Factors Influencing the Refrigeration of Packages of Apples

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The straight-sided tub bushel basket shown on the cover was the standard container used in the experiments reported in this bulletin, except where type of package was being tested. Grimes apples were used for all tests.

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Factors Influencing the Refrigeration of Packages of Apples

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MAINTENANCE of perishable fruits and vegetables at low temperatures is generally recognized as the most economical method of extending their life span and reducing losses between the time they are harvested and the time they are offered for sale on a distant market.

Precooling of these products before shipment in refrigerator cars has been recommended and is used in some localities to reduce their temperatures rapidly to a point where they can safely be transported. In many localities where facilities for precooling are not available, the refrigerator car itself is relied upon to reduce the temperature of the load to a point which allows perishable products to reach distant markets in satisfactory condition. Heavy losses of fruits transported under such conditions are frequent.

Studies by the Illinois Station regarding factors responsible for losses of non-precooled fruits in transit are reported in Bulletin 334.[5*] Further experiments, with air circulation and temperature conditions in refrigerator cars,[10*] indicated that a knowledge of how the fruit within a package cools and of how certain internal and external factors influence the behavior of the packaged fruit is essential to a complete understanding of the refrigeration problem.

The tests reported herein attempt to answer some of the questions that arise in a study of the phenomena occurring in a package of fruit while cooling, namely: How does cooling of the fruit progress within a package? What is the effect of air velocity about the package upon the rate of cooling of the fruit within? How does the temperature of the fruit at the time of packing affect the rate of cooling? Does the size of the fruit affect the rate at which the package of fruit cools? Does the type of package affect the rate of cooling?

REVIEW OF LITERATURE

Many phases of the marketing and storage of apples have been studied. Some of the facts established by earlier workers on the relation of temperature to ripening and of ripeness to decay of fruits are of importance in connection with the studies here reported.

Eustace and Beach[2*] pointed out that the ripening process is accelerated in a high temperature and retarded in a low temperature, and that early varieties, such as Wealthy, respond more markedly to temperature differences than do the late-maturing varieties, such as Winesap. Magness and Diehl[7*] found a distinct difference in the response of different varieties of apples to various temperatures, some varieties softening much more rapidly at high temperatures than others. Grimes apples harvested by Magness *et al*[8*] on September 23 were "full eating soft" by October 10 when stored at 70° F., but were not "full eating ripe" until January 1 when stored at 32° F. Morris[9*] found that apples kept in a warm warehouse from one to three days before being placed in cold storage often lost more than a month of their storage life. Smith[14*] showed that rapid cooling of fruit is very important in preventing rapid maturation.

Brooks and Cooley[1*] found that a slight increase in the ripeness of apples of a particular variety caused a definite increase in susceptibility to rot. Earlier studies by the Illinois Station[6*] with Yellow Transparent apples showed that delay in loading the apples after they were picked increased the amount of damage due to internal browning of the tissues. Investigations by Palmer[11*] have shown that the breakdown not caused by low temperature is closely correlated with maturity of the fruit. The Empire Marketing Board[3*] reported that, in general, internal breakdown is more severe in "Extra Fancy" than in lower grade fruit.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Apparatus Used.—The equipment used in the experiments reported in this bulletin was so built as to provide conditions as nearly as possible identical with those found within a refrigerator car, except that the temperature and air velocity could be controlled and varied at will. A sketch of the main part of the apparatus is shown in Fig. 1[a]. For the want of a better term, this portion of the apparatus is designated as a "tunnel." The tunnel is in the form of a large U, the upper parts of which are connected by a comparatively small pipe.

At the lower left-hand corner of Fig. 1 is shown an electrically driven fan which is the source of air circulation within the tunnel. Just to the rear of the fan is a diaphram which regulates the air flow into the fan. The air passes upward thru a 6-inch tube and around to a draft gage, where the air force or pressure is measured. The draft

[a]This apparatus was designed and its construction supervised by H. M. NEWELL, formerly Associate in Fruit and Vegetable Marketing.

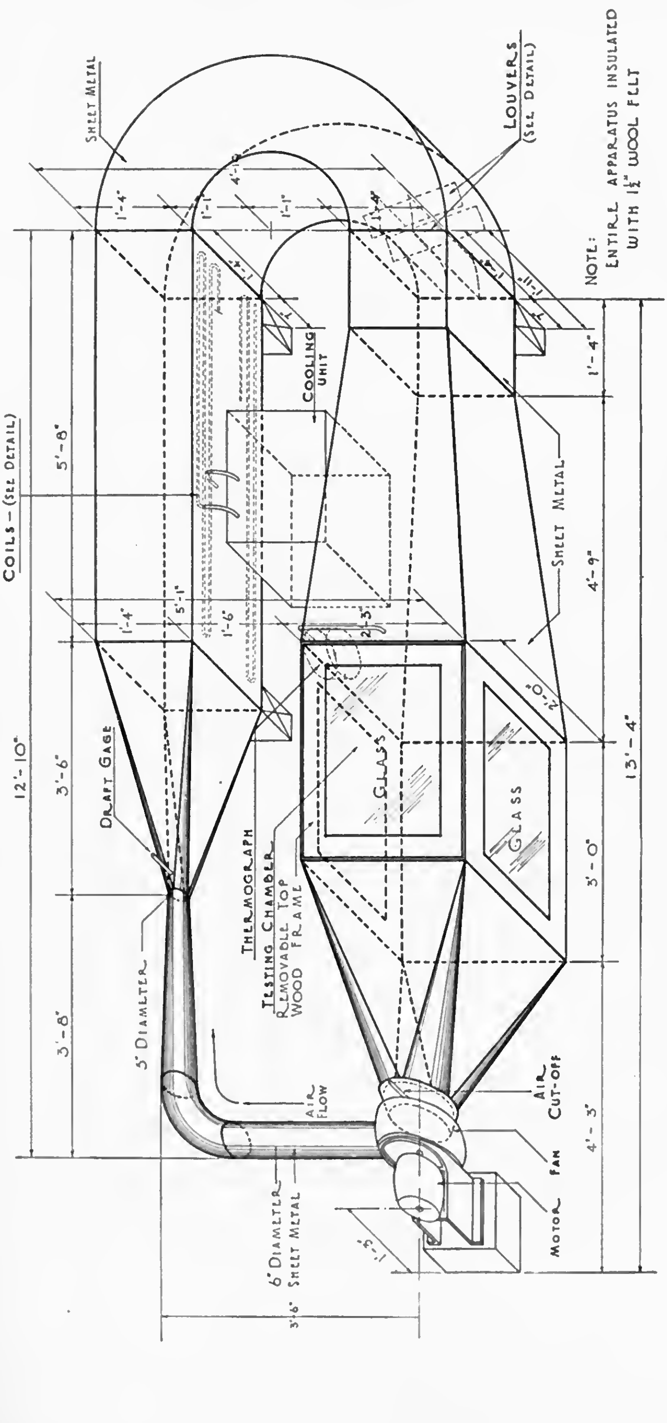

FIG. 1.—APPARATUS USED IN REFRIGERATION TESTS

gage reading is used to regulate the air cut-off diaphram so as to obtain the rate of air flow desired for the various tests.

As the air passes beyond the draft gage it enters an enlarged area, corresponding to one side of the U. At this point, the air comes in contact with a series of cooling coils, composed of 257 feet of half-inch copper tubing (Fig. 2-A). The air then passes around the base of

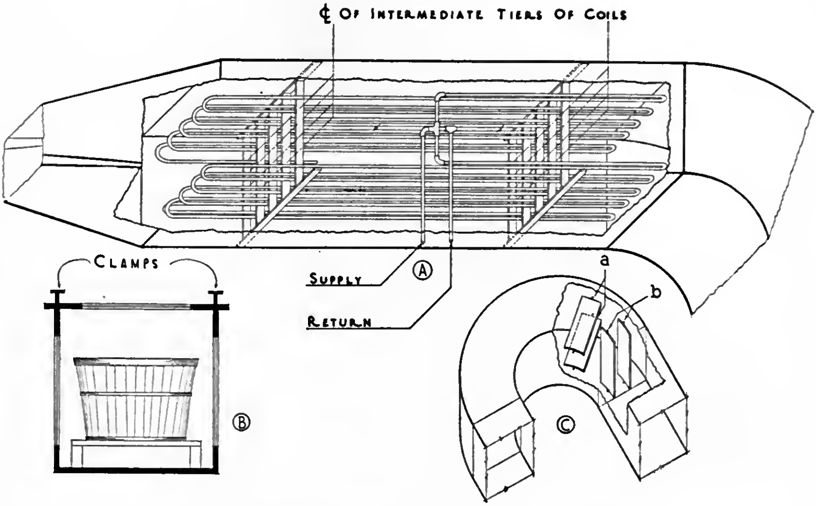

FIG. 2.—INTERIOR SECTIONS OF "TUNNEL"

(A) Detailed diagram of arrangement of cooling coils; (B) location of a tub bushel basket in the testing chamber; (C) louvers used to distribute the air vertically (a), and laterally (b).

the U and into the other side. As it comes into the straight side of the U, it strikes two sets of louvers (Fig. 2-C). One set is so regulated as to give an even vertical distribution of air thruout the area (a), the second to give an even lateral distribution thruout the area (b).

At the upper end of this side of the U is located a testing chamber. In it are placed the packages of fruit to be tested (Fig. 2-B).

The testing chamber door closes against a rubber seat and is firmly held in place by a series of screw clamps. The air passes by the package and back thru the fan and recirculates, giving a continuous and uniform flow.

The tunnel, except for the testing chamber, is made of heavy galvanized sheet metal which is insulated with 1½ inches of wool felt. The testing chamber is of glass in a wooden frame.

A Kelvinator cooling unit was attached to the copper coils to reduce the air temperature of the tunnel. The machine used was large enough to carry the load easily; therefore it was in operation only a portion of the time. The air temperature varied about three degrees with the cutting-in and cutting-out of the machine.

