAGE IN EXPORT GRAPES. Union South Africa, Dept. Agr. and Forestry Sci. Bul. 195, 25 pp.
- (24) FRIEDMAN, B. A. and RADSPINNER, W. A.
1956. VACUUM-COOLING FRESH VEGETABLES AND FRUITS. U.S. Dept. Agr. AMS Rep. 107, 15 pp.
- (25) GUILLOU, R. and PARKS, R. R.
1956. FRUIT COOLING BY FORCED AIR. Calif. Agr. 10(9) : 7, illus.
- (26) HARVEY, J. M.
1955. DECAY IN STORED GRAPES REDUCED BY FIELD APPLICATIONS OF FUNGICIDES. Phytopathology 45: 137-140.
- (27) _____
1955. A METHOD OF FORECASTING DECAY IN CALIFORNIA STORAGE GRAPES. Phytopathology 45: 229-232.
- (28) _____
1955. IMPROVED MARKETING OF STORED EMPEROR GRAPES BY USE OF DECAY FORECASTS. Blue Anchor 32(3) : 6, 28.
- (29) _____
1957. EFFECTS OF FREQUENCY OF SULFUR DIOXIDE FUMIGATION DURING STORAGE ON DECAY AND FUMIGATION INJURY IN EMPEROR GRAPES. Phytopathology 46: 690-694.
- (30) _____ and PENTZER, W. T.
1953. THE VALUES OF FUMIGANTS. U.S. Dept. Agr. Yearbook of Agriculture, pp. 844-850. Washington.
- (31) HUKILL, W. V. and SMITH, E.
1946. COLD STORAGE FOR APPLES AND PEARS. U.S. Dept. Agr. Circ. 740, 61 pp., illus.
- (32) JACOB, H. E.
1929. THE USE OF SULFUR DIOXIDE IN SHIPPING GRAPES. Calif. Agr. Expt. Sta. Bul. 471, 24 pp., illus.
- (33) _____
1939. GIRDLING VINES FOR TABLE GRAPES. Blue Anchor. 16(6) : 6-7.
- (34) LUTZ, J. M.
1938. FACTORS INFLUENCING THE QUALITY OF AMERICAN GRAPES IN STORAGE. U.S. Dept. Agr. Tech. Bul. 606, 27 pp.
- (35) MALAN, H.
1954. LONG-TERM STORAGE OF GRAPES. Farming in South Africa 29: 157-159.
- (36) MANN, C. W.
1929. THE HANDLING OF CALIFORNIA TABLE GRAPES. U.S. Dept. Agr. Circ. 83, 13 pp., illus.
- (37) MARIAS, P. G.
1952. AUTOMATIC CONTROL OF SO₂ WITH A PHOTO-ELECTRIC CELL IN THE LONG-TERM STORAGE OF GRAPES. Union South Africa Dept. Agr. Sci. Bul. 322, 10 pp.
- (38) MCGAVACK, J., Jr. and PATRICK, W. A.
1920. THE ABSORPTION OF SULFUR DIOXIDE BY THE GEL OF SILICIC ACID. Jour. Amer. Chem. Soc. 42: 946-978.
- (39) MÜLLER-STOLL, W. R.
1950. VERSUCHE ZUM PROBLEM DER WIRKSAMKEIT VON SEIFEN- UND SEIFENER-SATZMITTELN GEGEN DEN TRAUBENSCHIMMEL (BOTRYTIS CINEREA). Phytopathol. Z. 17: 265-286.
- (40) NELSON, K. E.
1951. FACTORS INFLUENCING THE INFECTION OF TABLE GRAPES BY BOTRYTIS CINEREA. Phytopathology 41: 319-326.
- (41) _____
1951. EFFECT OF HUMIDITY ON INFECTION OF TABLE GRAPES BY BOTRYTIS CINEREA. Phytopathology 41: 859-864.

