TB 550 (1937) USDA TECHNICAL BULLETINS
PROTECTION OF APPLES AND PEARS IN TRANSIT FROM THE PACIFIC NORTHWEST
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START
INTRODUCTION

The proper control of temperatures within refrigerator cars loaded with fresh fruits shipped during periods of low outside temperatures is difficult, especially during that part of the transcontinental movement across the northern portions of the Rocky Mountains and the Great Plains. The problem is not only to prevent the freezing of the fruit but also to prevent its extended exposure to high temperatures within the car while in transit which would materially shorten its subsequent storage life.

1 The experimental work discussed in this bulletin was conducted from 1927 to 1932 by B. R. Faulkner and Edwin Smith, of the Bureau of Markets, while the stationary tests at Roseville, Calif., were made under the direction of Lon A. Hawkins from 1927 to 1930, inclusive, and thereafter under the direction of D. P. Fisher. Other members of the staff of the Division of Fruit and Vegetable Crops and Diseases who assisted in this latter part of the investigation are C. L. Powill, C. O. Bunt, E. F. West, Edwin Smith, A. L. Ryall, J. C. Moore, A. G. Galloway, B. D. Good, F. T. Eagan, W. W. Eldred, W. S. Graham, and W. T. Pentzer. The drawings were made by A. F. Walshman. The helpful assistance of Edwin Jones, assistant meteorologist, U. S. Weather Bureau, Yakima, Wash., is gratefully acknowledged as having made possible the timing of experiments during desired weather conditions. Particular appreciation is expressed for the cooperation and assistance of the refrigerator-car lines, railroad companies, and various shippers and shipping organizations and their representatives, without which these experiments would not have been possible.
Certain conditions have limited the experimental work on the winter transportation of fruit to definite fields. Since the refrigerator car, which is built primarily for refrigeration and also adapted for heater service, it would not be advisable to make any radical change primarily for the prevention of freezing that would at the same time decrease the efficiency of the car for refrigeration. The development of a specialized car for heater service was not considered to be practicable, as heaters are used only for a short time each year in a comparatively small area of the United States. Costs of different methods of operation of heater service also had to be considered. The Department’s experiments, therefore, have been directed mainly to the improvement of heaters and methods of operation, the use of ventilation service, the development of special devices for increasing air circulation in the car to bring about more uniform temperature conditions, and methods of protecting shipments without artificial heat.

These investigations have been conducted in cooperation with the fruit shippers in the Pacific Northwest and the railroads serving that territory and eastern connecting lines. This report includes a summary of the results of a series of investigations conducted from 1917 to 1922, but for the most part is concerned with studies and tests made from 1927 to 1935.

SCOPE AND CONDITIONS OF EXPERIMENTS

Investigations on the prevention of freezing of fresh fruits while in transit from the Pacific Northwest to eastern destinations during periods of cold weather were first started during the winter of 1917-18 primarily as a war measure, to conserve food supplies, and were continued to 1922. No work was done thereafter until 1927, when investigations were resumed dealing not only with the prevention of injury to fruit from low temperatures but with methods to decrease or eliminate the damage to fruit from the high temperatures often resulting from the use of car heaters.

“Heater territory”, or the area in which heater service is regularly provided by the railroads, includes roughly that part of the United States west of Lakes Superior and Michigan and the Illinois-Indiana State line, as shown in figure 1. However, since a large percentage of the shipments originating in heater territory go to destinations outside, several of the experiments were continued to New York City, to study conditions where artificial heat was not then available. In figure 1 are also given the approximate routes of the experimental shipments, showing the location of the regular inspection stations at which the ventilators are opened and closed and the heaters are lighted, extinguished, refueled, and other necessary work is performed, in accordance with the operating rules of the railroads governing these services.

Most of the experiments were conducted during December, January, and February, when the coldest weather is ordinarily encountered. However, weather conditions were variable during the periods when the experiments were actually in progress, as shown in table 1. Information as to average weather conditions over a period of 20 years for the months of December, January, and February are shown in figures.
2, 3, and 4, respectively. These figures show that the average daily minimum temperatures in many sections were about the same for all 3 months. However, over wide areas there is a great variation in the

average minimum temperatures, especially from north to south, so that on some shipping routes severe weather conditions for longer periods are more likely to be encountered than on others.

The various test trips made during these investigations are listed in table 1, giving the number of hours each test was in heater terri-
tory and the total hours each heater burned when operated according to the rules of Carriers' Protective Service. In addition to these tests two series of stationary tests were conducted, one at Roseville, Calif., and the other at Havre, Mont. The tests at Roseville were conducted in 1917 and 1918 in an insulated room large enough to hold a refrigerator car and in which temperatures could be controlled. In the tests at Havre six carloads of apples were held in the railroad yards during December 1928 and January 1929. The outside temperatures during December were relatively high, with only a few nights of cold weather. During the first half of January the tempera-
tures were low enough to require the burning of heaters most of the time, whereas during the last 2 weeks of the month the outside temperatures were lower, ranging between \(-4^\circ\) and \(-38^\circ\) F.

**Table 1.**—Maximum and minimum outside temperatures in transit, time in heater territory, and time each heater burned in test cars shipped under rules of Carriers’ Protective Service, 1918-35

<table>
<thead>
<tr>
<th>Test trip</th>
<th>Destination</th>
<th>Time conducted</th>
<th>Cars in test</th>
<th>Outside temperatures during test</th>
<th>Time in heater territory</th>
<th>Total time heaters were burned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washington 1918-1</td>
<td>Chicago</td>
<td>January</td>
<td>1</td>
<td>(-40^\circ)</td>
<td>384</td>
<td>105</td>
</tr>
<tr>
<td>Washington 1918-2</td>
<td>St. Paul</td>
<td>do</td>
<td>6</td>
<td>(-30^\circ)</td>
<td>326</td>
<td>70</td>
</tr>
<tr>
<td>Washington 1918-3</td>
<td>Minneapolis</td>
<td>do</td>
<td>4</td>
<td>(-30^\circ)</td>
<td>288</td>
<td>70</td>
</tr>
<tr>
<td>Washington 1918-4</td>
<td>St. Paul</td>
<td>February</td>
<td>5</td>
<td>(-20^\circ)</td>
<td>269</td>
<td>64</td>
</tr>
<tr>
<td>Washington 1918-5</td>
<td>Chicago</td>
<td>do</td>
<td>7</td>
<td>(-20^\circ)</td>
<td>280</td>
<td>64</td>
</tr>
<tr>
<td>Washington 1918-6</td>
<td>St. Paul</td>
<td>do</td>
<td>10</td>
<td>(-10^\circ)</td>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>Washington 1918-7</td>
<td>Minnesota</td>
<td>do</td>
<td>3</td>
<td>(-10^\circ)</td>
<td>147</td>
<td>0</td>
</tr>
<tr>
<td>Washington 1918-8</td>
<td>Missouri</td>
<td>do</td>
<td>10</td>
<td>(-10^\circ)</td>
<td>191</td>
<td>0</td>
</tr>
<tr>
<td>Washington 1918-9</td>
<td>Arkansas</td>
<td>January</td>
<td>4</td>
<td>(-20^\circ)</td>
<td>170</td>
<td>37</td>
</tr>
<tr>
<td>Washington 1918-10</td>
<td>Alabama</td>
<td>do</td>
<td>6</td>
<td>(-20^\circ)</td>
<td>150</td>
<td>37</td>
</tr>
<tr>
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<td>Louisiana</td>
<td>do</td>
<td>5</td>
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<td>130</td>
<td>20</td>
</tr>
<tr>
<td>Washington 1918-12</td>
<td>Mississippi</td>
<td>do</td>
<td>6</td>
<td>(-10^\circ)</td>
<td>170</td>
<td>20</td>
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<tr>
<td>Washington 1918-13</td>
<td>New York</td>
<td>February-March</td>
<td>9</td>
<td>(-27^\circ)</td>
<td>258</td>
<td>103</td>
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<tr>
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<td>Alabama</td>
<td>do</td>
<td>4</td>
<td>(-20^\circ)</td>
<td>214</td>
<td>41</td>
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<tr>
<td>Washington 1918-15</td>
<td>Texas</td>
<td>do</td>
<td>6</td>
<td>(-20^\circ)</td>
<td>154</td>
<td>41</td>
</tr>
<tr>
<td>Washington 1918-16</td>
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<td>do</td>
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<td>(-10^\circ)</td>
<td>126</td>
<td>0</td>
</tr>
<tr>
<td>Washington 1918-17</td>
<td>Texas</td>
<td>do</td>
<td>7</td>
<td>(-20^\circ)</td>
<td>112</td>
<td>0</td>
</tr>
<tr>
<td>Washington 1918-18</td>
<td>Missouri</td>
<td>do</td>
<td>6</td>
<td>(-10^\circ)</td>
<td>110</td>
<td>57</td>
</tr>
<tr>
<td>Washington 1918-19</td>
<td>Oklahoma</td>
<td>do</td>
<td>6</td>
<td>(-20^\circ)</td>
<td>110</td>
<td>57</td>
</tr>
<tr>
<td>Washington 1918-20</td>
<td>Kansas</td>
<td>do</td>
<td>6</td>
<td>(-20^\circ)</td>
<td>110</td>
<td>57</td>
</tr>
<tr>
<td>Washington 1918-21</td>
<td>Missouri</td>
<td>do</td>
<td>6</td>
<td>(-20^\circ)</td>
<td>110</td>
<td>57</td>
</tr>
<tr>
<td>Washington 1918-22</td>
<td>Alabama</td>
<td>do</td>
<td>6</td>
<td>(-10^\circ)</td>
<td>110</td>
<td>57</td>
</tr>
<tr>
<td>Washington 1918-23</td>
<td>Louisiana</td>
<td>do</td>
<td>6</td>
<td>(-10^\circ)</td>
<td>110</td>
<td>57</td>
</tr>
</tbody>
</table>

1. Each test is identified by the State of origin, year, and chronological number of experiment made during the year from each State.
2. Prior to season of 1930-31 only 1 heater, placed in the front bunker, was furnished in cars shipped under Carriers’ Protective Service.

The experimental work on the use of heaters in refrigerator cars conducted during the period 1917 to 1922, inclusive, dealt largely with (1) various types of heaters burning kerosene, charcoal, hard coal, and alcohol; (2) car construction and equipment, including floor racks, bulkheads, bulkhead openings, and insulation in car walls; (3) a method of supplying heat through ducts built in the floor; and (4) patented heater cars. During this period 14 transportation tests with a total of 87 cars and the stationary tests at Roseville were made.

During the period from 1927 to 1935 the experimental work relative to protection against freezing by the use of artificial heat had for its objectives (1) testing modifications of charcoal heaters, (2) determining the results of operating heaters according to temperature conditions within the car, (3) determining the need for and testing means of preheating cars, (4) equalizing temperatures throughout the load by forced-air circulation, and (5) determining the conditions...
under which ventilation should be given. Experimental work was also conducted to determine the effectiveness of (1) various supplementary insulating materials placed within the car and around the load, and (2) the latent heat of fusion of water as a means of preventing or retarding the freezing of fruits while in transit. During this period 21 transportation tests with a total of 130 cars and a stationary test at Havre, Mont., were made.