Instruments for Recording Data.—The air temperatures during the tests were recorded by the use of a thermograph, the bulb of which was located just in front of the testing chamber in order to register the temperature of the air that came in contact with the package of fruit.

Altho the draft gage was used as a guide in regulating the air flow, it could not be relied upon to give an accurate measurement of the rate of air flow about the package of fruit being tested. The kata-thermometer has proved to be a useful instrument for the measurement of low air velocities[10*] and it was used thruout these tests. The rate of air movement on either side of the package was measured by five or more kata-thermometer readings for each test. The air velocity for the duration of a single test was found to be very uniform, but the velocity was less uniform for different tests.

Changes in the temperature of the fruit within the package were ascertained by the use of thermocouples. Chromel and constantan insulated thermocouple wires, No. 30 B and S gage, were used. The ends were twisted and soldered to assure contact between the wires. In order that the exposed wires might not be attacked by the fruit juices, and in order that they might easily be inserted into the fruits, the points were covered with ambroid cement and a thin glass tube drawn to a closed point.

A portable precision potentiometer designed for measuring thermocouple e.m.f. was used in taking the thermocouple readings. The limit of error of the instrument using the slidewire alone was .5 percent of the range. With the slidewire and up to 5 studs on the dial switch, the limit of error was from .5 percent to .1 percent. A cold junction of cracked ice in a thermos bottle was used thruout the tests.

The thermocouples used in obtaining the fruit temperatures were inserted to the center of the fruit. Those used in obtaining the air temperatures between fruits were prevented from coming into contact with the fruits by passing the thermocouple thru a hole in a triangular piece of wood that was wedged between the fruits, thus suspending the point of the thermocouple in midair. Unless otherwise stated, the thermocouples were arranged in a cross-section thru the center of the package. In all, twenty-four thermocouples were distributed around and within the package as shown in Figs. 3 and 11. The thermocouple wires were carried out thru the testing chamber door, and then the door was sealed by clamping it upon the rubber seat. The ends of the wires were then attached to a switch board, from which connections were made with the potentiometer thru the cold junction of cracked ice. By this arrangement the twenty-four thermocouples could easily be read within seven minutes.

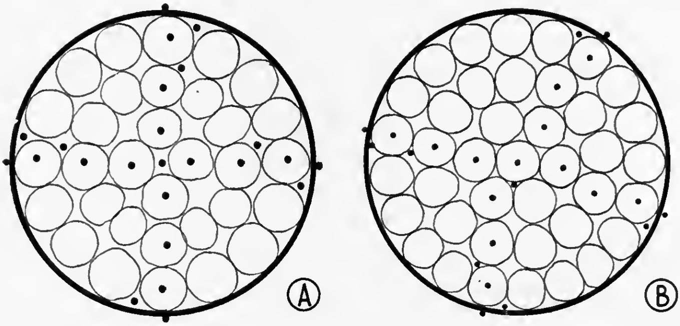

FIG. 3.—CROSS-SECTIONS SHOWING THERMOCOUPLE ARRANGEMENTS USED IN LINED TUB BUSHEL BASKETS OF APPLES

The thermocouple arrangement used for tub bushel baskets containing fruits 2¼ to 2¾ inches in diameter and 2¾ to 3 inches is shown in A; for fruits from 2 inches to 2¼ inches in B. The outside row of fruit is referred to in the tests as the first row, the next row as the second row, etc. There are four thermocouples in each row of fruit, and a composite of the readings is taken as representing the temperature of the row. The air temperature between two rows is obtained by taking a composite of the thermocouple readings between the rows.

Procedure.—The first reading for a test was made just before the fruit was placed in the testing chamber. A second reading was taken after the fruit had been in the testing chamber for 15 minutes. Readings were then made at intervals of 30 minutes for 8 hours. After that time the readings were made at 2-hour intervals, except for an 8-hour period between the 12th and 20th hours of the test. No readings were made during that period. Each test was continued until the temperature of the fruit had reached 45° F. or slightly lower.

The package being tested was placed on a floor rack in the testing chamber. Considerable space was left on each side of the package and above the package for air circulation (Fig. 2-B). A second and similar package was placed in front of the package being tested; that is, in the direction from which the circulating air approached the package under test. This prevented the air from striking the test package directly, and thus made the conditions more comparable to those in a loaded refrigerator car.

Conditions of the Tests.—The straight-sided tub bushel basket with ventilated paper liner and corrugated paper facing pad is a standard container used by commercial growers of apples and peaches thruout the central states. It was therefore selected as the standard container for these studies, except where type of package was under consideration.

In order that conditions might be as uniform as possible, a single variety of apple, the Grimes, was used for all the tests. The fruits were carefully graded into three sizes: (1) below 2¼ inches in diameter, (2) 2¼ to 2¾ inches, and (3) above 2¾ inches. Except when otherwise indicated, the medium-sized fruits (2¼ to 2¾ inches) were used.

All tests were run in duplicate under each set of conditions, and some were run a larger number of times. The air temperature of the tunnel varied somewhat, but it was kept as near 35° F. as possible. This is approximately the temperature of air as it comes from the bottom of the ice bunker of a refrigerator car.

HOW FRUIT WITHIN A PACKAGE COOLS

In most of the studies conducted on the cooling of fruits in refrigerator cars the package has been the smallest unit considered. Comparatively little attention has been given to the way in which cooling progresses thru the package. Griffith and Awbery[4*] have concluded from their experiments that the temperature differences between an individual apple and the air in the immediate neighborhood is quite small at all times.

In order to obtain a better understanding of the cooling of fruit within a tub-bushel basket a number of tests were made. In these tests the progress of cooling was traced by thermocouples arranged as shown in Fig. 3-A.

The fruit temperatures recorded at the different points in the baskets are summarized in Table 1. The progress of cooling for all baskets followed closely the averages shown in Table 1. The air temperature just outside the package dropped rapidly as soon as the fruit was placed in the testing chamber, and then more slowly as the fruit within the package cooled. An occasional increase in temperature outside the package shown by the record is explained by the fact that the air temperature of the tunnel varied about three degrees due to the cutting-in and cutting-out of the cooling machine.

The tests were continued until the package contents had cooled to about 45° F., which is generally agreed to be the most economical temperature for summer apples in transit.

TABLE 1.—PROGRESS OF COOLING OF APPLES IN LINED TUB BUSHEL BASKETS
(Degrees Fahrenheit)

Time (hours)	Start	1/4	1	2	3	4	5	6	7	8	10	12	20	22	24	26
Outside of package	71.1	50.1	48.3	46.2	46.1	45.4	44.8	43.6	43.9	43.1	42.6	41.7	40.4	39.7	39.6	39.6
First row of fruit	88.3	87.5	83.0	78.0	73.7	70.0	66.8	64.2	61.4	59.0	55.4	52.5	47.9	45.1	43.4	43.3
Second row of fruit	88.8	88.7	88.0	85.9	83.2	79.8	76.5	73.2	70.3	67.7	62.8	58.6	49.6	47.8	46.8	45.2
Third row of fruit	88.2	88.1	88.2	87.1	85.0	82.4	79.0	76.4	73.3	70.6	65.5	61.2	50.9	49.2	48.0	46.5

The way in which the different rows of fruit cooled when placed in the testing chamber is shown in Fig. 4. It is clear that the outside row of fruit cooled the most rapidly. The temperature differences between the first, or outside, row and the other rows were quite large during the early part of the cooling period, tho as cooling progressed the temperatures of the different rows gradually approached one another.

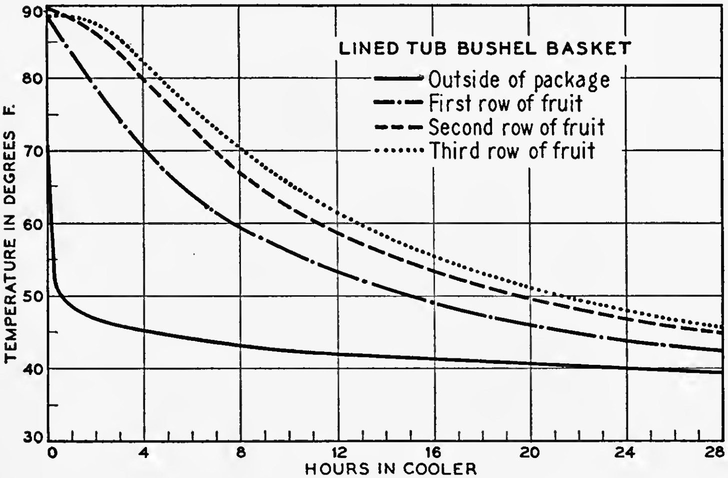

FIG. 4.—PROGRESS OF COOLING WITHIN A LINED TUB BUSHEL BASKET OF APPLES

The first or outside row of fruit cooled more rapidly than the inner rows. The temperature difference between the first and second rows was considerably greater than the temperature difference between the second and third rows.

The number of degrees of drop in temperature per unit of time (2 hours) for the outside row was greatest during the early part of the cooling period and then gradually decreased (Fig. 5). The second and third rows cooled much more slowly than the first, or outside, row at the start, but after a period of 5 or 6 hours conditions were reversed, and from that time on thruout the test the third row showed a greater drop per unit of time than the second row, and likewise the second row showed a greater drop than the first row. The total drop in degrees during the entire period of the test was about the same for the three different rows. It was only slightly less for the inner rows than for the outside row.