- (42) _____
1955. HIGH PICKING TEMPERATURES AND ROUGH HANDLING CAN REDUCE CONSUMER ACCEPTABILITY OF CALIFORNIA FRESH TABLE GRAPES. *Blue Anchor* 32(2) : 6-10.
- (43) _____
1956. THE EFFECT OF BOTRYTIS INFECTION ON THE TISSUE OF TOKAY GRAPES. *Phytopathology* 46: 223-229.
- (44) OSTERWALDER, A.
1943. VON TEILWEISEN LAHMSTIELER-TRAUBEN. (ON GRAPES WITH PARTIAL PEDICEL LAMENESS). *Schweiz. Z. Obst- u. Weinbau.* 52: 635-638.
- (45) PENTZER, W. T.
1939. METHODS OF APPLYING SODIUM BISULFITE TO GRAPE PACKAGES FOR MOLD CONTROL. *Blue Anchor* 16(7) : 2.
- (46) _____
1940. FACTORS AFFECTING THE STORAGE OF GRAPES. *Assoc. of Refrig. Whs. Spec. Bul.* 1(4) : 7 pp.
- (47) _____
1941. STUDIES ON THE SHATTER OF GRAPES WITH SPECIAL REFERENCE TO THE USE OF SOLUTIONS OF NAPHTHALENE ACETIC ACID TO PREVENT IT. *Am. Soc. Hort. Sci. Proc.* 38 : 397-399.
- (48) _____ and ASBURY, C. E.
1934. SULPHUR DIOXIDE AS AN AID IN THE PRESERVATION OF GRAPES IN TRANSIT AND STORAGE. *Blue Anchor* 11(8) : 2-4, 23.
- (49) _____ and ASBURY, C. E.
1935. THE SODIUM BISULPHITE TREATMENT OF GRAPES TO RETARD MOLD GROWTH. *Blue Anchor* 7(5) : 6, 26-27.
- (50) _____, ASBURY, C. E., and BARGER, W. R.
1945. PRECOOLING CALIFORNIA GRAPES AND THEIR REFRIGERATION IN TRANSIT. U.S. Dept. Agr. Tech. Bul., 899. 63 pp., illus.
- (51) _____, ASBURY, C. E., and HAMNER, K. C.
1933. EFFECTS OF FUMIGATION OF DIFFERENT VARIETIES OF VINIFERA GRAPES WITH SULPHUR DIOXIDE GAS. *Am. Soc. Hort. Sci. Proc.* (1932) 29: 339-344.
- (52) _____, ASBURY, C. E., and HAMNER, K. C.
1934. THE EFFECT OF SULFUR DIOXIDE FUMIGATION ON THE RESPIRATION OF EMPEROR GRAPES. *Am. Soc. Hort. Sci. Proc.* (1933) 30: 258-260.
- (53) _____, and BARGER, W. R.
1941. A COMPARISON OF FUNGICIDAL TREATMENTS FOR THE CONTROL OF BOTRYTIS ROT OF GRAPES IN STORAGE. *Am. Soc. Hort. Sci. Proc.* 39: 281-284.
- (54) _____, BRATLEY, C. O., and TUFTS, W. G.
1942. REPORT ON SULPHUR DIOXIDE INJURY IN COMMERCIAL SHIPMENTS OF TOKAY GRAPES, 1942 SEASON. U.S. Dept. Agr. Mimeo. Rpt., 11 pp., illus.
- (55) RATTRAY, J. M.
1938. GRAPE WASTAGE INVESTIGATIONS, 1937. Union South Africa, Dept. Agr. and Forestry, Low Temp. Research Lab. *Ann. Rpt.* 1936-37: 75-91. Capetown.
- (56) _____
1939. GRAPE WASTAGE INVESTIGATIONS, 1938. Union South Africa, Dept. Agr. and Forestry, Low Temp. Research Lab. *Ann. Rpt.* 1937-38: 65-74. Capetown.
- (57) _____
1940. THE EFFECT OF SO₂ GENERATING TABLETS. Union South Africa, Dept. Agr. and Forestry, Low Temp. Research Lab. *Ann. Rpt.* 1938-39: 48-60. Capetown.
- (58) REYNEKE, J. and DU PLESSIS, S. J.
1943. THE TREATMENT OF TABLE GRAPES FOR THE LOCAL MARKETS. *Farming in South Africa*, 18: 443-445.
- (59) _____ and PIAGET, J. E. H.
1952. THE USE OF BISULPHITES IN THE CONTROL OF WASTAGE IN FRESH GRAPES. *Farming in South Africa*, 27: 477-479.
- (60) ROSE, D. H., BRATLEY, C. O., and PENTZER, W. T.
1939. MARKET DISEASES OF FRUITS AND VEGETABLES: GRAPES AND OTHER SMALL FRUITS. U.S. Dept. Agr. Misc. Publ. 340, 27 pp., illus.
- (61) _____ and PENTZER, W. T.
1947. COMMERCIAL METHOD OF FUMIGATING GRAPES WITH SULPHUR DIOXIDE. *Blue Anchor* 24(4) : 6-7, 34.
- (62) RYALL, A. L.
1952. A STUDY OF PACKAGING MATERIALS. *Ice and Refrig.* 123(2) : 11-15, illus.