DEFINITION OF TERMS

A number of terms used in this report and in common usage are defined below. A "layer" is a course or stratum of the load, parallel to the floor of the car and one package in height. A "stack" is a pile of packages extending from one side of the car to the other, parallel to the ends of the car and one package in length. A "row" is a pile of packages lengthwise of the car parallel to the sides and one package in width. The "bunker position" is in the stack next to either bunker bulkhead, while the "quarter-length position" is in a stack midway between the doors and either bunker. The "center line" is a position in a row midway between the side walls of the car.

The "bunker" is the compartment at each end of the car where the ice or the heaters are placed. The top and bottom "bunker openings" are the openings, of varying height, at the top and bottom of each bunker bulkhead to permit air to enter and leave the bunkers. The "ice grate" is a wood or metal grating in the bunker which supports the ice or heater several inches above the drip pan. The "drip pan" is a shallow metal pan on the floor of the bunker to catch the water from the melting ice, which leaves the car through drain pipes. The term "divided load" is used to designate a load having an open space of varying width between the doors, where it is braced with timbers to prevent shifting. A "through load" is one in which no open space is left in the doorway, the containers extending from bunker to bunker. "Auxiliary insulation" is any insulating material placed about the load within the body of a refrigerator car, for the purpose of decreasing heat loss from the load.

"Initially iced; do not re-ice" is the waybill endorsement or instruction of the shipper to the railroad for the car to be iced to capacity prior to loading and not re-iced in transit. A "heater hour" indicates the burning of one heater for 1 hour, while "total heater hours" means the combined number of hours one or both heaters are burned during a particular period of time. "Carriers' Protective Service against cold" (17) means that—the carriers will protect the shipment against frost, freezing, or artificial overheating, furnishing, if necessary, artificial heat or such other protective service as may be necessary to accomplish that purpose, but only within the territories where tariffs specifically provide and permit such services.

In practice the operation of this service is governed entirely by outside weather conditions, with arbitrary rules providing for lighting and extinguishing heaters at certain designated temperatures. "Shippers' Protective Service against cold" (17) means that—the shipper will protect the shipment against frost, freezing, or artificial overheating, by furnishing artificial heat or such other protective service as may be necessary.

5 Italic numbers in parentheses refer to Literature Cited, p 53.
“Inside control” is a term applied in this report to any method of operating the car heaters according to temperature conditions within the car.

“Standard ventilation” (17) means that all ventilating devices will be closed after the outside temperature falls to 32 degrees above zero, and all ventilating devices will be opened when the outside temperature rises above 32 degrees on all perishable freight except that which is covered by special rules.

“Controlled ventilation” as used in this report means opening all ventilators when the outside temperature is within a certain designated range and closing the ventilators when it goes above or below this range, all manipulation of ventilating devices being done at regular inspection stations.

“Heater territory” (17) means the territory within which heater service is regularly provided at charges published in the perishable protective tariffs. The approximate boundaries of heater territory are given in figure 1.

The “test trips” reported herein are designated by the State in which the trip originated, the year and the numerical order of the test from that State during the year, as “Washington 1934-1”, which indicates the first trip from Washington in 1934.

EXPERIMENTAL EQUIPMENT AND METHODS

A complete record of conditions at time of loading, during transit, and upon unloading the experimental cars at destination was made by observers who accompanied each test. In transit the cars were attached to regular scheduled freight trains, and the heaters and ventilators in most cases were operated at the regular inspection stations in accordance with rules or methods of Carriers’ Protective Service, inside control, or other experimental procedure.

THERMOMETERS

Electrical resistance thermometers were used to obtain fruit and air temperatures within the cars. The sensitive part of the instrument known as the bulb was inserted into a fruit or hung in the air at desired locations in the car. Leads from these bulbs (12 per cable) were connected to a master cable which extended out of the car through a thin doorplate, placed at the top of the doorway, and thence to the running board on top of the car. Readings were made by connecting the end of the master cable to an indicator, or reading box, equipped with a suitable selector switch by which the temperatures of any of the bulbs could be determined. Thus it will be seen that the instruments are so designed and placed that temperature readings may be obtained at a number of places within the car without opening the doors or hatches. In the tests under discussion, temperature readings were made at intervals of 4 to 6 hours during the entire transit period.

The location of the thermometers in the various experiments was not always the same. The most common procedure was to place one thermometer in the fruit in the row next to the north side of the car and another in the air between the box and the side wall, at the top and bottom of the stack next to the front bunker, and at like positions at the rear bunker and at the doorway. The thermometers placed in the top-layer boxes were located near the top of the box; those in
the bottom-layer boxes were near the bottom of the box. The north side positions were chosen because of the greater danger of freezing along the north wall during transit. Outside air temperatures were obtained with a mercury thermometer. These temperature readings were plotted on cross-section paper, and the average temperatures reported herein were then obtained graphically.

**Anemometers**

In the later tests the velocity of the air under the floor racks in a few test cars was measured with electrical anemometers designed to measure very slow air currents. The instrument consists of a thermocouple having one junction heated by an electric current while the other is not heated. Both junctions are exposed to the air current, the motion of which cools the heated junction but does not affect the one not heated. The amount of cooling, which is measured by the difference in temperature between the two junctions, may be translated into air velocity by reference to a calibration chart.

The anemometer is small enough to be placed in the air channels under the floor racks without interfering with the air circulation. Four small wires which lead to a reading instrument are extended out through the door or hatch opening. Readings are made from the top of the car with a potentiometer and a small resistance box which is used in adjusting the amount of electric current applied to heating the hot junction. Readings of air movement may be made at any point in the car at which instruments may be placed without opening the car or disturbing it in any way while taking the readings.

**Hygrothermographs**

Hygrothermographs were placed on top of the load at the doorway of the test cars used in the stationary test at Havre, Mont., to obtain a record of the changes in relative humidity and air temperature during ventilation, when the ventilators were closed, and during heater service. These instruments were corrected once each week with a sling psychrometer.

**Gas-Analyzing Apparatus**

The percentages of carbon monoxide, oxygen, and carbon dioxide contained in the air within the experimental cars were determined with a gas analyzer of the Orsat type. Samples of air were taken from the cars before and after the heaters had burned varying lengths of time, to determine the effect of the heaters on the composition of the air.

For the taking of air samples, copper tubing was placed at time of loading in each of the six test cars used in the stationary test at Havre, Mont. The tubing extended from near the floor racks at the quarter-length position of the car to the nearest bunker opening. Four extra tubes were placed in one of the cars to determine whether there was any difference between the concentration of the gases at different levels and in different parts of the car.

**Car Heaters**

The heaters used in the main investigation from 1927 to 1935 were of the kind generally used by the railroads over whose lines the experiments were being conducted. In addition, experimental heaters were used in some of the tests, a description of which is given elsewhere in this bulletin. Fuel consumption was measured in nearly all tests.
REFRIGERATOR CARS

The cars used in these tests varied in age from a few months to 8 years and were taken from the supply of cars in active service furnished by the carriers at each loading point. Whenever possible, comparable cars of the same series were used for each test. The thickness of insulation was about the same in all of the cars used in the tests from 1918 to 1935, being about 2 inches in the floor, side walls, and ends and between 2 and 3 inches in the roof. The cars used in these experiments were representative of the best cars that were being used for general service.

EXPERIMENTAL FRUIT

In investigations of this kind it is practically impossible to draw accurate conclusions from apparent effects on fruits of unknown or uncertain history, such as the average commercial shipments. In this work, therefore, the fruit selected for the experimental tests was picked from one orchard, at the usual harvest time, and held in cold storage prior to shipment. Observations were made on carefully selected and comparable small lots that were placed in representative positions in the different experimental cars. During transportation the test boxes were placed in the top and bottom layers at the doorway, and after arrival they were placed in commercial cold storage for further study. The test fruit was inspected for quality and condition at time of loading, at unloading, and at intervals during the subsequent storage period. The firmness of the experimental apples and pears was determined by the use of a pressure tester (15).

LOADS

Because of the difference in length of the cars on the railroads serving the Pacific Northwest, where the tests originated, there was necessarily a difference in the manner of loading the cars in the different localities. A standard carload of apples comprises 756 boxes. In the Yakima Valley it is usually loaded 7 rows wide, 19 stacks long, 13 of the stacks being 6 layers high and the 6 stacks nearest the doorway being 5 layers high. In the Wenatchee Valley the cars are usually loaded 7 rows wide, 18 stacks long, and 6 layers high. In both districts the divided load is commonly used. The boxes in these loads were stacked close together, so as to leave a space 4 to 6 inches wide between each wall and the side of the load. The third, fifth, and top layers or the third and top were stripped with lath damage and nailed to prevent shifting of the load.

EXPERIMENTAL WORK AND RESULTS

REFRIGERATOR-CAR DESIGN AND STRUCTURE

Satisfactory protection of perishables in transit is dependent on adequate insulation of the car and proper air circulation within it. Air circulation within a refrigerator car is dependent to a large extent upon the arrangement of its interior. Pennington (18) and McKay (12) found that floor racks and solid bulkheads tended to improve air circulation in cars under refrigeration.
Prior to about 1920 the shippers generally built and installed any floor racks that were used in refrigerated cars. These were returned to them after the car had been unloaded at destination, or the carriers reimbursed the shippers and retained the racks in the car. Under these conditions there was no uniformity of design or construction. Many of the racks were built with the stringers crosswise of the car which partially or entirely cut off the circulation of air lengthwise. During the winters of 1917-18 and 1918-19 the Department of Agriculture conducted tests to develop information on floor racks. The results showed the necessity of having unobstructed passages at least 4 inches in height underneath the floor racks and lengthwise of the car, such as have since been almost universally adopted.

**Bulkheads**

When the investigation was begun many of the cars were so constructed that the top and bottom bulkhead openings were obstructed by metal braces, heavy wood timber, or well fenders. Some of the earlier cars were constructed with bulkhead openings only 5 inches in height. The experimental work demonstrated that openings at least 12 inches in height at the top and bottom of the bulkhead are desirable. At that time many of the cars had open instead of solid bulkheads. Tests in cars so equipped indicated that under heater service the fruit next to the open bulkheads became undesirably warm. The use of a solid bulkhead with suitable bunker openings was found to give a better distribution of temperatures.

**Car Floor with Ducts**

When the heaters are burning in the bunkers the natural circulation of air in a refrigerated car rises and passes through the top bulkhead opening into the body of the car, where it passes over the top of the load and gradually sinks to the floor as the heat is transferred, after which it returns to the bunker by the bottom bulkhead opening and is recirculated. If, to prevent freezing at the bottom of the load, additional heat is produced which causes excessive temperatures at the top of the load, due to poor circulation, an undesirable condition is created.

To discover methods to overcome this condition, several experiments on heating the car floors were conducted at Roseville, Calif., in 1918 and 1919. Encouraging results were obtained by placing the heater in a box under the frame of the car at the doorway and passing the heated air through ducts in the floor, to discharge into the bunkers. Cold-air return ducts were built in the floor between the warm-air ducts. Several tests were made with cars having this type of floor. The results showed that the air was circulated satisfactorily as long as the heaters burned, but a dependable heater had not then been developed.

**Insulation**

The kind, thickness, and condition of insulation in a refrigerated car has a great influence on the maintenance of desired temperatures within the car. Pennington (18) found that cars with 3 inches of insulation in the roof and 2 inches in sides, ends, and floor were more
efficient than those with 1½ inches in the walls and 2 inches in the roof and floor. McKay (7) showed that with newly built cars having 1, 1½, and 2 inches of insulation the fruit temperatures varied with the thickness of insulation. These experiments were made with oranges from California shipped during the winter months, without heaters, and with a minimum outside temperature of 5° F.