The difference in the range of temperature between the first and second rows was considerably greater than the difference between the second and third rows. The temperature differences between the first and second rows and the second and third rows increased as the difference between the temperature of the fruit when packed and the temperature of the cooling room increased (Fig. 5). When the fruit

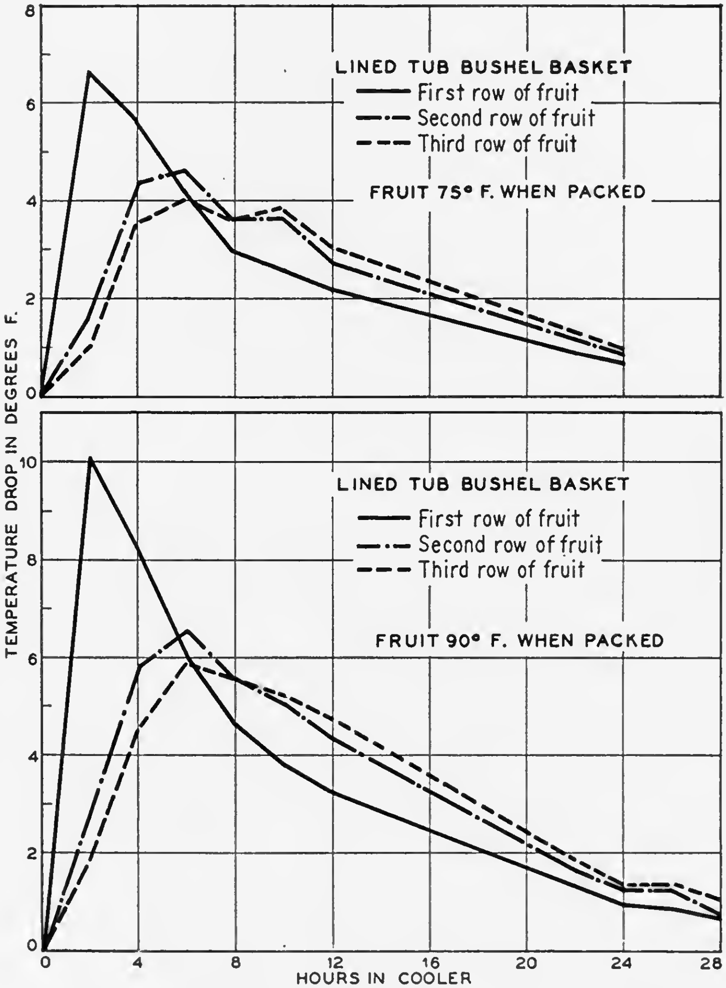

FIG. 5.—TEMPERATURE DROP PER TWO-HOUR INTERVALS IN DIFFERENT ROWS OF APPLES IN LINED TUB BUSHEL BASKETS WITH INITIAL TEMPERATURES OF 75 AND 90° F.

The first, or outside, row of fruit when packed at 75° F. and when packed at 90° F. cooled rapidly during the first part of the cooling period and then gradually less rapidly; while the second and third rows cooled slowly at first, reaching a peak after six hours in the cooler, and then cooled at a reduced rate but still at a more rapid rate than the outside row. The outside row of the 90° F. fruit cooled more rapidly than the outside row of the 75° F. fruit.

was at a temperature of 75° F. when packed, there was a maximum difference in drop per unit of time of 4.98 degrees between the outer row and second row of fruit, and a maximum difference of .82 degrees between the second and third rows. When the fruit was at a temperature of 90° F. when packed, there was a maximum difference in drop per unit of time of 7.38 degrees between the outside and second rows of fruit, and a maximum difference of 1.31 degrees between the second and third rows.

Air Spaces in Package of Value in Cooling

The question has been frequently raised as to how a temperature change reaches the center of a package of fruit. Opinions seem to be

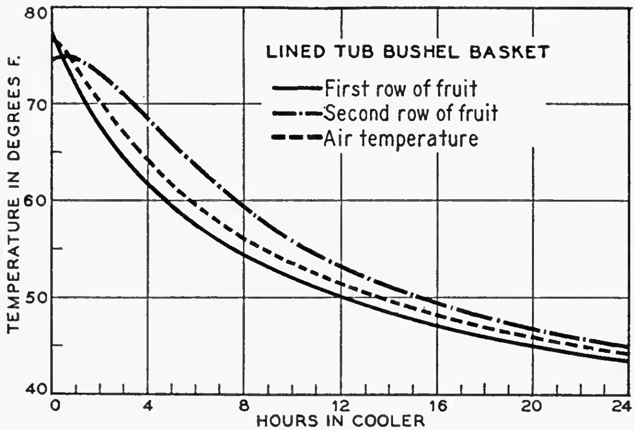

FIG. 6.—RELATION OF AIR TEMPERATURE TO FRUIT TEMPERATURE IN LINED TUB BUSHEL BASKET OF APPLES

The air temperature between the first, or outside, row and the second row was nearly midway between the fruit temperatures of the two rows.

divided, some holding that air circulation is responsible for the temperature change, while others are inclined to believe that the temperature change is due to conduction, that is, that the temperature change is carried from fruit to fruit.

In an effort to obtain data bearing upon this question a series of tests were made in which the relation of air to fruit temperature was followed thruout the cooling period. Records were taken of the temperatures of fruits in two consecutive rows and of the air temperature between the fruits. The relation of the fruit temperature to the air temperature in a lined tub bushel is shown in Fig. 6. These records show clearly that the air temperature between the two rows of fruit

TABLE 2.—RELATION OF AIR TEMPERATURE BETWEEN ROWS TO FRUIT TEMPERATURE IN LINED TUB BUSHEL BASKETS OF APPLES
(Degrees Fahrenheit)

Time (hours)	Start	¼	1	2	3	4	5	6	7	8	10	12	20	22	24
Diameter of fruit—2 to 2¼ inches															
First row of fruit	68.5	70.6	62.8	62.7	59.7	58.6	55.1	53.1	51.5	50.0	48.2	46.4	42.0	41.6	40.6
Air temperature	71.4	71.7	68.7	66.1	63.3	61.2	59.0	57.1	54.8	53.6	50.7	48.4	43.5	42.4	41.1
Second row of fruit	71.0	71.6	70.6	69.3	67.2	65.4	62.9	60.6	58.7	57.2	54.1	51.3	44.9	43.6	42.7
Diameter of fruit—2¼ to 2¾ inches															
First row of fruit	78.4	74.9	71.4	67.9	64.8	62.1	59.6	57.9	56.0	54.8	52.3	50.3	45.0	44.1	43.4
Air temperature	76.9	76.8	72.5	69.5	66.8	64.0	62.2	59.7	58.0	56.7	53.6	51.3	45.8	44.9	44.1
Second row of fruit	74.5	75.0	74.6	73.3	71.1	68.7	66.2	64.1	61.9	60.2	56.6	53.0	46.9	45.9	45.2
Diameter of fruit—2¾ to 3 inches															
First row of fruit	76.1	76.7	72.9	68.8	65.7	62.9	60.2	58.4	56.6	54.9	52.3	49.7	44.4	43.2	42.4
Air temperature	77.8	79.0	75.1	71.8	68.6	65.9	63.3	61.2	59.5	57.7	54.2	51.7	45.3	44.5	43.4
Second row of fruit	78.0	78.6	76.5	74.7	72.4	69.9	67.3	65.0	63.0	60.9	57.1	54.2	46.7	45.4	44.3

TABLE 3.—EFFECT OF AIR SPACES ON RATE OF COOLING IN LINED TUB BUSHEL BASKETS OF APPLES
(Degrees Fahrenheit)

Time (hours)	Start	¼	1	2	3	4	5	6	7	8	10	12	20	22	24	26	28	30	32	34	36	44	46	48
Air temperature																								
[a]Air spaces open	35.0	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
[b]Filled	34.8	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside of package																								
[a]Air spaces open	71.1	50.1	48.3	46.2	46.1	45.4	44.8	43.6	43.9	43.1	42.6	41.7	40.4	39.7	39.6	39.6	39.1	....	....	....	....	....	....	....
[b]Filled	69.0	48.6	45.1	45.4	44.4	44.3	43.2	42.9	42.2	40.8	41.7	41.3	38.9	39.1	39.0	38.7	39.5	38.4	38.8	38.3	38.5	37.5	37.4	38.6
First row of fruit																								
[a]Air spaces open	88.3	87.5	83.0	78.0	73.7	70.0	66.8	64.2	61.4	59.0	55.4	52.5	47.9	45.1	43.4	43.3	42.3	....	....	....	....	....	....	....
[b]Filled	82.3	81.8	78.3	75.3	72.4	70.0	67.8	66.0	64.1	62.6	60.3	57.7	50.5	49.1	48.2	47.3	46.3	45.5	44.9	44.6	43.4	41.8	41.2	40.8
Second row of fruit																								
[a]Air spaces open	88.8	88.7	88.0	85.9	83.2	79.8	76.5	73.2	70.3	67.7	62.8	58.6	49.6	47.8	46.8	45.2	44.8	....	....	....	....	....	....	....
[b]Filled	83.6	83.7	83.7	83.3	82.6	81.6	80.2	78.9	77.4	76.0	72.9	70.3	60.1	58.0	56.4	54.8	53.2	51.9	50.7	49.6	48.6	46.1	45.5	44.8
Third row of fruit																								
[a]Air spaces open	88.2	88.1	88.2	87.1	85.0	82.4	79.0	76.4	73.3	70.6	65.5	61.2	50.9	49.2	48.0	46.5	45.5	....	....	....	....	....	....	....
[b]Filled	83.4	83.5	84.0	83.9	83.5	83.5	82.8	82.2	81.2	80.1	77.7	75.0	64.3	62.2	60.1	58.1	56.5	54.8	53.3	51.9	50.8	47.1	46.3	45.6

[a]With air spaces open. [b]With air spaces filled with mineral wool.

lay between the fruit temperatures. This relationship was found to exist for the three sizes of apples tested, as is shown in Table 2.

Such data lend some support to the theory that air circulation is of no importance and that the fruit is cooled by conduction. The rate of cooling in the different rows of fruit within the package (Fig. 4) also tends to substantiate the conduction theory.