- (63) SCHELLENBERG, A.
1955. KULTURMASSNAHMEN ZUR VERMINDERUNG DER TRAUBENFÄULNIS.
Schweiz. Z. Obst- u. Weinbau. 64: 107-112.
- (64) SNYDER, E.
1937. GRAPE DEVELOPMENT AND IMPROVEMENT. 1937. U.S. Dept. Agr. Yearbook
of Agriculture, pp. 631-644, illus. Washington.
- (65) STAEBELIN, M.
1946. STATION FEDERALE D'ESSAIS VITICOLES ET ARBORICOLES ET DE CHIMIE
AGRICOLE, À LAUSANNE ET À PULLY. Rapport d'activité 1945. Ann.
Agr. Suisse. 47(8): 741-842.
- (66) ——— and WURGLER, W.
1947. STATIONS FEDERALES D'ESSAIS VITICOLES, ARBORICOLES ET DE CHIMIE
AGRICOLE, À LAUSANNE ET À PULLY. Rapport d'activité 1946. Ann.
Agr. Suisse. 48(8-9): 701-792.
- (67) STALDER, L.
1953. DAS PROBLEM DER BOTRYTISBEKÄMPFUNG IM WEINBAU. Schweiz. Z.
Obst- u. Weinbau. 62: 105-107, 128-132.
- (68) ———
1953. WITTERUNG UND TRAUBENFÄULNIS. Schweiz. Z. Abst- u. Weinbau. 62:
477-484.
- (69) ———
1953. UNTERSUCHUNGEN ÜBER DIE GRAUFÄULE (*botrytis cinerea* PERS.) AN
TRAUBEN. 1. Mitteilung. Phytopathol. Z. 20: 315-344.
- (70) STUBENRAUCH, A. V. and MANN, C. W.
1913. FACTORS GOVERNING THE SUCCESSFUL STORAGE OF CALIFORNIA TABLE
GRAPES. U.S. Dept. Agr. Bul. 35, 31 pp., illus.
- (71) UOTA, M.
1957. EVALUATION OF POLYETHYLENE FILM LINERS FOR PACKAGING EMPEROR
GRAPES FOR STORAGE. Am. Soc. Hort. Sci. Proc. 70: 197-203.
- (72) ——— and COOK, F. L.
1958. UNITED STATES DEPARTMENT OF AGRICULTURE TEST REPORT: IMPROVED
METHODS NEEDED FOR SO₂ GRAPE FUMIGATION. Blue Anchor 35(3):
20-21, 36.
- (73) VAN DER PLANK, J. E. and VAN WYK, G. F.
1940. THE PREPARATION OF TABLETS FOR THE RELEASE OF SULPHUR DIOXIDE IN
PACKAGES OF STORED TABLE GRAPES. Union South Africa, Dept. Agr.
and Forestry, Low Temp. Research Lab. Ann. Rpt. 1938-39: 43-47.
Capetown.
- (74) WILE, D. D. and HALLS, H. A.
1956. HOT CARCASS COOLERS—BRINE SPRAY OR "DRY" COIL? Refrig. Eng.
64(11): 48-53, 104, 106, illus.
- (75) WILHELM, A. F.
1944. UNTERSUCHUNGEN ZUR FRAGE EINER CHEMISCHEN BEKÄMPFUNG DER
TRAUBENFÄULE (*botrytis cinerea*). Wein u. Rebe 26(4-6): 29-49;
(7-9): 67-73.
- (76) WINKLER, A. J.
1932. MATURITY TESTS FOR TABLE GRAPES. Calif. Agr. Expt. Sta. Bul. 529, 35
pp.
- (77) ——— and JACOB, H. E.
1925. THE UTILIZATION OF SULFUR DIOXIDE IN THE MARKETING OF GRAPES.
Hilgardia 1: 107-131.
- (78) WRIGHT, R. C.
1942. THE FREEZING TEMPERATURES OF SOME FRUITS, VEGETABLES, AND FLORISTS'
STOCKS. U.S. Dept. Agr. Cir. 447, 12 pp. (Revised.)
- (79) ———, ROSE, D. H., and WHITEMAN, T. M.
1954. THE COMMERCIAL STORAGE OF FRUITS, VEGETABLES, AND FLORIST AND
NURSERY STOCKS. U. S. Dept. Agr. Handbook 66, 77 pp. (Revised.)