Three tests were conducted to determine the effectiveness of various thicknesses of insulation in the prevention of freezing. In test, Washington 1919-1, a comparison was made of cars built in 1912 and 1913, having 2 inches of insulation, with cars built in 1916 and having only 1½ inches of the same insulating materials. A comparison of the temperature records showed that the thicker insulation was more efficient in protecting the fruit, notwithstanding the fact that the more heavily insulated car had been in service 3 to 4 years longer.

In test, Washington 1918-2, a comparison was also made of a car having 2 inches of insulation with one having 1½ inches of the same insulating materials. The best protection was obtained in the car having 2 inches of insulation.

In the third test, Washington 1928-2, a comparison was made of a car having 2 inches of insulation in ceiling and walls and 3 inches in the floor (built in 1924), with another car which was rebuilt in 1925 with only 1 inch of insulation throughout. The heaters in both cars were manipulated in the same manner during the test. The cars were under ventilation during the first part of the trip. During the last 2½ days, when outside temperatures ranged between −5° and 38° F, the front heater in each car was burning most of the time. In this moderately cold weather the temperatures were 3° to 3½° lower at comparable positions in the bottom layers of the car with lighter insulation. When the cars were unloaded in Minneapolis, Minn., an inspection of the fruit from the bottom layers showed that freezing had occurred in the lightly insulated car, but not in the other.

**AIR MOVEMENT UNDER FLOOR RACKS**

Records of air velocity in a few test cars were obtained by means of an electric anemometer (10) during the Washington 1934-1 test. An anemometer was placed under the floor rack near the front bunker in one of the air ducts near the center line of the car. All the readings were taken while the cars were standing still, since an accurate reading of the instrument was impossible while the train was in motion. Although readings of less than 10 feet per minute may not be strictly accurate, they are given to show that the air movement was very slow at such times. (See table 3.)

**UNDER VENTILATION**

The air velocity within a refrigerator car was found to fluctuate very rapidly when the ventilators were open, depending on the velocity of the wind and its direction with reference to the car. This fluctuation was so extreme that the maximum and minimum speeds, instead of single readings, are given in table 2. Since all readings were taken while the cars were standing, it is likely that the air movement during most of the time the train was in motion was much faster than the recorded velocities.
The rate of air movement within cars having the ventilators closed depends on convection currents set up by temperature differences within the car, and varies with these differences.

In this test the weather prior to and during the time of loading was bright and warm, so that the structure of the cars was thoroughly warmed, while the fruit coming from cold storage was several degrees colder. This difference in temperature between the fruit and the walls of the car set up convection currents which continued for about 1 day (table 2). Later, the outside temperatures encountered were very close to the fruit temperature so that the car walls cooled to a temperature approximating that of the fruit. Table 2 shows that the velocity of the air movement then dropped from 51 feet per minute to about 4 feet per minute. The lower outside temperatures, starting the morning of February 20, cooled the car walls below that of the fruit and again caused an increase of 10 to 16 feet per minute in the velocity of the air under the floor racks.

### Table 2.—Velocity of air under the floor racks of two refrigeration cars with ventilators closed and of one refrigeration car with ventilators open, heaters not burning

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Outside temperature</th>
<th>Ventilators closed</th>
<th>Ventilators open</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Car A</td>
<td>Car B</td>
<td>Car A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>°F.</td>
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<td>Feet</td>
<td>Feet</td>
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<td>43</td>
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<td>22</td>
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<td>Dec.</td>
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<td>31</td>
<td>20</td>
<td>28</td>
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<tr>
<td>Dec.</td>
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<td>2:50 p.m.</td>
<td>33</td>
<td>18</td>
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</tbody>
</table>

1 At time of loading, the average fruit temperature in car A was 32° F., and the fruit temperatures in this car during the period represented in this table were almost continually within 2° or 3° of this figure. In car B the loading temperature was 32°, and during the period represented in this table the fruit temperatures were almost continually between 31° and 33°.

2 These are are of significance only in connection with the car whose ventilators were open.

### WITH HEATERS BURNING

The air velocity under the floor rack at the front end of the car is shown in table 3 to be much greater during the times the heaters were burning, increasing from 20 feet per minute or less to between 75 and 85 feet per minute. The velocity was greatest when both heaters were burning. With one heater burning the increase in air circulation was largely confined to the end of the car in which the heater was located. In this test the velocity was between 60 and 87 feet per minute in the end having the heater burning, but generally less than 20 feet per minute in the opposite end. These data indicate that to obtain the most uniform temperature conditions possible with these heaters and to avoid high temperatures in one end of the car and low temperatures in the opposite end, two heaters should be burning when heat is necessary for the protection of the fruit.
APPELES AND PEARS IN TRANSIT DURING WINTER

VENTILATION

The experiments with various methods of ventilation in connection with heater tests were made when high outside temperatures were not likely to occur. The fruit used in these tests had been cooled to usual cold-storage temperatures prior to loading. Therefore, this discussion will be confined to results obtained with cooled fruit.

Table 3.—Velocity of air under floor racks near front end of refrigerator car when heaters were burning

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Car A velocity per minute</th>
<th>Heaters burning</th>
<th>Car A velocity per minute</th>
<th>Heaters burning</th>
<th>Car B velocity per minute</th>
<th>Heaters burning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb. 20</td>
<td>12-00 p.m.</td>
<td>82</td>
<td>Front</td>
<td>15</td>
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<tr>
<td>Feb. 21</td>
<td>12-00 a.m.</td>
<td>70</td>
<td>Do</td>
<td>15</td>
<td>None</td>
<td>10</td>
<td>None</td>
</tr>
</tbody>
</table>

STANDARD VENTILATION

Standard ventilation is a part of Carriers' Protective Service, in that when the outside temperature rises above 32° F. the rules require that the ventilators be opened and kept open, regardless of how high the outside temperature goes above 32°. However, ventilation is not desirable when outside temperatures are higher than that of the fruit, a condition likely to occur during the early and late parts of the period between October 15 and April 15 when Carriers' Protective Service is available.

CONTROLLED VENTILATION

Experimental cars shipped with controlled ventilation had the ventilating devices open when the outside temperatures were between 28° and 45° F. and closed when the outside temperature was above or below this range. This method of ventilation is intended to prevent the entrance of air with temperatures that would materially increase the rate of ripening of the fruit or cause it to freeze. In practice, this method did not prove to be a marked improvement over standard ventilation, because it was often impossible to operate the ventilators at the specified temperatures due to railroad operating conditions. Controlled ventilation calls for a rather narrow range of temperatures within which the ventilators are to be open. Since in most cases ventilators can only be operated at inspection points it was found in actual practice that in many cases the outside temperatures fluctuated so rapidly that controlled ventilation gave results differing little from those obtained with standard ventilation, it not being generally possible to open or close the vents at the specified temperatures.
VENTILATORS CLOSED TO DESTINATION

With fruit from cold storage it was found to be more practical to keep the ventilators closed to destination than to use either standard ventilation or controlled ventilation. Ventilation may be used either to lower high temperatures or to remove harmful gases. At the present time practically all the fruit moving from the Pacific Northwest during the winter months has been cooled to a satisfactory temperature for shipment, so there is no need of ventilation to remove the heat of the load. On pages 14 and 41 data are given showing that injurious gases do not accumulate in heated cars in concentrations sufficient to cause injury to fruits. Ventilation to reduce temperatures in the top of cars in which the heaters have been burning is not always successful, as this may lower the bottom temperatures with less marked results in the top temperatures. It would seem to be more desirable to operate the heaters by some form of inside control (p. 28) and thus avoid the high temperatures. Each season a number of cars are shipped under Carriers' Protective Service that are not ventilated because the outside temperature does not rise above 32°F. The fact that these shipments carry satisfactorily is a further indication that ventilation is not necessary in the satisfactory transportation of fruit.

During the Washington 1935-2 test the outside temperature dropped from 44° to 11° F. within a few hours while the ventilators of the test cars were open and the train was between inspection points. This caused a drop of 7° to 10° in the air temperature within the cars, while the fruit in the bottom layer of the front half of the cars dropped 3° to 5°. In the same test in another car that had the ventilators closed there was practically no change in temperature. This test indicated further the desirability of keeping the ventilators closed.

The effect of gases on fruit was shown when a number of tests were conducted at Havre, Mont., to determine the concentrations of carbon monoxide, carbon dioxide, and oxygen in cars in which the heaters had been burning for varying lengths of time. In one of these tests two heaters burned continuously for 48 hours with the ventilators closed. The highest concentration of carbon monoxide found was 1.2 percent and of carbon dioxide 3.0 percent; the lowest concentration of oxygen was 16.7 percent (the normal amount in the air is 20 to 21 percent). The conditions of these tests were more severe than those encountered under ordinary operating conditions since normally the ventilators of cars in heater service are opened for 10 to 20 minutes on an average of once a day, to light, extinguish, or inspect the heaters, it being necessary for the safety of the inspector when heaters have been burning that the ventilators be open for at least 5 minutes before he enters the car.

The influence of carbon dioxide on apples has been studied by several investigators. Brooks, Cooley, and Fisher (2) report that apples held in concentrations of 2 to 6 percent for a period of 6 to 8 weeks were uninjured. Magness and Diehl (13) found that 5 and 10 percent of carbon dioxide had no appreciable effect on the flavor, but with a 20-percent concentration there was a slight flavor of fermentation. They also reported that concentrations of 2 to 3 percent do not injure the fruit, but may be directly beneficial through retarding the softening process. Thornton (24) has shown that
fruits and vegetables stored for 3 to 7 days were apparently not injured by concentrations of CO₂ varying from 6 to 83 percent. The concentration of carbon dioxide tolerated by each fruit and vegetable was influenced by the storage temperature and by the ripeness, firmness, and freshness of the commodity. Brooks et al. (4) reported no impairment of flavor of Bartlett pears held 3 days in concentrations of 45 percent, with Anjoues held 3 days at 20 percent, or with Seckels held 17 days in 48-percent concentrations of carbon dioxide. They also reported that the carbon dioxide not only inhibited the growth of decay organisms but checked the softening of the fruit.

Rose and Haller (1) found that there was no noticeable effect on either the appearance or the taste of apples, pears, citrus fruits, or potatoes by any concentration of carbon monoxide up to 7.5 percent when these commodities were held at a temperature of 70° to 75° F.

Since there is no need of removing gases from cars shipped under Carriers' Protective Service and there is a possibility of injuring the fruit by exposing it to warmer outside air, thereby increasing its rate of ripening and shortening its subsequent storage life, ventilation of such cars in transit is not only unnecessary but undesirable.

PROTECTION OF SHIPMENTS WITHOUT HEATERS

Some carlot shipments of perishables originating in heater territory during the period from October 15 to April 15 are not shipped under Carriers' Protective Service. In former years shippers making such carlot shipments generally employed one of three methods—(1) sending a messenger with the car to attend to the heaters and ventilators according to the shipper's instructions, (2) the use of auxiliary insulating materials, or (3) shipment in refrigerator cars without special protection.

The use of messenger service has been largely discontinued and shipments without special protection are generally changed in transit to heater service if outside temperatures become low.