Later tests, however, indicated quite the reverse. It was reasoned that if cooling is due entirely to conduction, then the air spaces between fruits would be of no value in the cooling process. Tests were made with packages of fruit in which the spaces between the fruits were filled with mineral wool without interfering in any way with the contact between fruits. Packages so treated cooled much more slowly than packages with open air spaces, the cooling period being extended from 28 to 48 hours (Table 3). It would therefore seem that the air space between fruits is of value in bringing about a rapid change in the temperature of the fruit within a package, and that while the air circulation within a tub bushel basket exposed to low air velocity is very slow, it does play an important part in the cooling of the contents of the package.

EFFECT OF AIR VELOCITY ABOUT A PACKAGE ON RATE OF COOLING WITHIN

Forced air circulation at a high velocity is commonly used as a means of precooling fruits being prepared for transit. If the fruit is cool at the time of loading, it can be held without difficulty at a desirable temperature in the average ice refrigerator car by means of the cooling power of the car. However, if warm fruit is placed in a car, difficulty is experienced in reducing the temperature to a point considered desirable for retarding ripening and preventing decay. Results of studies already published show that there is a wide range of temperatures within a car of fruit being cooled while in transit,[10*] and that rate of air flow is an important factor in the cooling process.[5*]

In order to test the effect of the velocity of the air about a package on the rate at which the contents of the package will cool, lined tub bushel baskets filled with Grimes apples were subjected to four air velocities—still air, and air moving at the rate of 88.4, 114.4, and 156.2 feet per minute. This is a wider range of air velocities than is commonly found within a refrigerator car. The average temperature of the air before it came in contact with the package varied only slightly in the different tests. The thermocouples were arranged as indicated in Fig. 3-A.

TABLE 4.—EFFECT OF FOUR DIFFERENT AIR VELOCITIES ON RATE OF COOLING IN LINED TUB BUSHEL BASKETS OF APPLES
(Degrees Fahrenheit)

Time (hours)	Start	¼	1	2	3	4	5	6	7	8	10	12	20	22	24	26	28
Air temperature																	
[a]Still	38	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
[b]Slow	37.2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
[c]Medium	35	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
[d]Rapid	36	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Temperature outside of package																	
[a]Still	58.7	51.7	49.3	47.8	46.9	45.8	45.2	44.8	44.3	44.1	43.3	42.4	40.7	40.2	40.0	40.0	39.6
[b]Slow	72.8	49.9	48.0	46.6	47.0	47.0	47.7	45.6	46.3	45.2	44.1	43.3	41.5	42.2	42.4	42.0	40.5
[c]Medium	69.7	45.5	44.4	43.3	42.2	42.5	42.4	40.7	39.8	40.5	41.8	41.0	39.5	39.2	38.7	40.4	38.3
[d]Rapid	69.7	45.7	45.4	43.6	43.3	43.0	45.1	42.7	41.8	41.4	42.0	40.5	40.1	39.5	40.6	....	....
First row of fruit																	
[a]Still	73.8	74.0	71.0	67.9	65.3	62.8	60.6	59.4	57.8	56.6	54.1	51.9	46.1	45.0	44.2	43.5	42.9
[b]Slow	77.1	76.4	72.8	69.2	66.7	64.7	62.4	59.2	58.9	57.5	54.8	52.9	47.1	46.2	45.5	45.2	44.2
[c]Medium	75.1	74.8	71.7	68.7	65.8	63.2	60.8	58.7	57.3	56.6	54.0	51.8	46.7	45.8	45.0	44.3	43.9
[d]Rapid	75.8	75.6	71.8	67.9	64.5	61.3	58.6	56.4	54.4	52.7	50.0	47.7	42.7	42.0	41.6	....	....
Second row of fruit																	
[a]Still	72.7	73.9	73.5	72.7	71.1	69.0	67.1	65.5	63.7	62.2	59.1	56.1	48.7	47.5	46.7	45.5	44.7
[b]Slow	77.7	77.4	76.8	74.0	73.7	72.0	69.6	66.1	65.4	63.8	60.2	57.4	50.0	48.7	47.4	47.1	46.0
[c]Medium	75.5	75.6	75.0	73.7	71.9	69.8	67.2	65.0	63.9	62.3	58.6	56.0	49.1	47.9	47.0	46.4	45.7
[d]Rapid	76.3	76.5	76.2	74.4	71.7	68.5	65.3	62.8	60.4	58.2	53.8	51.1	44.3	43.2	42.9	....	....
Third row of fruit																	
[a]Still	72.6	74.7	74.1	73.9	72.7	70.8	69.4	68.0	66.3	64.6	61.4	58.3	55.4	48.8	47.6	46.7	45.7
[b]Slow	78.1	77.6	77.0	75.5	74.5	72.7	70.6	67.3	66.5	64.8	61.0	58.3	50.5	48.8	47.7	47.3	46.3
[c]Medium	75.5	75.6	75.3	74.5	73.0	71.0	68.9	66.5	64.8	63.6	59.8	57.2	49.6	48.3	47.4	46.1	46.1
[d]Rapid	75.8	76.3	76.8	75.7	73.9	71.2	68.5	65.6	63.6	61.3	56.6	53.4	45.6	44.4	43.5	....	....

[a]Still air, convection current only. [b]Slow air, 88.4 feet per minute. [c]Medium air, 114.4 feet per minute. [d]Rapid air, 156.2 feet per minute.

The rates of temperature drop that occurred at the four different air velocities are shown in Table 4. The records designated "still air" were obtained by placing the fruit in a large coil-cooled storage room in which there was no forced air circulation. The other records were obtained by tests made in the special apparatus already described.

No differences in the rate of cooling that may be attributed to air movement were shown at the first three velocities; but when the air velocity was increased to 156 feet per minute, the time required for cooling the fruit within the package was reduced about 8 hours, or about 28 percent.

A graphic comparison of the temperature drop within the packages subjected to the different air velocities is shown in Fig. 7. The

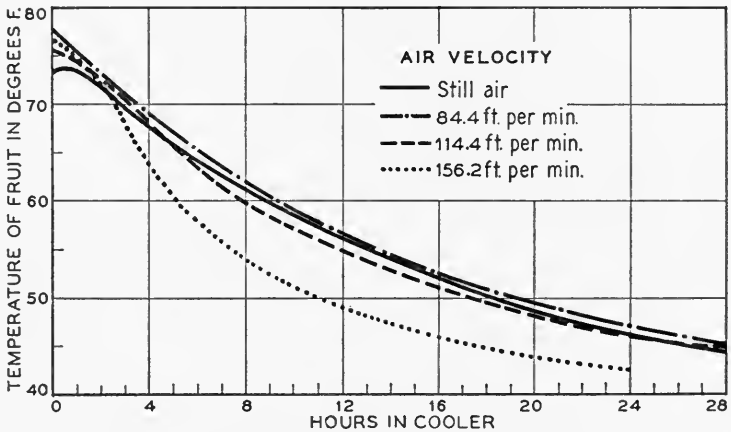

FIG. 7.—EFFECT OF AIR VELOCITY ON RATE OF COOLING IN LINED TUB BUSHEL BASKETS OF APPLES

Air velocities below 115 feet a minute did not influence the rate of cooling of fruit packed in a lined tub bushel basket. As the air velocity was increased, a point was reached at which the rate of cooling increased.

curve was obtained by taking an average of all the fruit temperature records within the package. The packages subjected to the three lower air velocities show only small temperature differences that are experimentally insignificant. The packages subjected to the higher air velocity show a distinctly more rapid drop in temperature thruout the test.

Earlier studies[10*] have shown that the rate of air circulation varies considerably in different parts of the refrigerator car. On the average, the highest velocity within any part of a car under normal conditions seldom goes above 80 feet per minute, while in other parts of the same car the velocity may be below 20 feet per minute. The results obtained under laboratory conditions with the tub bushel basket would

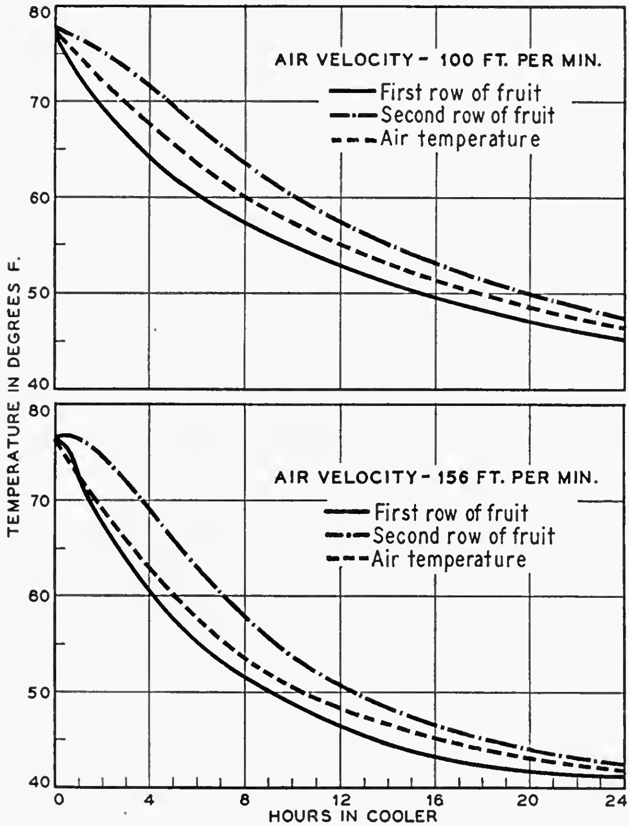

FIG. 8.—EFFECT OF AIR VELOCITY ON RELATION OF AIR TEMPERATURE TO FRUIT TEMPERATURE IN LINED TUB BUSHEL BASKETS OF APPLES

When the velocity of the air about the package was less than 100 feet a minute, the air temperature between the first and second rows of fruit in a lined tub bushel basket was about midway between the temperatures of the fruit in the first and second rows. An increase in air velocity to 156 feet a minute caused the air temperature between the first and second rows of fruit to approach more nearly the temperature of the fruit in the outside row.

seem to indicate that the value of increasing the air velocity in a refrigerator car up to 100 percent above the velocities normally found in such cars is due, not to increased air circulation within the package, but to the lowering of the air temperature about the package.