Appendix

Calculation of the Refrigeration Requirements of a Theoretical Plant

When planning a new plant or determining the capacity of an existing one all sources of heat have to be considered. As an example consider the refrigeration requirements of the following theoretical plant:

Plant Design and Operation

A single-story storage plant adjoins a packing room and contains three 40- by 50-foot storage rooms with 18-foot ceilings for multiple-pallet stacking. Each storage room will hold approximately 22,000 lugs of grapes. The plant also contains two 22- by 26-foot precooling rooms with 12-foot ceilings, each of which hold 4,000 lugs of fruit. Since the maximum capacity of the packing room is 4,000 lugs of grapes per day, one precooling room is filled each day during the peak season. The precooling period is 24 hours and, during the warmest part of the season, fruit temperature is reduced from an average of 80° F. to 36° F. during precooling. At the end of the harvest season the plant contains a peak storage load of 74,000 lugs. The plant is mechanically refrigerated with individual room dry-coil bunkers. Each storage room has five 1½-horsepower fan motors which deliver air at a total rate of 22,500 c.f.m. Each precooling room has three 1½-horsepower fan motors which, when operated for precooling, move a total of 27,000 c.f.m of air. Exterior walls are insulated with 6 inches and the ceiling with 8 inches of shredded redwood bark. The floor has 4

inches of corkboard beneath the concrete wearing surface.

Refrigeration Requirements

The refrigeration requirements of this plant when operated at capacity would be as follows:

Removal of field heat:	
24 hours in precooling room.	
Fruit, 4,000 lugs reduced	<i>B.t.u.</i>
44° F.	
44 (°TR) × 112,000	
(lbs.) × 0.82 (S) ----	4,040,960
Boxes, 4,000 lugs reduced	
44°.	
44 (°TR) × 16,000	
(lbs.) × 0.33 (S) ----	232,320
24 hours in storage after precooling.	
Fruit, 4,000 lugs reduced	
5°.	
5 (°TR) × 112,000	
(lbs.) × 0.82 (S) ----	459,200
Boxes, 4,000 lugs reduced	
5°.	
5 (°TR) × 16,000	
(lbs.) × 0.33 (S) --	26,400
Total field heat per day -----	4,758,880
Heat of respiration:	
4,000 lugs of Thompson Seedless during precooling at an average temperature of 53° F.	
56 (tons) × 1,690	
(B.t.u. per ton per day) -----	94,640
30,000 lugs of Thompson Seedless in storage during peak of receiving season, average 32°.	
420 (tons) × 430	
(B.t.u. per ton per day) -----	180,600
Total vital heat per day during packing season -----	275,240
74,000 lugs of Emperor in storage at end of packing season, average 32°.	
1,036 (tons) × 350	
(B.t.u. per ton per day) -----	362,600

Heat leakage:	<i>B.t.u.</i>	16.5 (total HP) × 3,000 (B.t.u. per hr.) × 24 (hrs.) -----	<i>B.t.u.</i> 1, 188, 000
Exterior wall surfaces, 7,920 square feet. 7,920 (sq. ft.) × 48 (°TD) × 1.03 (B.t.u. per day) -----	391, 565	Electric lights, 32 200-w lamps. 6.4 (KW) × 3,500 (B.t.u. per hr.) × 6 (hrs.) -----	134, 400
Ceiling surface, 7,144 square feet. 7,144 (sq. ft.) × 54 (°TD) × 0.77 (B.t.u. per day) -----	297, 048	Workmen, 2 for 8 hours per day. 2 (men) × 1,000 (B.t.u. per hr.) × 8 (hrs.) --	16, 000
Floor surface, 7,144 square feet. 7,144 (sq. ft.) × 35 (°TD) × 1.6 (B.t.u. per day) -----	400, 064	2 (1-ton electric fork truck × 35,000 (B.t.u. per 8 hrs.) -----	70, 000
Total heat leakage per day -----	<u>1, 088, 677</u>	Total from inci- dental sources per day -----	<u>1, 408, 400</u>
Air infiltration:		Recapitulation:	
One 8 x 8 foot outside door in each room.		Field heat (peak load) ---	4, 758, 880
Storage room doors are open average of 2 hours daily.		Heat of respiration (re- ceiving period) -----	275, 240
Precooling room doors are open average of 4 hours daily.		Heat leakage through ex- ternal surfaces -----	1, 088, 677
14 (open-door hrs.) × 250,000 (B.t.u. per hr.) -----	3, 500, 000	Air infiltration (peak load) -----	3, 500, 000
Other heat sources:		Other heat sources -----	1, 408, 400
Electric fan motors, 15 ½- HP and 6 1½-HP.		Total -----	11, 031, 197
		11,031,197 (B.t.u.) ÷ 288,000 (B.t.u. per ton) = 38.3 tons of refrigeration.	