Under many conditions it is not desirable to use the present methods of heating with pear shipments because of the quick response of this fruit to high temperatures, hence some method of protection without the use of artificial heat is needed. It is particularly important for shipments of pears for export via Atlantic ports, which are in transit for a long time, and for those showing advanced maturity at time of shipment. Paper, straw, sawdust, and mill shavings are used, alone or in various combinations, as auxiliary insulation, and in some cases the doors are also covered with a layer of paper on the outside. Auxiliary insulation is largely used with pear shipments from Medford, Oreg., throughout the winter months and to some extent also from other shipping points in the Pacific Northwest.

AUXILIARY INSULATION

A number of tests were conducted to determine the value of various combinations of auxiliary insulating materials in the prevention of freezing of fruit in transit. It was found that building paper applied over the floor or the floor racks had no noticeable effect on temperatures within the car; likewise, none of the tests indicated that paper

*Unpublished data on file in the Division of Fruit and Vegetable Crops and Diseases.
applied around the load was of any particular value. The use of straw or sawdust and shavings was found to be unsatisfactory; in fact, there was more severe freezing when these materials were used, probably because they interfered with the air circulation. These materials are usually placed under the floor racks, sometimes partly way up between the wall and the load, and paper is sometimes used to prevent them from falling into the load. Prepared in this way a load has the appearance of being well protected against freezing, since straw and shavings are known to have fair insulating qualities. Although it is probable that the heat loss from a load insulated with these materials is less than from loads not so protected, the interference with the normal air circulation under the floor racks and about the load, due to the presence of the straw or shavings, may have serious results because there is no great reserve of heat in fruit from cold storage. In a regular load all parts are at least several inches away from the outside walls and floor. In a period of cold weather the walls are colder than the air within the car and tend to cool the air in contact with them. In a car containing no auxiliary insulation, the cooled air, becoming heavy, flows to the floor and is replaced with air warmed by the load, which is in turn cooled. This air movement (table 3) and the resultant mixing of warm and cold air, slow as it may be, tends to distribute the effect of heat loss to all parts of the load. If the space between the load and walls or floor is filled or partially blocked with straw, shavings, sawdust, or other material this circulation is stopped or at least materially decreased.

The tests showed that the harmful effect of stopping air circulation by the use of auxiliary insulation outweighed the beneficial effect of lessening the heat loss to the outside. This is illustrated by the results obtained during the Oregon 1931-2 test, as shown in figure 5, in which car B was heavily insulated with straw under the floor racks, up the side walls, and each bulkhead, while car A was lightly insulated with straw under the floor racks only. The cars and loads were comparable at time of loading, and temperature conditions in the two cars were about the same for the first 4 days in transit. On the fifth day the outside temperature dropped, causing a noticeable drop in bottom-layer temperatures in the car having heavy auxiliary insulation and a smaller drop in the one with light auxiliary insulation. Top-layer fruit temperatures were about the same in the two cars, although at some positions those in the lightly insulated car were slightly higher. The difference of 3° to 3½° between the bottom-layer temperatures in the heavily and lightly insulated cars evidently resulted from differences in the facility of air movement under and about the load.

Similar results were obtained the following winter during the Oregon 1932-1 test with three cars, as given in figure 6, one without auxiliary insulation, one lightly insulated with straw, and the third heavily insulated near the floor with shavings and sawdust. The first car was shipped under Carriers' Protective Service, and the other two were under Shippers' Protective Service. It was originally planned that these last two cars would go through to destination without the use of heaters; however, the weather became so cold that they were changed to heater service at Ogden, Utah. It will be noted that on December 9 the fruit temperatures at the bottom doorway, north
Chart 7: Temperatures of pears in bottom of load while in transit. Car A, lightly insulated with straw, pear movement slightly impeded; car B, heavily insulated with straw, pear movement greatly impeded, showing that the addition of auxiliary insulating materials resulted in increasing the danger of freezing damage, depending on the manner in which it interfered with the movement of air in the car.

Chart 8: Temperatures in three cars of pears in transit (West Oregon 1932-33): Car A, no auxiliary insulation; air movement unimpeded; Car B, lightly insulated with straw, air movement slightly impeded; and Car C, heavily insulated near the floor with shavings and sawdust, air movement greatly impeded.
side, dropped in all cars at about the same rate and went below 28° F. within a short time of each other, showing that the auxiliary insulation did not protect the fruit against freezing any better than the cars without the extra insulation, with an outside temperature between 8° and -9°.

Figure 6 further shows that after the heaters were lighted there was an increase in the bottom-layer temperatures in car A without auxiliary insulation, a slight increase in car B lightly insulated, while in car C, heavily insulated beneath the floor racks, the temperatures continued to drop for a few hours and then remained fairly constant, indicating that the movement of air was impeded in cars B and C.

When the fruit was unloaded in New York the inspection showed no freezing injury in car A; in car B, however, about 80 percent of the bottom-layer boxes had from 1 to 60 percent of the pears (average 25 percent) frozen, with one layer of pears in the bottom and up the sides of the boxes next to the well badly frozen. The pears in car C, heavily insulated, were badly frozen in the three bottom layers of fruit in the bottom layer of boxes and up the sides of the boxes next to the walls of the car into the second layer of boxes.

These results indicate a serious disadvantage in using auxiliary insulation which interferes with air circulation. Further, if an emergency should arise as in the Oregon 1932-1 test when it is desired to install heaters in the car while in transit they cannot be used effectively to raise the bottom-layer temperatures. Moreover, top layers in a car thus equipped are subjected to more severe overheating than if normal air circulation is allowed to take place. For a discussion of overheating see pages 31 and 47.

USE OF LATENT HEAT OF FUSION OF WATER

A method of protection, not previously used, was tried in several different tests to avoid the need for heater service. This was the use of mill sawdust or sawdust saturated with water and placed under the floor racks in such a way that there was a small air channel left under the rack and over the wet sawdust. This proved to be more effective than the use of the same material in a dry condition as previously described. The purpose of this method was not to add insulation to the floor but to make use of the latent heat of fusion of the absorbed water when it froze. This is comparable to, although the exact reverse of, the use of ice for refrigeration. In the case of refrigeration the melting ice absorbs heat from its surroundings, whereas with wet sawdust or shavings the freezing water releases heat to its surroundings. The water in the sawdust freezes at a temperature of 32° F., but the freezing temperature of the fruit is 3° to 4° lower. This makes it possible for the water to freeze first and release its heat before the temperature is low enough to damage the fruit. The sawdust or shavings serve merely to hold the water.

The sawdust and shavings were placed in the car either wet or dry. In the latter case the sawdust was wet down with a hose shortly before loading, in order to prevent freezing of the water prior to loading. The sawdust was spread evenly several inches deep over the entire floor of the car, including the drip pans of the bunkers, using an estimated volume of 200 to 300 cubic feet of sawdust. There was considerable variation in the weight of water held by the sawdust in the various test cars, but in most cases it was estimated that 2,000
pounds (approximately 250 gallons) or more was held. As a pound of water releases 144 B. t. u. upon freezing, a ton of water would provide a potential means of supplying 258,000 B. t. u., or the equivalent of burning about 22 pounds of charquetttes (1 pound of charquetttes furnishes approximately 13,000 B. t. u.) the quantity ordinarily consumed by the common type of heater in from 25 to 36 hours. Since the latent heat of fusion of water is released slowly at the very place it is needed most, the value of this method is considerably greater than is indicated by the total heat released by the two methods of heating or by the time required by a charcoal heater in usual operation to release an equivalent amount of heat. This is supported by the fact that during the Oregon 1932-1 test freezing of the fruit was delayed about 41 hours in the car with wet sawdust.

The first two tests in which cars were prepared in this way with wet sawdust encountered extremely cold weather. To prevent freezing of the fruit, it was necessary to install heaters in these as well as in all other cars in the tests before the destination was reached. As shown in figure 7 (Oregon 1932-1 test), the bottom-layer temperatures in the car with wet sawdust were much slower in reaching the average freezing point of pears (approximately 25°F.) (25) than in the other two cars, one having auxiliary insulation and the other no additional insulation. Fruit temperatures in the car under Carrier's Protective Service went below the freezing point of pears at about 10 a. m. on December 9, while in the car with wet sawdust the freezing point was not reached until 3 a. m. on the 11th, or about 41 hours later. This delay, which was due to the latent heat of fusion of the water, occurred during a period when the outside temperature ranged between -8° and 17°, mostly between 0° and 10° F. Although the two cars with sawdust under the floor racks were changed to heater service at Ogden, the influence of the water in the wet sawdust is shown in the bottom-layer temperatures, since those in the car with dry sawdust continued to drop and those in the car with wet sawdust remained practically unchanged.

The results of these tests indicate that for short periods of cold weather and probably for more extended periods of less severe weather the freezing of the fruit in transit can be prevented or materially delayed by using wet sawdust under the floor racks. In more severe weather, such as may be encountered in transit a few times each winter, the protection afforded by water will delay freezing of the fruit for a limited time, but additional heat will be necessary to prevent damaging temperatures during an extended period of extremely cold weather, such as that encountered in the Oregon 1932-1 test.

There appears to be a limit to the amount of wet sawdust that can be effectively used. In the Washington 1933-1 test there was a car in which the floor racks were raised to give about 8 inches of space, which was filled to a depth of about 6 inches with wet sawdust. The load in this car was not protected much longer than that in a car having only about 3 inches of wet sawdust under the racks, although there was at least twice as much water used in the car with the raised floor racks. It is possible that this was because the water in the sawdust drained to the bottom in the former, leaving the top few inches comparatively dry, thus interposing a blanketing effect.

*Compressed charcoal in the form of egg-size lumps.*
that more or less insulated the fruit from the heat released when the wet sawdust froze.

It is recognized that use of wet sawdust under the floor racks is somewhat objectionable, on account of possible damage that may result from absorption of moisture by the floor and insulation. It is not believed, however, that such damage from use of wet sawdust would be as great as that resulting from the body icing of vegetables in which several tons of ice are melted in the body of the car during transit, despite which, however, this latter method is annually used on many thousand carloads.

Refrigeration is rather commonly used with shipments of fruit originating in heater territory during mild periods in some of the months when Carriers' Protective Service is available. Apples and pears are commonly shipped under refrigeration from the Yakima and Wenatchee districts of Washington during October, November, March, and April and from the Medford district in Oregon during most of the winter months.

The ice is used primarily for refrigeration. Among some shippers, however, an impression prevails that the presence of ice in the bunkers of a car tends to retard or prevent freezing of the loading in cold weather. When shipments are to be protected against freezing in transit, ice in the bunkers of a car loaded with fruit tends to reduce the temperature of the fruit and causes it to freeze more quickly on reaching territory where the outside temperatures are low. The higher the temperature of the fruit the greater is its resistance to freezing, but at the same time the greater the likelihood of its be-
coming overripe. Therefore, the extent to which warm fruit temperatures can be tolerated is limited by the rate of ripening brought about by such temperatures.

In three of the tests conducted during this investigation (Washington 1928-4 and 1931-2 and Oregon 1931-2) there were cars shipped under refrigeration. Data were obtained in a car shipped "initially iced, do not re-ice", and in another one without ice with ventilators closed to destination during the Washington 1928-4 test. The fruit temperatures were about the same in both cars at time of loading. Fruit temperatures rose slightly in the car shipped without ice, but decreased in the iced car until there was a difference of from 2° to 6° between comparable positions in these cars. A sharp drop in the outside temperature to \(-8°\) F. caused a slight cooling of the fruit that was about equal in both cars. While there was no freezing injury in either car a continued drop in the outside temperature doubtless would have caused the fruit in the iced car to freeze before that in the other car.