When, however, in the presence of a uniform air temperature, more rapid cooling is obtained by increasing the velocity of the air about the package, it is clear that some other factor than the temperature of the air on the outside of the package must be responsible for the lowered temperature within the package. How the different air velocities outside the packages influenced the air and fruit temperatures within the packages is indicated by Fig. 8. When the air velocity outside the package was 100 feet per minute, the air temperature within the package was very nearly midway between the temperature of the two rows of fruit; while with an air velocity of 156 feet per minute, the air temperature within the package was considerably closer to that of the outside row of fruit. These results would seem to indicate that even in these lined bushel baskets the air circulation within the package was influenced by the more rapid air velocities outside the package. With more open types of containers, the influence of the air velocity outside the package on the air circulation within the package would of course be more marked.

EFFECT OF TEMPERATURE OF FRUIT AT TIME OF PACKING ON RATE OF COOLING

Studies by various investigators have shown that the temperature of the fruit during harvest and packing determines to some extent the amount of mechanical injury it will sustain and the losses that will result during marketing. Many fruits must be harvested and marketed during the summer months when temperatures are high. The question of how the temperature at the time of packing influences cooling may therefore be of considerable importance. A series of tests were conducted to obtain information on this point.

The lined tub bushel basket filled with Grimes apples 2¼ to 2¾ inches in diameter was used in all the tests. The fruits at the time of packing were of two general temperatures—"medium," or about 75° F. when packed, and "warm," or about 88° F. The tests were started immediately after the packing of the fruit. The thermocouple arrangement was as shown in Fig. 3-A.

Under the conditions of these tests, the "warm" fruit cooled at a more rapid rate than did the fruit of "medium" temperature (Table 5). While the initial difference in temperature of the medium and warm fruit was about 12 degrees, this difference was reduced to one degree when the fruit had been in the cooler for a period of 28 hours. The narrowing of the temperature difference was gradual, the difference

TABLE 5.—EFFECT OF TEMPERATURE OF FRUIT AT TIME OF PACKING ON RATE OF COOLING IN LINED TUB BUSHEL BASKETS OF APPLES
(Degrees Fahrenheit)

Time (hours)	Start	¼	1	2	3	4	5	6	7	8	10	12	20	22	24	26	28
Air temperature																	
[a]Medium	35.0	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
[b]Warm	35.1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Temperature outside of package																	
[a]Medium	69.7	45.5	44.4	43.3	42.2	42.5	42.4	40.7	39.8	40.5	41.8	41.0	39.5	39.2	38.7	40.4	38.3
[b]Warm	70.8	49.4	48.5	45.8	47.1	46.4	46.6	44.7	45.6	45.7	44.2	43.1	41.7	41.2	40.8	40.2	38.3
First row of fruit																	
[a]Medium	75.1	74.8	71.7	68.7	65.8	63.2	60.8	58.7	57.3	56.6	54.0	51.8	46.7	45.8	45.0	44.3	43.9
[b]Warm	86.8	83.5	81.9	77.4	73.8	70.8	67.9	66.5	63.2	61.2	56.1	53.8	47.6	46.7	45.6	44.9	44.0
Second row of fruit																	
[a]Medium	75.5	75.6	75.0	73.7	71.9	69.8	67.2	65.0	63.9	62.3	58.6	56.0	49.1	47.9	47.0	46.4	45.7
[b]Warm	87.8	87.6	86.9	85.2	83.2	80.5	77.6	74.8	72.2	70.0	64.7	61.5	51.4	50.1	48.8	47.7	47.0
Third row of fruit																	
[a]Medium	75.5	75.6	75.3	74.5	73.0	71.0	68.9	66.5	64.8	63.6	59.8	57.2	49.6	48.3	47.4	46.1	46.1
[b]Warm	87.8	86.4	87.0	86.1	84.5	82.5	78.9	77.8	75.1	72.8	67.4	64.0	53.8	51.4	49.9	48.4	47.6

[a]Fruit of medium temperature (about 75° F.) when packed. [b]Fruit warm (about 88° F.) when packed.

being 12.1 degrees at the start, 9.9 degrees after 4 hours, 7.2 degrees after 8 hours, 4.8 degrees after 12 hours, 2.5 degrees after 20 hours, and 1 degree after 28 hours. After 28 hours in the cooling chamber the fruit in both groups registered temperatures in the neighborhood of 45° F. These findings are in accord with those obtained in tests in refrigerator cars loaded with bushel baskets of apples. In the earlier studies[10*] cars of fruit that differed about 15 degrees when loaded had temperature differences of about 11 degrees after 10 hours, 9 degrees after 20 hours, 7 degrees after 30 hours, 6 degrees after 40 hours, and 5 degrees after 50 hours.

In the laboratory tests much more rapid cooling occurred than in the previous tests made in standard refrigerator cars.[10*] The cooling unit in the laboratory had ample power to carry the load, maintaining a uniform air temperature of about 35° F. The cooling power of the refrigerator cars under test[10*] was insufficient to reduce the temperature of the fruit rapidly. It would appear, therefore, that the extent of injury resulting from the packing of high-temperature fruits is largely dependent upon the cooling power of the space, room, or car in which the packages are placed after packing.

Temperature differences such as occurred in these tests between the fruits in the medium and warm groups during the cooling period (Table 5) may be sufficient to cause considerable difference in losses due to overripeness and decay. Differences in losses between medium and warm fruit are likely to be even greater under the conditions found in refrigerator cars.

SIZE OF FRUIT HAD NO APPARENT EFFECT ON RATE OF COOLING

In order to ascertain whether size of fruit has any influence on rate of cooling, a number of tests were made with three sizes of Grimes apples packed in lined tub bushels. The small-sized fruits were 2 to 2¼ inches in diameter; the medium, 2¼ to 2¾ inches; the large, 2¾ to 3 inches.

The temperature of the fruits in the different lots was between 70 and 75° F. when packed. The thermocouple arrangement for the two larger sizes is shown in Fig. 3-A; the arrangement for the small-sized fruit is shown in Fig. 3-B.

The tests were conducted in the laboratory with air velocities below those found to cause a difference in the rate of cooling due to increased air circulation, as discussed on page 28. Each record reported represents a composite of a number of tests for a given size of fruit.

TABLE 6.—EFFECT OF SIZE OF FRUIT ON RATE OF COOLING IN LINED TUB BUSHEL BASKETS OF APPLES
(Degrees Fahrenheit)

Time (hours)	Start	¼	1	2	3	4	5	6	7	8	10	12	20	22	24
Air temperature															
[a]2–2¼″	33.9	....	....	....	....	....	....	....	....	....	....	....	....	....	....
[b]2¼–2¾″	36.4	....	....	....	....	....	....	....	....	....	....	....	....	....	....
[c]2¾–3″	35.0	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Outside of basket															
[a]2–2¼″	66.2	44.2	41.1	40.5	40.4	39.7	39.1	38.8	39.4	39.8	38.9	38.4	37.8	36.4	36.2
[b]2¼–2¾″	64.0	47.6	46.5	44.9	44.1	43.8	44.2	42.7	42.0	42.0	42.4	41.3	40.1	39.6	39.8
[c]2¾–3″	67.8	49.9	44.0	43.4	42.6	42.0	41.0	41.0	41.2	40.4	40.5	40.1	38.0	38.6	37.3
First row of fruit															
[a]2–2¼″	69.6	69.6	65.9	62.7	59.8	58.3	55.3	53.3	51.8	50.7	48.5	46.7	42.3	41.4	41.0
[b]2¼–2¾″	74.9	74.8	71.5	68.2	65.2	62.4	60.0	58.2	56.5	55.3	52.7	50.5	45.2	44.3	43.6
[c]2¾–3″	77.8	78.0	74.4	69.3	65.9	63.8	60.0	58.2	56.3	54.6	51.9	49.4	43.3	42.4	41.5
Second row of fruit															
[a]2–2¼″	71.1	71.9	70.1	69.3	67.4	65.8	63.6	61.1	59.2	57.8	54.6	51.7	45.4	44.0	43.1
[b]2¼–2¾″	74.8	75.3	74.9	73.6	71.6	69.1	66.5	64.4	62.7	60.9	57.2	54.4	47.4	46.2	45.5
[c]2¾–3″	79.9	80.5	77.5	75.3	72.8	70.5	67.4	65.2	63.8	62.3	57.0	53.9	46.0	44.6	43.6
Third row of fruit															
[a]2–2¼″	71.0	71.5	70.5	70.1	69.0	68.1	66.1	64.4	62.4	60.9	57.4	54.4	46.7	45.3	44.2
[b]2¼–2¾″	74.6	75.3	75.2	74.7	72.5	71.0	68.2	66.7	64.9	62.4	59.3	56.3	50.2	47.2	46.2
[c]2¾–3″	77.9	78.8	82.0	76.1	74.4	72.7	70.3	68.4	66.3	64.0	60.0	56.4	47.8	46.1	44.8
Center fruit															
[a]2–2¼″	69.8	69.7	69.2	68.6	67.9	67.4	65.9	64.5	62.8	61.1	57.9	54.8	46.7	45.3	43.3

[a]2 to 2¼ inches diameter. [b]2¼ to 2¾ inches diameter. [c]2¾ to 3 inches diameter.

The temperature drops for the different rows of fruits, as shown in Table 6, indicate that the outside row cooled most rapidly, the inner rows lagging behind in much the same way as shown in Fig. 4.