During the Washington 1931-2 test the outside temperatures ranged between \(26°\) and \(64°\) F., mostly between \(30°\) and \(40°\), so no freezing temperatures were found in any of the cars. Also, the fruit temperatures in this test were generally \(3°\) to \(5°\) lower in the iced cars than in those under standard ventilation.

Further information was obtained during the Oregon 1931-2 test as to the conditions in cars under refrigeration and in those without ice with ventilators closed, as shown in figure 8. The outside temperatures ranged between \(45°\) and \(-10°\) F. while the test was in transit between Medford, Oreg., and Jersey City, N. J. The fruit temperatures in both cars were about the same at time of loading. Freezing started at the bottom doorway about the same time in both cars, but at the bottom bunker there was considerable freezing in the iced car while there was none in the car without ice. This was no doubt due to the influence of the ice at this position.

Theoretically, ice at \(32°\) F. has a protective value equal to the weight of the ice, times its specific heat, times the difference between \(32°\) and \(28.5°\) (freezing point of apples). This means that about \(18,700\) B. t. u. are released from \(10,600\) pounds of chunk ice, which is the bunker capacity of most refrigerator cars. If this amount of heat were available it would be the equivalent of burning about \(1\frac{1}{4}\) pounds of charcoal. Since most ice is stored at \(29°\) to \(30°\) or \(10\), the amount of available heat would be even less than that calculated above, which is based on an ice temperature of \(32°\).

It is evident not only that the ice has no effectual protective value against freezing, but also that when outside temperatures are sufficiently low to cause freezing damage the loading is likely to freeze more quickly and over a larger part of the bottom layer in iced than in noniced cars. Furthermore, the expense for winter icing is wasted when it is not required for refrigeration, because the ice is of no benefit in preventing freezing.

**PROTECTION OF SHIPMENTS WITH HEATERS**

Carlot shipments of perishables in which artificial heat is used for protection against freezing can be shipped under either Shippers' Protective Service or Carriers' Protective Service. Practically all the shipments with which artificial heat is used are now made under the latter service.
Under Shippers’ Protective Service the ventilators and heaters are operated by messengers employed by the shipper to accompany the shipment and who assume all responsibility in this connection. Under Carriers’ Protective Service the heaters and ventilators are operated by employees located at heater inspection stations, according to standard rules adopted by all carriers in heater territory. The carriers assume all responsibility for their proper manipulation and are compensated accordingly.

CAR HEATERS

Experiments have been conducted under actual transit conditions with several types of car heaters. A brief description of the heaters and of the results of the tests is given in the following pages.

![Diagram of temperatures in bottom of load in two cars of pears while in transit (Oregon 1231-2): Car A, under refrigeration; and car B, without refrigeration, ventilators closed; showing that the presence of ice in the B increases the danger of freezing the fruit.](image)

**KEROSENE HEATERS**

The kerosene (coal-oil) burning heaters (fig. 9, 1) were among the first used in refrigerator cars. They had the advantage of being light in weight and the rate of burning could be regulated, but they had the disadvantage of consuming oxygen very rapidly. After the oxygen in the air within the car was depleted, the heaters smoked, tainting the fruit with the odor and taste of kerosene. Several methods of introducing fresh air into the cars were tried, but none proved successful.

**STEAM HEATERS**

In 1918 and 1919 attempts were made to work out methods of utilizing steam in heating cars in regular freight trains. Steam heaters in which temperatures were thermostatically controlled gave satisfactory results; however, in long freight trains there was no practical source of obtaining steam for all of the cars. During cold weather it appeared certain that the steam line of a train of refrigerator cars would freeze, making this method impractical.
A system of steam heating (I) was used in a limited way by one of the midwestern carriers as early as 1903–5. Heating units in the cars were heated by locomotives while the trains were standing or moving, or with special connections at terminals. Air temperatures as high as 50° to 69° F. were reached, as there was no control of the temperature after the units were heated.
Three patented methods built by commercial concerns were included in the tests. The first consisted of a coal-burning heater suspended beneath the body of the car. The heated air entered the car near the ceiling and the cooled air returned to the heater through ducts in the floor. This method proved very unsatisfactory since it gave extremely high temperatures in the top of the load and also very fluctuating temperatures.

The second method used heated brine circulated through pipes under the floor racks. The brine was heated by live steam introduced into brine tanks at each end of the car at railroad division points or at points where steam was available when heat was required. The temperatures were not thermostatically controlled. Because there was a tendency for the pipes to leak when the cars received rough handling, dependable results could not be secured and this method proved unsatisfactory.

The third method was the circulation of a heated nonfreezing solution through a closed system of pipes located under the floor racks. The solution was heated by means of a thermostatically controlled gas burner located in a compartment in one end of the car. This method gave satisfactory results on the one test that was made.

ALCOHOL HEATERS

Tests were conducted with alcohol heaters in 1917, 1918, and 1919. The alcohol heaters then used did not give satisfactory results, as the alcohol dissolved metal from the containers which was precipitated on the “burner” to such an extent that in time the heater was stopped from burning. Also it was found that these heaters did not produce enough heat to prevent freezing during extremely cold weather, and they were considered an unduly dangerous fire hazard.

Recently tests have been made with thermostatically controlled alcohol heaters. When the heaters were placed in the bunkers of the car, the heat was distributed either by natural circulation or by a self-driven fan blowing the heated air under the floor racks. The thermostat was generally built in the heater near the bottom, so that the heaters were operated according to the temperature of the air near the bottom of the bunker. These heaters are still in a developmental stage, so that final conclusions regarding their reliability and efficiency have not been reached. It would appear, however, that the use of thermostatically controlled heaters is the logical way to meet the requirements of inside control.

CHARCOAL HEATERS

The charcoal heater later came into common use in the protection against freezing of shipments under Carriers’ Protective Service. Heaters burning charcoal “charquottes” were employed in all of the tests conducted from 1927 to 1935.

Two new experimental types of charcoal-burning heaters were developed and tested in this investigation. One of them was insulated and had a pipe leading from the top of the heater to a position under the floor rack and was used in an effort to force the heat under the racks. This heater was difficult to place in position in the bunker.
and to remove, because of its weight and the pipe connections; and it did not prove successful in distributing the heat.

The second type was built in one piece and was so constructed that there was a 2-inch air space between the inner and outer walls of the heater similar to the jacket of a pipeless furnace. This was done in an effort to increase the air circulation within the car. This heater was tried with 5-, 6-, and 7-inch fire pots, and gave encouraging results during the stationary tests at Havre, Mont. However, during subsequent transportation tests this heater did not always give sufficient protection in the bottom layers, nor did it decrease the difference in temperature between top and bottom of the load sufficiently to indicate any particular advantage over the heaters in common use.

The charcoal heaters in common use with shipments under Carriers' Protective Service are built either in one piece (fig. 9, B) or in two pieces (fig. 9, C). These heaters are capable of releasing sufficient heat to protect the fruit in the bottom layers of the load from freezing during extremely cold weather. This is illustrated in figure 10, which shows the top and bottom fruit temperatures in a car equipped with one-piece heaters operated according to the rules of Carriers' Protective Service in a test from Wenatchee, Wash., to New York, N. Y. As shown in this figure, the bottom-layer temperatures rose from about 30° to a maximum of 44° F. during a period when the outside temperature ranged between 8° and -28°. During this time the top-layer temperature rose from about 35° to a maximum of 63°. The increase of 13° to 15° in the temperature of the fruit on the bottom layer indicates the capacity of the heaters to release great quantities of heat when allowed to burn over a long period.

Similar results were obtained during the same season in a test from Medford, Oreg. However, the use of too much heat may be as detrimental to the fruit as freezing, since it accelerates the rate of
ripening and shortens the time during which the fruit remains in merchantable condition (pp. 31 and 47).

The tests of 1928 indicated that the two-piece charcoal heaters burned too rapidly. Experiments were conducted in which the rate of burning in the fire pot (fig. 9, D) was reduced by using 6- and 8½-inch reducers. The use of the 8½-inch reducers (fig. 9, E) decreased the burning surface of the fire pot about 48.5 percent; the 6-inch reducer decreased it about 72 percent. The effect of the reducers on the average rate of burning in transit and stationary tests is shown in figure 11. The slower rate of burning during the stationary tests was due to the accumulation of ashes on the burning charquettes and also, no doubt, less fuel went into the fire pot, whereas during transportation tests the motion of the car shook the ashes into the ash receiver and the fuel into the fire pot. The 8½-inch reducers in the heaters gave the most satisfactory results. They decreased the flow of heat into the cars, and, during periods of low outside temperatures, heaters equipped with them furnished sufficient protection in the bottom layers and at the same time reduced the temperatures in the top layer.

A great variation was found in the rate of burning of individual heaters, even between two heaters of the same kind in the same car. The one-piece heater burned fuel at a rate ranging from 0.25 to 0.92 pound per hour, with an average of 0.48 pound. With the two-piece heaters, without reducers, the rate varied from 0.51 to 0.93 pound, with an average of 0.83 pound. The rate with the same type heater equipped with 8½-inch reducers was from 0.33 to 0.92 pound, averaging 0.57 pound; while with the 6-inch reducer the rate of burning varied between 0.27 and 0.47 pound, with an average of 0.37 pound per hour. This variation in the rate of burning with each type of heater was probably due to such conditions as the clogging of fuel in the throat of the heater, loose or tight lids to the fuel magazine, the condition of the fuel, and the jarring or other movement that the heaters received.

Records show that the heaters burn for a few hours after being cut off. Data obtained during the Washington 1935–1 test show that the heaters were still warm 9 hours after the fuel supply had been cut off. This is an undesirable condition and could be remedied either by improving the heater to provide for quicker and more effective control of the rate of burning or by removing the burning heaters and replacing with heaters which are not lighted, as is now done on some of the Canadian lines.

As ordinarily employed, the heaters are usually placed either on the ice grates or the drip pan in the bunkers, one in each end of the car. The 1917 and 1918 tests indicated that the bottom layer boxes...
received better protection against freezing when the heaters were on the drip pan. However, most of the cars used in those tests were equipped with open bulkheads, so that when the heaters were on the drip pans they drew air from the body of the car at a lower level than when placed on the ice grates. During the 1928, 1929, and 1930 tests, using cars equipped with solid bulkheads, no difference in temperature of the bottom layers was found that could be considered as due to a difference in the elevation of the heater. This no doubt resulted from the fact that when the heaters are in such cars the air can enter the bunkers only at the bottom opening and largely from beneath the floor racks.

**OPERATION OF HEATERS**

The charcoal heaters were operated during these tests according to two methods, (1) standard rules of Carriers' Protective Service and (2) inside control. The operation of thermostatically controlled alcohol heaters and of charcoal heaters operated by inside control are similar in principle in that both are lighted and darkened according to the need for heat.

### CARRIERS' PROTECTIVE SERVICE

The rules applying to this service are promulgated by the National Perishable Freight Committee, an organization maintained jointly by the railroads. Under this service one heater is ordinarily placed in each bunker of the car at the shipping point, or at the first station where this work can be done after the car has been accepted for shipment under this service. The heaters are lighted or extinguished at regular inspection points, and at other points designated for the inspection, lighting, and extinguishing of the heaters (fig. 1), according to the prevailing weather conditions or to the outside temperature at that station. In some cases consideration is also given to the weather conditions anticipated to prevail to the next inspection point. The standard rules provide that the heater in the front bunker of cars loaded with apples, pears, and onions shall be lighted when the outside temperature drops to 10°F. or below, and extinguished when it rises to 10°F. or above; the rear heater is to be lighted when the temperature falls to -5°F. or below and extinguished when it rises to that point or above.

The rules are somewhat different with other perishables; for example, with potatoes the front heater is lighted and extinguished at 20°F and the rear heater at 10°F above zero. In all cases the hatch plugs and covers are placed in position and generally the drip pipes are plugged. Sometimes a layer of building paper is placed on the floor under the floor racks, extending up the side walls about 3 feet, before the cars are placed for loading. Carlot shipments under this service are also given standard ventilation; that is, all ventilating devices are opened when the outside temperature is above 32°F. and are closed at or below 32°F. The Perishable Protective Tariff (17), which embodies the rules governing this service, states that cars shipped under Carriers' Protective Service and destined to points outside heater territory "will be considered as having arrived at final destination when they shall have reached the terminus of the territory." Under these conditions the cars are generally given standard ventilation after leaving heater territory.
Inside control is a coined term used to designate a method of lighting and extinguishing car heaters that differs materially from Carriers' Protective Service, which is based entirely on outside temperatures. In the experiments with inside control, charcoal heaters and thermostatically controlled alcohol heaters were used. The plan of operating the former was to light and extinguish the heaters manually according to temperature conditions inside the car.

The purpose of inside control is to add only the minimum amount of heat required for the maintenance of temperatures as close as possible to the optimum for fruit storage. There is, therefore, no great reserve of heat in the load, and when charcoal heaters are used their operation must be governed to some extent by the weather conditions anticipated between one heater inspection point and the next; that is, when dangerously low temperatures are liable to be encountered before reaching the next regular inspection station, the heaters are lighted even if the minimum air temperature inside the car is not down to the predetermined point at which both heaters are to be lighted. On the other hand, when higher outside temperatures are anticipated the heaters are not lighted, regardless of inside temperatures. The temperature of the air inside the car may be determined by means of a distance-reading thermometer, or a thermostat activating an electric light, or some other device. These instruments may be mounted at some convenient position so that they can be easily read without opening the car. In most of these experiments an effort was made to maintain an air temperature not lower than 30°F at the bottom doorway.

It is obvious that the results obtained with shipments under inside control are dependent largely on the temperatures at which the heaters are lighted and extinguished. Under simulated transit conditions (27) with wrapped apples from the Pacific Northwest, packed in standard bushel boxes, it was found that apples could be exposed to an air temperature of 25°F for several hours before any of the fruit reached the average freezing point of apples (28.5°C). Table 4, composed of data from a study by Rose and Lutz (9), shows that the length of time required depends on the initial temperature of the fruit as well as upon the air temperature to which it is exposed.

In most cases the apples did not actually freeze until a few hours after reaching 28.5°C, having undercooled for varying lengths of time, while a few froze shortly after reaching 29°C. From these data it would appear that using 30°C as a minimum air temperature in a refrigerator car at which to light the heaters would give a sufficient margin of safety unless the cars were held abnormally long periods between inspections. A minimum air temperature of 30°C was used on most of the transit tests with safety.

Methods of inside control have been used commercially by midwestern carriers. In a few steam-heated cars as early as 1908 (1) a mercury thermometer was mounted on the side of the car about midway between the roof and the floor, with the bulb going through the wall into the interior of the car for the purpose of determining the need for heat. More recently another carrier followed the method of opening the doors and reading a thermometer inserted into the fruit for the purpose of governing the operation of charcoal heaters.

* Unpublished data on file in the Division of Fruit and Vegetable Crops and Diseases.
However, opening the doors was found to be objectionable, and this as well as the other method was discontinued.

Table 4.—Rate of cooling of apples to their freezing point as affected by initial temperature of the fruit and temperature of the surrounding air

<table>
<thead>
<tr>
<th>Initial temperature of the fruit</th>
<th>Temperature of surrounding air</th>
<th>Time required to reach freezing point of the fruit</th>
<th>Initial temperature of the fruit</th>
<th>Temperature of surrounding air</th>
<th>Time required to reach freezing point of the fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F.</td>
<td>°F.</td>
<td>Hours</td>
<td>°F.</td>
<td>°F.</td>
<td>Hours</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
<td>12</td>
<td>32</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>32</td>
<td>28</td>
<td>9</td>
<td>32</td>
<td>28</td>
<td>9</td>
</tr>
<tr>
<td>34</td>
<td>24</td>
<td>6</td>
<td>32</td>
<td>24</td>
<td>6</td>
</tr>
</tbody>
</table>

Factors Influencing Temperatures Within Cars

There are a number of factors that influence the temperatures within a carload of fruit under heater service and that must be considered in attempting to maintain optimum temperatures for the satisfactory protection of the fruit against both freezing and excessive heating. Chief among these are (1) the condition of the car, (2) the rate of burning of the heaters or their heat-producing capacity, (3) the temperature of the fruit at time of loading, and (4) weather conditions en route.

Most of the refrigerator cars now in service have from 1 to 3 1/2 inches of insulation, a majority having from 2 to 3 inches, and range from new to 15 years of age or more. In general, the efficiency of a refrigerator car in maintaining temperatures depends upon its construction and the amount, type, and condition of insulating material used. It is obvious that there is a variation in the efficiency of different cars.

The rate of fuel consumption varies greatly with individual heaters. Even apparently comparable charcoal heaters in the same car have been found to burn at different rates in these tests, ranging from 0.25 to 0.93 pound per hour. The amount of heat released varies of course with the fuel consumption. This variation alone renders the uniform handling of all cars undesirable.

The average temperature of the fruit at time of loading varies a great deal, depending largely on the storage from which it is taken. As shown in tables 9 and 10, the average temperature of the fruit loaded in the various cars used in two experiments ranged from 30.5° to 42.5° F. Fruit having an average temperature as high as 42.5° will not freeze as quickly as fruit at a lower initial temperature. When such fruit is given regular heater service it is also more likely to be damaged by overheating than fruit loaded at a lower temperature.

Low outside temperatures may have a marked influence on temperatures within the cars, depending largely on their duration and severity. In these tests it was found, however, that short periods of low or high outside temperatures had little or no influence on fruit temperatures within the car, provided the ventilators were closed. The variability in duration and severity of cold weather is so great that no outside temperature can be selected at which the heaters should be lighted to prevent freezing under all conditions. The effect of different weather conditions is given in more detail in the next few paragraphs.
From this brief discussion of the four major factors influencing temperatures within the cars it is apparent that to obtain the best results each car should be operated individually, in accordance with its need for protection. Of these factors the heater is the only one over which any immediate control is possible.

Results obtained with inside control

A number of tests were conducted to compare the results of operating the heaters by inside control and by Carriers' Protective Service. A comparison of the two methods as to total heater hours made in the experiments of 1927, 1928, 1932, 1933, 1934, and 1935 is given in table 5. The decrease in heater hours in the cars under inside control ranged from 4% to 91. For the most part this wide variation was due to weather conditions. For example, during the Washington 1935-1 test the weather was so severe that there were only 4% heater hours difference between the two methods. During the Washington 1928-1 test the weather was less severe and the heaters were not lighted at all in the cars under inside control, whereas under Carriers' Protective Service they were burned 7 hours.

The reduction in the amount of heat released in the cars under inside control gave measurable benefit in reducing the rate of ripening and at the same time provided sufficient protection against freezing under most conditions. During the extreme cold weather encountered in the test conducted in 1933 slight freezing occurred in the experimental cars shipped under both methods, but it was not more severe in one than in the other.

Table 5.—Total number of hours heaters burned in test cars shipped from the Pacific Northwest during 6 years' experiments when lighted and extinguished according to rates of Carriers' Protective Service and by inside control, also decrease in heater hours expressed in number and percentage.

<table>
<thead>
<tr>
<th>Test trip</th>
<th>Carriers' Protective Service</th>
<th>Inside control</th>
<th>Decrease, in heater hours due to inside control of heaters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours</td>
<td>Percent</td>
<td></td>
</tr>
<tr>
<td>Washington 1927-1</td>
<td>63</td>
<td>42</td>
<td>21.4</td>
</tr>
<tr>
<td>Washington 1928-1</td>
<td>73</td>
<td>61</td>
<td>12.8</td>
</tr>
<tr>
<td>Washington 1929-2</td>
<td>84</td>
<td>61</td>
<td>23.1</td>
</tr>
<tr>
<td>Washington 1930-1</td>
<td>75</td>
<td>55</td>
<td>13.9</td>
</tr>
<tr>
<td>Washington 1931-1</td>
<td>77</td>
<td>55</td>
<td>21.5</td>
</tr>
<tr>
<td>Washington 1932-2</td>
<td>75</td>
<td>55</td>
<td>28.6</td>
</tr>
<tr>
<td>Oregon 1932-3</td>
<td>86</td>
<td>56</td>
<td>35.5</td>
</tr>
<tr>
<td>Oregon 1933-4</td>
<td>82</td>
<td>56</td>
<td>30.2</td>
</tr>
<tr>
<td>Average</td>
<td>80</td>
<td>56</td>
<td>30.8</td>
</tr>
</tbody>
</table>

1. Rear heater failed to burn for 2.5 hours, which is included in this total.

2. This figure is the percentage average decrease based on the average total Carriers' Protective Service hours.

The difference in the rate of ripening of the fruit as measured by the pressure tester (75) is shown in figure 12. Anjou pears were used as test fruit for this purpose, because they are more quickly responsive to temperature differences than are winter apples. The pears were
comparable at time of loading and were stored under the same conditions after arrival in New York, differing only in transit treatment. The reduction of 22 percent in the time that the heaters were burned in the car under inside control caused an average difference of 7.5° and 8.5° in the temperature of the experimental fruit in the top layers of the load, at the doorway, in the test cars. This lower temperature was responsible for a definite extension of at least 30 days in the subsequent storage life of the fruit, as compared with that forwarded in the cars under Carriers' Protective Service. While the fruit from both cars had about the same firmness upon arrival, that shipped under inside control was in a firm condition after 60 days in storage, while the fruit shipped under Carriers' Protective Service was soft and fully ripe before the end of 30 days in storage.

The effect on fruit temperatures of curtailing the burning of heaters by using inside control during a period of moderately low outside temperatures is shown in figure 13. It is evident from this figure that burning both heaters a total of 27 heater-hours under inside control gave not only lower but more uniform fruit temperatures throughout the load than burning one heater a total of 44 hours under Carriers' Protective Service. In the rear half of the car under Carriers' Protective Service in which the front heater was burned for 44 hours the temperatures were much lower than in the front half, indicating the need of lighting both heaters to maintain more uniform and desirable temperatures in all parts of the load.