The average temperature drop for each size of fruit is shown graphically in Fig. 9. (The average was obtained by considering all the fruit temperature records within a package.) The temperature

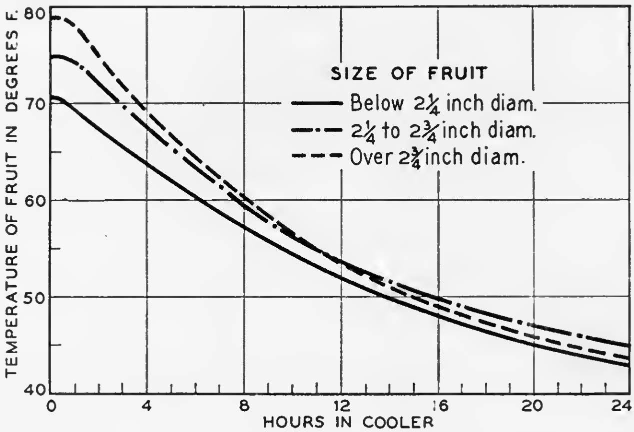

FIG. 9.—EFFECT OF SIZE OF FRUIT ON RATE OF COOLING IN LINED TUB BUSHEL BASKETS OF APPLES

The size of fruit used in filling a package did not materially affect the rate at which the contents cooled.

drops for the three sizes nearly paralleled one another, no difference occurring that could be attributed to a difference in the size of fruit. This would lead to the conclusion that the size of the specimens of fruit within a package is not a factor influencing the rate of cooling so long as the total weights of the contents of the packages are similar.

EFFECT OF TYPE OF CONTAINER ON RATE OF COOLING OF CONTENTS

Marked changes have taken place during the last few years in the packages used for apples in some commercial producing sections. Evidently the old standard package was not entirely satisfactory. Many different types of packages have been tried.

Cars loaded with rectangular packages were shown in earlier studies[10*] to cool more rapidly than cars loaded with bushel baskets. Eustace and Beach[2*] found that the type of container used had a definite effect upon the rate at which apples placed in storage cooled.

From the data available it would appear that the efficiency of the refrigerator car in reducing the temperature of a load of fruit might be greatly improved by the selection of the proper container. Tests were therefore made of a number of containers commonly used for packing apples. Also a few not in common use, but which are of interest because of some construction feature, were included in the tests (Fig. 10). Each package being tested was protected from direct

FIG. 10.—TYPES OF CONTAINERS USED IN EXPERIMENTS ON RATE OF COOLING

A—Peck basket; B—half-bushel basket; C—wire-bound slat crate; D—tub bushel basket; E—western apple box; F—unventilated corrugated box; G—ventilated corrugated box; H—select apple package; I—bushel hamper.

exposure to the air by a package of the same type placed on the side toward the wind. Conditions were thus created that were similar to those found in cars loaded with the packages.

The thermocouple arrangement for each type of container is shown in Fig. 11. In so far as possible, the arrangements were similar in order to have a proper basis for comparing the rate of temperature drop of the contents in the various types of containers. Since the tub bushel basket with a ventilated liner and a corrugated facing pad was used as a standard container for the tests reported in the fore

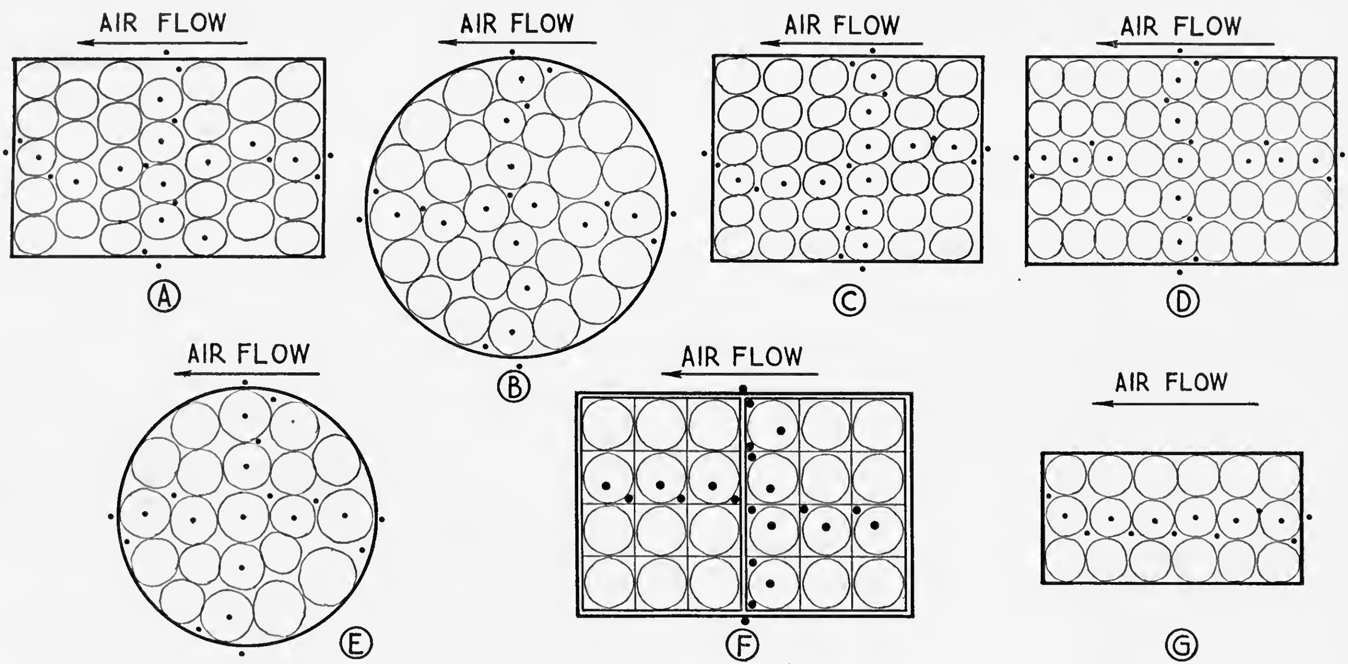

FIG. 11.—THERMOCOUPLE ARRANGEMENTS USED IN PACKAGES TESTED FOR RATE OF COOLING

The thermocouples were arranged in a cross-section thru the center of the package, as indicated above. A—Western apple box (*Fig. 10-E*); B—tub bushel basket and bushel hamper (*Fig. 10-D and I*); C—wire-bound slat crate (*Fig. 10-C*); D—ventilated and unventilated corrugated bushel boxes (*Fig. 10-F and G*); E—half-bushel basket (*Fig. 10-B*); F—select apple package (*Fig. 10-H*); G—peck basket (*Fig. 10-A*).

part of this publication, the other containers tested are compared with this package.

Ventilated Corrugated Bushel Box Cooled as Rapidly as Lined Tub Bushel Basket

The corrugated boxes used in these tests were the same as those used in the shipping tests reported in an earlier bulletin of this Station.[10*] The dimensions are approximately the same as those of the western apple box. The ventilated box has seven one-inch holes on each of the long sides and five one-inch holes on each end. There are no openings in the top or bottom. The thermocouple arrangement used is shown in Fig. 11-D.

In the shipping tests referred to above, the corrugated boxes proved superior to the lined bushel baskets in the rate at which the load was cooled. Under laboratory conditions these two packages proved about equally efficient in permitting cooling of their contents (Fig. 12). In the laboratory a uniform air temperature was maintained thruout the cooling period, while in the refrigerator car the cooling power was insufficient and the air temperature was not uniform but was reduced as the temperature of the load was reduced. A more rapid air movement took place in cars loaded with the corrugated boxes than in those loaded with bushel baskets.[10*] The advantage in using boxes in refrigerator cars would appear to be due to the lower air temperature made possible by the more rapid air movement.

Unventilated Corrugated Bushel Box Cooled Slowly

Corrugated boxes were tested that were the same in every respect as the one described above except that there were no holes for exchange of air. The thermocouple arrangement was the same as for the ventilated box (Fig. 11-D).

Apples packed in the unventilated corrugated box required about eight hours longer to cool than those packed in the lined bushel basket or the ventilated corrugated box (Fig. 12). The question arises whether this difference in the rate at which the fruit cooled in the unventilated and ventilated corrugated boxes was due to a difference in the insulating value of the two containers or to a difference in the rate at which air circulated within the packages. A study of the relation of air temperature to fruit temperature within the two packages shows no differences that might be attributed to a difference in rate of air movement within the packages (Table 7). The difference in the performance of the two packages would appear to have been due primarily to differences in the insulating value of the containers.