Figure 14 presents the maximum and minimum fruit temperatures in transit during periods when the outside temperatures were extremely low, ranging from 46° to \(-38°\) F. in test Washington 1933-1. In car A, which was under Carriers' Protective Service, the heaters burned 284.5 heater-hours (the rear heater failing to burn for 21.3 hours, otherwise the total would have been 306). One or both of the heaters in this car burned nearly the entire time from Wenatchee,
Wash., to the Illinois-Indiana State line. On the other hand the heaters in cars B and C under inside control burned only 215 and 240.5 heater hours, respectively. This difference between methods resulted in maximum fruit temperatures 10° to 11° lower in the inside control cars and average top-layer temperatures 5° to 7° lower. While the temperature of the fruit in the bottom layer at the doorway of cars B and C went below the average freezing point of apples, there was no evidence of freezing injury in the fruit when the cars were unloaded in New York City. Under inside control the heaters were lighted and extinguished four times in car C and only once in car B (fig. 14). So far as can be determined, the cars and loads were comparable at the start of the test. A difference in the rate of burning of the heaters in the two cars under inside control may have been the cause for the difference in total heater hours.

It was found in test Washington 1931-1 that moderately low outside temperatures, which were for the most part between 10° and 20° F. for about 3 days, caused freezing when the heaters were not lighted. Figure 15 shows fruit temperatures in the top- and bottom-layer boxes at the doorway in one of the cars of this test that are typical of those found in the other five cars of the same test. Temperatures in the same layers throughout the cars were nearly uniform, those at the bunker differing not more than a degree from those at the doorway. The outside temperature for the entire trip ranged between 4° and 40°. During the last 6 days the temperature was for the most part between 10° and 20°, although on four occasions it dropped to 8° or below. Two of these occasions were when the experimental cars were in heater territory and between inspection stations, so that the heaters were not lighted; the other two were during the last 2 nights of the test after the cars had left heater territory. After 3 days with the outside temperature for the most
part below 20°, the fruit started to freeze in the bottom layer boxes, and considerable frozen fruit was found in those boxes at destination.

From the data obtained in these tests it is obvious that knowledge of present and anticipated weather conditions is not adequate for determining whether to light or extinguish the heaters. Knowledge of the air temperature inside the car at a position where the minimum temperatures occur together with knowledge of weather conditions in the territory through which the car is to pass gives a more definite basis for operating the heaters. None of the methods tested gave the desired optimum storage temperatures for the fruit, but inside control materially decreased overheating so that the subsequent storage life of fruit carried under that method was longer than that of fruit shipped under Carriers' Protective Service.

![Figure 15. Top and bottom-layer temperatures of apples in car steel Washington 1935-2 shipped under Carriers' Protective Service during a period of moderate outside temperatures when heaters were not lighted.](image)

**RESULTS OBTAINED WITH HUMIDIFIED AIR**

During the Washington 1935-2 test the air in one of the cars under inside control was humidified by placing a 14-gallon metal container of water on top of each heater in this car, with a ½-inch copper tube soldered into the can and so arranged that about 3 or 4 pounds (1½ to 2 quarts) of water per hour were allowed to drip from the can onto each heater while burning. This water evaporated as fast as delivered and tended to saturate the air leaving the heater.

When dry air moves from a warm body, such as a heater, to a colder body, such as the load in a refrigerator car, where it is cooled, it delivers an amount of heat proportional to the drop in temperature of the air. On the other hand, if the air is saturated with moisture when it leaves the warm body a certain amount of water is condensed or deposited by the air as it cools to the temperature of the cold body. When this water condenses it gives up its latent heat of evaporation to the cold body. The heat so delivered is in addition to the amount given up by the drop in temperature of the air, so that to deliver a given amount of heat a smaller temperature difference is required for moist air than for dry air.

Humidity readings were taken near the top of the load at the doorway in the humidified car and in another car under inside control. During a period when heaters were burning in both cars the relative humidity of the air in the humidified car ranged between 85 and 89 percent and in the dry-air car between 53 and 75 percent.
During the heater periods, covering parts of 3 days, the top air at the front bunker was from 6° to 14° lower in temperature than in the dry-air car. This method was apparently more effective in equalizing temperatures at the doorway than at the bunkers. The difference between top and bottom fruit temperatures at the doorway in the humid car was less than 9° throughout the trip, while in each of two other cars under inside control this difference was about 14° and in the check car (Carriers’ Protective Service) about 20°.

INSTRUMENTS FOR USE WITH INSIDE CONTROL OF MANUALLY OPERATED HEATERS

An essential for the successful application and use of inside control with charcoal heaters is an instrument that will give the temperature of the air at a desired position inside the car and that may be used without the necessity of opening the car. To be satisfactory for the purpose an instrument must be accurate, dependable, durable, easily read, and so constructed as to withstand the rigors of usage on freight trains.

The information or records desired would determine somewhat the type of instrument to be selected for use with inside control of charcoal heaters. If the mechanical operation of heaters is all that is desired thermostatic indicators may be used; however, if a knowledge of the exact temperature is desired, distance-reading thermometers are necessary.

In these experiments several instruments of five general types were tested: (1) Mercury thermometers, (2) bimetallic thermostats, (3) vapor-pressure thermometers, (4) liquid-expansion thermometers, and (5) electric resistance thermometers.

In using the mercury thermometer the instrument was encased in wood for protection and support. It was inserted into the car through a hole in the frame just above the floor racks, the wooden case forming a stopper for the hole. Readings had to be made quickly when the instrument was withdrawn. The wooden case served not only to protect the instrument but to prevent a quick change in its reading when withdrawn from the car. This method of obtaining temperatures did not prove satisfactory, however, as the wood absorbed moisture and eventually swelled to such an extent that the instrument could not be withdrawn without breaking it. Another objectionable feature was that the mercury column sometimes separated, making it impossible to obtain accurate readings.

A bimetallic thermostat was mounted in the car and so adjusted as to close the contacts at a desired temperature. Wires extending from this instrument to the outside of the car were temporarily attached to a specially constructed flashlight at the time of each reading. If the temperature was below the chosen point the apparatus turned the light on; if above it did not. In a modification of this instrument used in some tests the flashlight had two light bulbs and was connected to the thermostat so as to make contact at two different temperatures. For example, in one test one bulb was lighted when the air temperature at the bottom doorway dropped to 30°F, or below, while the second was lighted when the temperature at this location was above 32°F. Neither bulb was lighted when the temperature was between 30°F and 32°F.
This instrument does not give the actual temperature readings, but indicates when the heaters should be lighted or extinguished under the plan of inside control. In general these instruments proved satisfactory, only one failure being obtained in over 230 readings, and then the flashlight was found to be short-circuited. The thermostats remained in adjustment over long periods.

Two distance-reading vapor-pressure thermometers were used in each car, one to give the air temperature at the bottom of the load and the other that at the top. The instrument consisted of a bulb located at the desired position, a reading dial mounted on the outside of the car, and an armored capillary tubing about 15 feet long connecting the bulb and dial. A change in the vapor pressure due to a change in the temperature of the bulb activated a hand on the dial which was calibrated to show temperature readings. This instrument did not prove accurate under the conditions of these experiments.

Two types of distance-reading liquid-expansion thermometers were used during these experiments. The first consisted of a dial, armored tubing, and bulb and was carried by the person making the readings. Metal tubes were permanently inserted through holes in the side of the car. To obtain a temperature reading, the bulb of the thermometer was inserted through the tube and held inside the car until a constant reading was obtained. The tubes were kept plugged except when readings were being taken. This method was not only slow, but on account of heat conduction along the tube it was inaccurate as well. The presence of tubes protruding through the walls of the car was also found to be objectionable during loading and unloading.

The second instrument of this type is similar in appearance to the vapor-pressure thermometer previously described, but differs in internal structure. This instrument was found to give readings that for the most part were sufficiently close to those obtained with the electric resistance thermometers which were used for comparative purposes in the same positions.

The special electric-resistance thermometers, similar in construction and operation to those used as standard equipment in all of the other phases of the investigation, consisted of one or two bulbs, wire leads, and a portable indicator or "reading box." One bulb was used to obtain the air temperature at the bottom of the load, and the other to obtain it near the top. Leads from both bulbs were carried to the outside of the car where they could be conveniently attached to the indicator. It has been found that most of the electric resistance thermometer bulbs require individual corrections. The addition or subtraction of the correction factor that is necessary to obtain the correct temperature is a disadvantage to be considered in this type of thermometer. Against this, however, must be considered the general convenience and reliability of the results obtainable with this instrument under proper usage.

Of the temperature-indicating devices tested during this investigation— the bimetallic thermostat, electric-resistance thermometers, and liquid-expansion thermometers—were found to be adapted to inside control of manually operated heaters. However, none of these instruments except the liquid-expansion thermometer was designed or built for the hard use incident to service on refrigerator cars, but were standard instruments so modified that they could be used for the purpose in these tests. There is little doubt that instruments
of the other two types found to be adapted could be constructed with sufficient durability to allow their use in the rigorous service on freight trains.

**LOCATION OF INSTRUMENTS**

The most convenient place to take the temperature readings is on top of the car, since in attending the heaters it is necessary to enter the car from the roof. If the instruments are mounted on the side of the car, part of the cars would have them on one side of the train and part on the other, thus increasing the difficulties and hazards of taking the readings.

The location of the bulb or sensitive part of any temperature-indicating device is important, and the critical temperature at which the heaters are lighted or extinguished depends on its location. It is essential to place permanently located bulbs so that they will not interfere with the loading and unloading of the cars. Portable instruments could be placed in the car after loading and removed before unloading without interfering with these operations. If the sensitive part of the temperature-indicating device were inset in the side wall it would be unduly influenced by the temperature of the wall.

A study was made of relative temperatures in various parts of several test cars to determine the most desirable location of the thermometers for inside control. This study showed that many possible locations were unsatisfactory. A position near the top of the bottom bunker opening proved unsatisfactory, since the bulbs so placed were unduly influenced by the radiant heat from the heaters. A position under the floor rack was not entirely satisfactory because temperatures below the rack were not always a good indication of temperature conditions above the rack. Likewise, a bulb located under the rack in one end of the car did not indicate the desired control temperature for the car when one of the heaters failed to burn, especially the one in the opposite end from the bulb. A position a short distance out from the side walls and above the floor racks near the doorway was found to yield the desired control temperatures, but was not satisfactory as a permanent location because of interference with loading and unloading.

Minimum temperatures generally prevail at the bottom doorway. Temperatures obtained level with the floor rack midway between the doors were generally from 1° to 2° higher than those obtained just above the rack at the north side doorway. The latter position could not be used because cars may be turned in transit. This should limit the placing of the bulb to a level with the floor rack near the center line of the car between the doors.

**EFFECTS OF HEATERS BURNING IN REFRIGERATOR CARS**

The burning of heaters in refrigerator cars causes a change in the conditions within the car as to temperature of the air and the fruit, air circulation, relative humidity, and composition of the air.

**TEMPERATURES OF AIR AND FRUIT**

Fruit and air temperatures were obtained at a number of different positions in each car, so that it was possible to determine the changes in temperature brought about by varying conditions. A marked difference in the temperatures in various parts of the load was found to result from the burning of one or two heaters in a car. In order
to obtain more complete information as to temperature conditions in cars having one and two heaters burning, 48 thermometers were placed in each of two cars shipped from Wenatchee, Wash., during February 1934. One heater burned continuously for 71 hours in car A, whereas in car B two heaters burned continuously for 17 hours, or a total of 34 heater hours. These data are given in figures 16 and 17. The boundaries of the temperature zones in the load for the different days in transit as indicated in these figures were determined by interpolation of the temperature data.