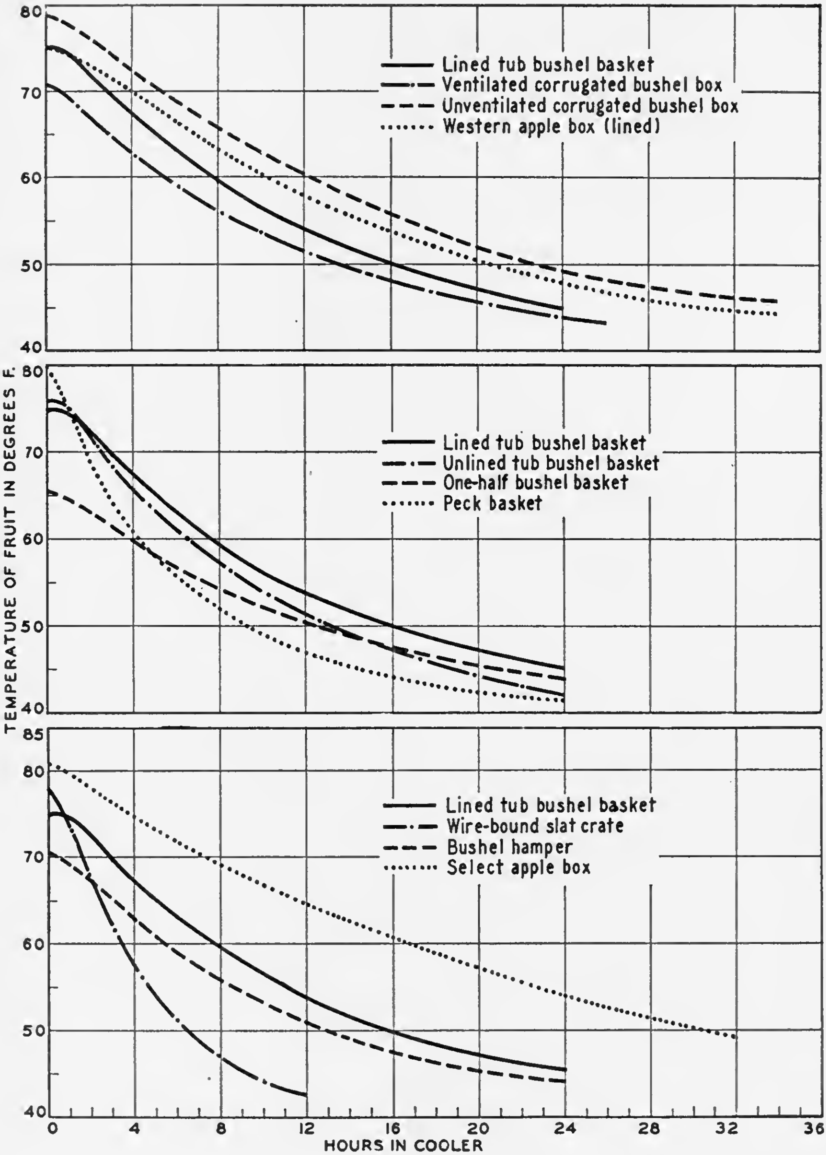

FIG. 12.—EFFECT OF TYPE OF CONTAINER ON RATE OF COOLING OF CONTENTS

Apples packed in a ventilated corrugated box cooled at a rate nearly equal to that in a lined tub basket; while fruit in an unventilated corrugated box and in a western apple box cooled at a much slower rate. An unlined tub bushel basket and a peck basket cooled more rapidly than the lined tub bushel basket. A "select apple package" cooled more slowly than the lined tub bushel basket, while a slat crate cooled much more rapidly.

TABLE 7.—RELATION OF AIR TEMPERATURE TO FRUIT TEMPERATURE IN VENTILATED AND UNVENTILATED CORRUGATED BUSHEL BOXES OF APPLES
(Degrees Fahrenheit)

Time (hours)	Start	¼	1	2	3	4	5	6	7	8	10	12	20	22	24	26	28	30	32	34
Ventilated corrugated box																				
First row of fruit	71.1	70.5	67.7	64.8	60.8	58.9	57.0	54.9	53.7	52.1	50.3	48.5	43.8	43.0	42.9	42.6	....	....	....	....
Air temperature between	71.5	69.7	67.1	64.2	62.1	59.9	57.8	56.1	54.8	53.7	51.7	49.6	45.0	44.1	43.9	42.6	....	....	....	....
Second row of fruit	71.4	71.4	70.3	71.0	67.0	64.9	62.9	60.9	59.2	57.8	54.8	52.8	46.6	45.6	45.0	44.2	....	....	....	....
Second row of fruit	70.4	70.1	69.2	65.0	65.9	64.2	62.0	60.1	58.6	56.9	54.5	52.0	46.4	45.1	44.5	43.8	....	....	....	....
Air temperature between	70.7	70.5	71.7	67.5	65.5	63.3	61.4	59.5	57.7	56.4	54.0	51.5	45.9	45.1	44.3	43.6	....	....	....	....
Third row of fruit	70.9	70.7	69.9	68.4	66.6	64.9	60.2	61.4	59.8	57.8	55.5	52.8	46.8	45.4	44.7	43.9	....	....	....	....
Unventilated corrugated box																				
First row of fruit	76.8	77.5	74.6	71.9	70.0	67.9	66.1	64.4	63.0	61.4	58.8	56.7	49.8	48.9	47.9	47.0	45.9	45.6	45.2	44.5
Air temperature between	78.4	78.2	76.3	74.2	72.0	69.5	67.7	65.7	64.0	62.4	58.8	55.4	48.9	48.8	48.0	47.0	46.2	46.0	45.1	44.6
Second row of fruit	78.8	78.6	78.3	77.4	76.5	74.8	73.1	71.4	69.5	67.7	64.6	61.5	53.0	51.8	50.5	49.3	48.0	47.5	46.8	46.2
Second row of fruit	78.9	79.1	78.7	77.8	76.6	74.9	73.1	71.3	69.3	67.4	64.0	61.0	52.4	51.0	49.7	48.6	47.2	46.7	46.1	45.4
Air temperature between	79.5	79.2	77.7	75.9	73.9	71.8	69.8	68.0	66.0	64.2	61.1	58.3	51.0	49.9	48.9	47.8	46.9	46.3	45.8	45.1
Third row of fruit	78.2	78.5	78.2	77.8	76.8	75.5	74.1	72.3	70.6	68.9	65.6	62.7	53.6	52.2	50.7	49.5	48.2	47.7	46.9	46.2

Western Apple Box Cooled Less Rapidly Than Lined Tub Bushel Basket

The wooden bushel apple box, which is a standard container among western apple growers and used to a limited extent by a few mid-western growers, was found to be similar to the unventilated corrugated box in its effect upon the cooling of its contents, or about 30 percent less efficient than the tub bushel basket (Fig. 12). A cross-section of the box, showing packing and thermocouple arrangement, is shown in Fig. 11-A.

Under refrigerator car conditions, however, the wooden bushel box may be as efficient as the tub bushel, owing to the more rapid air movement that takes place when rectangular packages are used and are loaded according to standard specifications.

Ventilated Liner in Tub Bushel Slightly Retarded Cooling

The liner in an apple basket is considered essential by most packers, especially for tender apple varieties, but oftentimes it is used because the method of packing requires it rather than as a means of protecting the fruit. It is advisable to use liners that will interfere as little as possible with the cooling, especially if the temperature must be reduced rapidly.

In tests made with the ventilated liner, ventilation was obtained by two rows of holes located at about one-fourth the distance from the top and the bottom. There were twenty-one ¾-inch holes in each liner. Apples packed in an unlined basket cooled in about 15 percent less time than those packed in a lined basket (Fig. 12). It is probable that cooling would have been retarded even more had an unventilated liner been used.

Cooling of Fruit in Half-Bushel Basket

The general trend in some apple markets is toward a smaller package. The half-bushel basket is one of the packages being used. In the tests made to determine the rate of cooling in one of these baskets, liners were used that were perforated with one row of eight ¾-inch holes. The thermocouple arrangement used is shown in Fig. 11-E.

The temperature of the fruit at the time of packing was lower in these tests than in the tests of the bushel packages. The time required to reduce the temperature to 45° F. was about the same as required in the lined bushel basket (Fig. 12). This is not in accord with opinions that have been advanced,[12*] and the data at hand are insufficient to warrant definite conclusions.

Rectangular Corrugated Peck Basket Cooled More Rapidly Than Lined Bushel Basket

A peck basket made of single-cell corrugated paper material, folded in such a way that the sides are of double thickness, is proving quite popular on some of the midwestern markets. The cover is made of the same material as the basket, and a large opening left in the center is covered with cellophane in order that the contents may be displayed to advantage. The peck basket is an attractive package of convenient size for the average family. The thermocouple arrangement used in the peck basket is shown in Fig. 11-G.

The records show that this package cooled in about 30 percent less time than a lined bushel basket (Fig. 12). It is questionable, however, whether this difference would be maintained in carload lots. The way in which these packages are loaded in the car would be of considerable importance in determining the rate of cooling.

Open-Slat Crate Permitted Rapid Cooling

Among the containers tested which are not in common use for apple packaging is a strong wire-bound open-slat bushel crate. This crate is a little shorter than the bushel box and a little wider. The thermocouple arrangement used in the tests is shown in Fig. 11-C.

Fruit in this package cooled to 45° F. in 10 hours, as compared with 24 hours in the lined bushel basket (Fig. 12). This very rapid rate of cooling was accompanied by a low air temperature about the fruit. The air temperature between two rows of fruit was below that of the outside row (Fig. 13), which is a marked contrast to the relationship of fruit and air temperatures in a lined bushel basket (Fig. 6). This condition was undoubtedly caused primarily by a combination of two factors: the low insulating value of the container and the air circulation among the fruits in the package.

This package may prove of considerable value for carload shipments of perishable products that must be cooled rapidly.

Bushel Hamper Cooled as Rapidly as Lined Bushel Basket

Tests with apples packed in a bushel hamper showed that the rate of cooling in the hamper was about the same as in the lined bushel basket (Fig. 12). The thermocouple arrangement used was the same as for the bushel basket (Fig. 11-B).

The hamper used in these tests is of much stronger construction than the hampers commonly used for shipping vegetables. It has a top about the same diameter as the bushel basket, but the package is taller than the basket and considerably smaller at the base (Fig. 10-I).

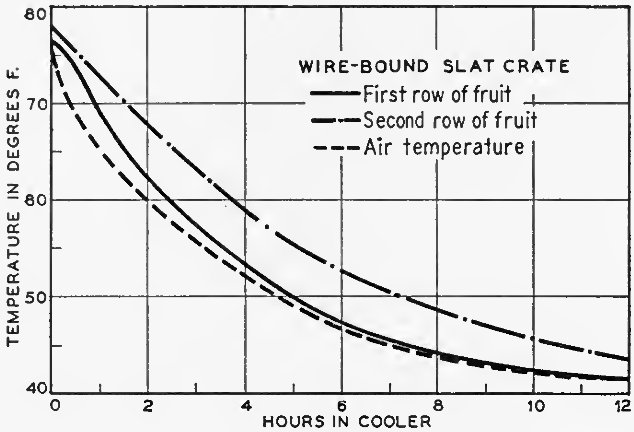

FIG. 13.—RELATION OF AIR TEMPERATURE TO FRUIT TEMPERATURE IN WIRE-BOUND SLAT CRATE OF APPLES

The air temperature between the first and second rows of fruit in the wire-bound slat crate was lower than the fruit temperature of the outside row. This is a marked contrast to the conditions in a lined tub bushel basket, where the air temperature was found to be midway between the fruit temperatures of the two rows.

Apples Shipped in "Select Apple Package" Need Precooling

The "select apple package" tested in these studies is composed of twelve boxes, each holding twelve apples. The boxes are made of heavy-grade paper, are lined with a single-celled corrugated paper, and are divided into twelve individual compartments with corrugated paper (Fig. 10-H). The twelve boxes are then packed in a larger single-celled corrugated box.

Fruit placed in this package cooled very slowly (Fig. 12). Three times as much time was required to cool the contents as was required in a lined bushel basket. The thermocouple arrangement shown in Fig. 11-F was used in tracing the rate of cooling.

While the select apple package may be used to advantage in marketing a limited quantity of fancy apples, these studies show strongly the advisability of cooling the fruit before packing it. Apples placed in this package while at a high temperature are liable to damage from overripeness and decay even under the best refrigerator car conditions.

EFFECT OF WRAPPING FRUIT ON RATE OF COOLING

It is a common practice in some regions to wrap the higher grades of fruit. Especially is this true of apples packed in bushel boxes in the West and to a less extent of fancy apples packed in bushel baskets in other regions. Advantages claimed for wrapping apples include the preservation of their bright color, checking of transpiration, reduction in amount of wilting, prevention of bruising, prevention of spread of rot,[13*] and in some varieties, prevention of scald in storage. In spite of these advantages in wrapping apples for long-time storage, there is some question regarding the desirability of the practice from the standpoint of its effect on the rate of cooling of apples packed and shipped during warm weather.

To determine the effects of wrapping upon rate of cooling, tests were made in lined tub bushel baskets with apples wrapped in 20-percent oil paper wraps and others without wraps. The arrangement of thermocouples in the baskets is shown in Fig. 11-B. Thirty-six hours were required to reduce the temperature of the wrapped fruit to 45° F., while only 24 hours were required to bring about an equal change in the temperature of the unwrapped fruit (Fig. 14).

Other tests were made to determine the rate of cooling of wrapped apples in a western wooden apple box. The fruit was packed in the same way as the unwrapped box apples (Fig. 11-A). The box in which the wrapped fruit was packed was not lined, while the one in which the unwrapped fruit was packed contained a liner. The unwrapped fruit cooled in 34 hours, while the wrapped fruit cooled in 46 hours, a difference of about 35 percent (Figs. 12 and 14). How much a liner in the box of wrapped fruit would have still further retarded cooling was not tested. In a lined bushel basket the retarding effect of the oil-paper wraps was equivalent to about 50 percent of the time required to cool the unwrapped fruit.

These findings are in accord with those of Eustace and Beach,[2*] which show that wrapping materially retards the rate of cooling and that the type of container, to some degree, determines the extent of retardation.

Under the conditions found in the average refrigerator car, it would probably require two days longer to reduce the temperature of a carload of wrapped fruit to the desired degree than a carload of unwrapped fruit, when shipped during the summer months.

The rate of temperature drop per unit of time for the different rows within the baskets of wrapped and unwrapped fruits is shown

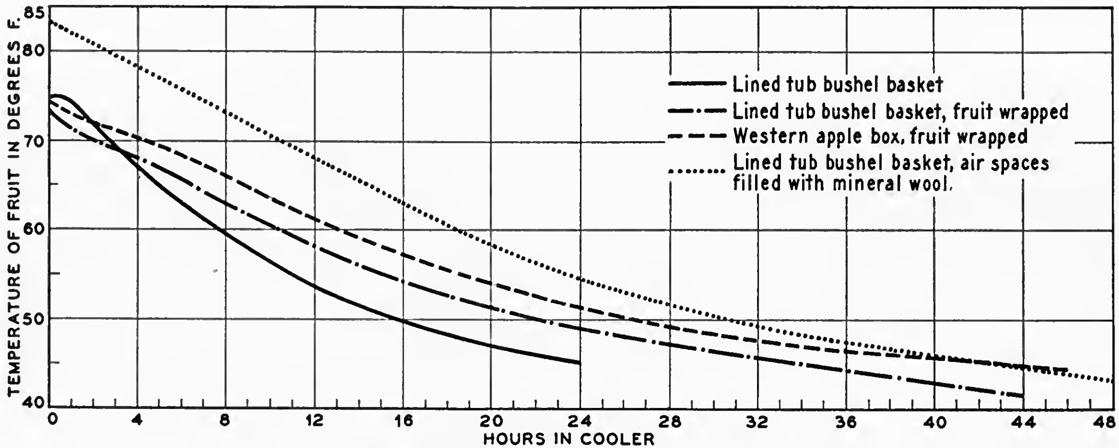

FIG. 14.—RATE OF COOLING OF PACKAGES OF WRAPPED AND UNWRAPPED FRUIT

The wrapping of fruits with oiled wraps materially retarded the rate of cooling. The effect was very similar to that obtained by filling the air spaces with mineral wool.

TABLE 8.—TEMPERATURE DROP PER UNIT OF TIME FOR DIFFERENT ROWS OF WRAPPED AND UNWRAPPED APPLES IN LINED TUB BUSHEL BASKETS
(Degrees Fahrenheit)

Time (hours)	Start	2	4	6	8	10	12	22	24	26	28	30	32	34	36
First or outside row															
Unwrapped	75.8	7.9	6.6	4.9	3.7	2.7	2.3	.7	.4	...	...	...	...	...	...
Wrapped	72.3	8.2	4.1	4.2	2.2	1.8	1.6	.3	.4	.7	.6	.4	.7	.5	.4
Second row															
Unwrapped	76.5	2.1	6.9	5.7	4.6	4.4	2.7	1.1	1.3	...	...	...	...	...	...
Wrapped	73.9	.2	2.0	3.0	2.6	2.7	2.2	1.1	1.1	2.0	1.5	.8	.9	.8	.8
Third or center row															
Unwrapped	76.8	1.1	4.5	5.6	4.3	4.7	3.2	1.2	.9	...	...	...	...	...	...
Wrapped	73.7	0	1.1	1.7	2.2	2.2	2.4	1.3	1.4	1.6	1.1	.8	1.2	1.0	.8

in Table 8. During the first part of the cooling period the temperature drop in the outside row of fruit was about equal for the wrapped and unwrapped fruit, but in the later periods the wrapped fruit cooled more slowly than the unwrapped. The second and third rows of wrapped fruit cooled much more slowly than the corresponding rows of unwrapped fruit during the early part of the cooling period; but as cooling progressed, the rates of cooling of the wrapped and unwrapped fruit gradually approached each other.

After five or six hours in the cooling chamber the two inner rows of unwrapped fruit were cooling more rapidly than the outer row. The corresponding rows of wrapped fruit were in the cooling chamber nine or ten hours before they showed a similar relationship. In an attempt to ascertain the value of the air spaces in the cooling of fruits, tests were made with lined bushel baskets of fruit in which the air spaces were filled with mineral wool (page 27). The results were very similar to those obtained when the fruit was wrapped (Fig. 14). The effect of the wrap on the cooling of the fruit does not seem to be due entirely to its power to insulate the fruit—it seems also to be due to the filling of the air spaces between the fruits.

Most of the data regarding the value of the wrap in improving the keeping quality of apples have been obtained by tests upon fall and winter varieties. It is a question whether equally good results would be obtained with wrapping if the fruit was packed while at a high temperature and then loaded into a refrigerator car and sent to market during the summer months. The high temperature of the fruit would tend to overcome any value of the oil wrap in checking physiological processes.

SUMMARY AND CONCLUSIONS

1. In this study special apparatus was constructed to produce conditions similar to those found in refrigerator cars.

2. Lined tub bushel baskets filled with Grimes apples and placed in a cooling chamber developed comparatively large temperature gradients between the outer and inner rows of fruit during the early part of the cooling period. As cooling progressed, the temperatures became more nearly uniform thruout the package.

3. The temperature difference between individual apples in a lined tub bushel basket and the air in the immediate neighborhood is quite small thruout the cooling period. Packages that permit much

more rapid cooling, such as the wire-bound slat crate, have an air temperature below that of the fruit in the immediate neighborhood.

4. The air spaces between apples packed in a lined tub bushel basket exposed to low air velocities materially contribute to the cooling of the fruit even tho the temperature in these air spaces resembles the fruit temperature. As the air velocity is increased, a point is reached at which it causes the contents of a package to cool more rapidly, owing apparently to the lowering of the air temperature about the fruits as the result of the increased rate at which the air contents of the package are exchanged.

5. Air velocities below 100 feet per minute are not sufficient to affect the rate of air movement within a lined tub bushel basket and therefore do not influence the rate at which the contents cool, provided the air temperature remains constant.

6. The higher the temperature of the fruit when packed, the more rapidly it drops, given similar conditions of temperature and air velocity.

7. The size of apples used in filling a lined tub bushel basket does not alter the rate at which the package cools.

8. The type of container may alter greatly the behavior of a package of apples under refrigeration. The contents of a lined tub bushel, a ventilated corrugated bushel box, and a bushel hamper behaved similarly in cooling tests. The contents of an unventilated corrugated bushel box and a lined western apple box cooled more slowly than the contents of the lined tub bushel basket. The contents of a wire-bound slat crate cooled much more rapidly than the contents of the lined tub bushel basket.

9. The use of oil wraps in the packing of apples materially retards the rate of cooling.

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