Figure 16, D, shows the approximate temperature zones in various parts of the load in car A just before the heater in the front bunker was lighted. It will be noted that the temperatures were fairly uniform. The maximum fruit temperature was 39.2° F. and the minimum 33.3°, being for the most part between 36° and 37°.

The temperature conditions in the same car after the front heater had burned continuously for 36 hours are shown in figure 16, B. The fruit temperatures in the top layer and at the bottom front bunker position rose, while those in the bottom layer at the doorway and in the rear half of the car dropped. The minimum fruit temperature at this time was 30.5° F. and the maximum was 49.6°.

Figure 16, C, illustrates the conditions found after the heater had burned continuously for 71 hours. The temperatures in the top layer and at the bottom front bunker were higher than those shown in the previous figure, while those in the bottom layer of the rear half of the car continued to drop. The maximum fruit temperature was 52.6° F. and the minimum was 29.7°. Shortly after these temperatures were obtained the heaters were removed from the car. Figure 16, D, shows the approximate temperature zones in the load 91 hours after the heater had been removed in Chicago, Ill. (the limit of heater territory). The maximum fruit temperature at this time was 40° and the minimum 28.5°, the temperatures throughout the car having dropped.

Similar results were likewise noted in an analysis of the temperature conditions in several other cars shipped during the 1927 to 1933 seasons under Carriers' Protective Service and in which only one heater was lighted. It was found that the highest fruit temperature in the car was always in the top layer in the end of the car in which the burning heater was located, while the lowest temperature of the top layer was in the opposite end of the car. In the bottom layer the lowest fruit temperature was generally found at the bottom doorway on the north side of the load.

Figure 17, A, shows conditions just before two heaters were lighted in car B in the same test from Wenatchee, Wash., in February 1934. It will be noted that the temperatures were lower at the time heaters were first lighted in this car than in car A (fig. 16, A), because the average fruit temperature at time of loading was 4° lower and the heaters were lighted 12 hours later. During that 12-hour interval when a heater was burning in car A there was a drop of temperatures in car B, in which two heaters were burned subsequently, averaging $1\frac{3}{2}°$ to $2\frac{3}{2}°$ in the bottom layer and $1°$ to $1\frac{1}{2}°$ in the top layer. The minimum air temperature in car B just prior to lighting the two heaters was 29.9°, whereas the minimum fruit temperature was 31.4° and the maximum fruit temperature was 35.2°.

Figure 17, B, shows the approximate temperature zones in the car after two heaters had burned 17 hours (a total of 34 heater hours), or
Figure 16.—Approximate temperature zones in a load (over A) of apples while in transit from Wenatchee, Wash., to Jersey City, N. J., shipped under Carter's Progressive system. Average temperature of fruit at time of loading was 30° F. A., 70 hours after loading (Feb. 20, 1935); B. 20 hours after front heater was in use; B., after front heater had burned 50 hours; C., after front heater had burned 71 hours (Chicago); D., after front heater had been extinguished 91 hours (Jersey City).
approximately the same number of heater hours as shown for car A in figure 16, B. There was an increase in the fruit temperatures of the bottom layer in car B, ranging from 0.3° F. at the bottom doorway to

![Diagram showing temperature zones in a load of apples in transit from Wenatchee, Wash., to Jersey City, N. J., shipped under inside control. The average temperature of fruit at time of loading was 32° F. A. After 97 hours after loading and just before both heaters were turned on, B. After both heaters had burned 17 hours, C. Approximate temperature zones at arrival in Chicago, Ill.]

between 2° and 3° at the bunkers. In the top layer, however, the effects were apparent in a rise of 5° to 11°. The minimum fruit temperature was 31.7° and the maximum 46.6°.

Figure 17, C, shows the approximate temperature zones of the load upon arrival in Chicago and at the same time as shown in figure 16, C, for car A. It will be noted that temperature conditions were more
uniform from front to rear of the load than from top to bottom. The maximum fruit temperature in car B at this time was 45.8° F, and the minimum 31.4°, whereas in car A (fig. 16, C) the maximum fruit temperature was 52.6° and the minimum 29.7°.

Similar results were likewise noted in an analysis of conditions in 41 cars used in the tests between 1928 and 1933 under varying outside temperatures and with both heaters burning. The highest temperatures in both the top and bottom layers were found next to the bunkers and the lowest at the doorway. The minimum temperatures found in these cars were at the bottom doorway on the north side of the load. The maximum difference in fruit temperatures between top and bottom layers ranged between 7° and 28° F, and averaged between 13° and 14°. There was generally some difference between temperatures on the north and south sides of the load, because the cars were for the most part moving in an easterly direction and the south sides of the cars were affected by the sun. As a result there were times when the fruit temperatures on the south side were 1° to 2° higher than on the north side. The temperatures at the center line, bottom doorway, were 2° to 4° higher than at either side, whereas at the bottom bulkhead position the temperatures at the center line were 1° to 2° higher than at either side.

These data indicate that more uniform temperatures were obtained in the cars with both heaters burning. The decided difference in temperature conditions found between the top and bottom layers made it evident that air circulation should be increased or the heat should be released beneath the floor racks to obtain more desirable temperatures throughout the load.

AIR CIRCULATION

It was not possible to obtain very detailed information as to the circulation of air inside the cars when charcoal heaters were burning. The smoke given off by the heaters made it impossible to make "smoke tests," and the concentration of carbon monoxide being sufficient to cause death within a short time made it very dangerous to enter the cars. The movement of air was insufficient to activate a mechanical anemometer, and the direction of the air movement could not be ascertained by the electrical anemometer used in the later tests. However, from the change in temperature in various parts of the load and a few smoke tests made when kerosene heaters were used, the following information was deduced.

When the front heater only is burning the heated air passes through the top front bulkhead opening over the top of the load. Although some of this heated air passes downward between the stacked boxes, most of it seems to be divided, with part flowing down over the edge of the load between the stacked fruit and side walls of the car, part descending to the floor at the center of the car through the space where the divided load is braced, and part passing on into the rear bunker before cooling sufficiently to descend to the floor. The cooled air returns to the front bunker along the floor of the car under the racks and through the bottom bulkhead opening. When two heaters are burning the circulation of air is similar except that the movement from and to each bunker is more or less confined to the half of the car in which the heater is operating. For a more detailed discussion of the movement of air under the floor racks see page 11.
APPLES AND PEARS IN TRANSIT DURING WINTER

RELATIVE HUMIDITY

Hygrothermographs, placed on top of the load at the doorway in the test cars used in the stationary test at Havre, showed that the relative humidity was approximately 85 percent at 40° F., 70 percent at 50°, and 50 percent at 60°. The recommended relative humidity for apples and pears in storage is 85 to 90 percent (22).

In three of the experimental cars used in the Oregon 1932-1 test the relative humidity was obtained with a sling psychrometer before the cars were unloaded at New York City. The air temperature was between 33° and 33.5° F., and the relative humidity was between 86 and 87 percent.

CONCENTRATION OF GASES

Charcoal heaters burning in a refrigerator car decrease the percentage of oxygen and increase that of carbon monoxide and carbon dioxide in the air. Determinations of the concentrations of these gases were made during the stationary test at Havre. The results of these analyses are given in table 6. The maximum concentration of carbon monoxide was 1.2 percent and of carbon dioxide 3.0 percent. The lowest percentage of oxygen was 16.7, as compared with the normal percentage of about 21. The tests indicated that there was no stratification of the gases in the car. Smith (23) also found that in a ship's hold "when once the gases have been thoroughly mixed in the hold, there will, apart from leakage, be no tendency for the carbon dioxide to settle out again in a heavier layer at the bottom."

As pointed out elsewhere in this report, such concentrations of combustion gases as are ordinarily found in heater cars are not likely to injure the fruit.

<table>
<thead>
<tr>
<th>Car</th>
<th>Concentration</th>
<th>Position in car</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>Carbon dioxide</td>
<td>Oxygen</td>
</tr>
<tr>
<td>Percent</td>
<td>Percent</td>
<td>Percent</td>
</tr>
<tr>
<td>A</td>
<td>1.2</td>
<td>2.8</td>
</tr>
<tr>
<td>B</td>
<td>1.1</td>
<td>2.0</td>
</tr>
<tr>
<td>C</td>
<td>1.1</td>
<td>2.0</td>
</tr>
<tr>
<td>D</td>
<td>1.1</td>
<td>2.0</td>
</tr>
<tr>
<td>E</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>F</td>
<td>1.0</td>
<td>2.7</td>
</tr>
</tbody>
</table>

After 12 hours, burning of 1 heater in car A and B, June, 1936:

<table>
<thead>
<tr>
<th>Car</th>
<th>Concentration</th>
<th>Position in car</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>Carbon dioxide</td>
<td>Oxygen</td>
</tr>
<tr>
<td>Percent</td>
<td>Percent</td>
<td>Percent</td>
</tr>
<tr>
<td>A</td>
<td>1.2</td>
<td>2.0</td>
</tr>
<tr>
<td>B</td>
<td>1.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

FORCED CIRCULATION OF AIR

The data collected in these tests indicate that the normal circulation of air within a refrigerator car with heaters burning in the bunkers was not only slow but permitted high temperatures in the
top part of the car and much lower temperatures near the floor rack; that is, there was too great a spread between the temperatures in the top and the bottom of the load. A method of equalizing temperatures in a heated refrigerator car is by forced or mechanical circulation of the air.

Preliminary experiments were conducted during the stationary test at Havre in January 1929 to determine the effectiveness of centrifugal and propeller fans and the most effective position in which to place them. These fans were electrically driven, the power being supplied from batteries temporarily placed in the bunkers. Since it was necessary for observers to be inside the cars to conduct tests to trace the induced air currents, and as the presence of carbon monoxide from charcoal heaters would have made this too hazardous, heaters were not burned during these tests.

The centrifugal fan, driven at a speed of 1,750 revolutions per minute, had an intake 4 inches and an exhaust 3.5 inches in diameter. This fan was tried at different positions, but did not prove satisfactory. The propeller fan used was 12 inches in diameter and was built for fruit-conditioning rooms. When it was located at the top bulkhead opening or at the doorway, directing the air over the top of the load, the air currents became dissipated after traveling half a car length. The circulation appeared to be confined inside the loading space, only a small amount going into the bunkers; however, when placed in a car at the ceiling between the doors, and directing the air movement toward the floor racks through the doorway bracing of the load, this fan proved most effective in circulating the air around the divided load. Anemometer readings indicated that the air blast divided at the floor rack and traveled under the load into each bunker with approximately the same velocity. The circulation over the top of the load was also practically the same on each side of the fan. With the fan in this position the air was forced through the passages under the floor racks and was drawn from that part of the car where the highest temperatures prevail under heater service.

Further tests of using fans in refrigerator cars under heater service were conducted in 1932 at Arlington Experiment Farm, Rosslyn, Va., and at Alexandria, Va., to select a satisfactory fan and to determine the best means of propelling it. Power for forced circulation of air in the car in transit may be derived from several sources, two of which are from the rotation of the car wheels and from wind outside the car or air pressure due to the motion of the train. Of these two, the latter seems the more desirable because of the simplicity and the small number of moving parts necessary in an apparatus designed to make use of it. The power from this source is limited, however, because of practical restrictions on the maximum height of the car structure. A device depending on the rotation of the axles of the car wheels for power is inactive when the car is not in motion. In order to drive these devices when the car is standing still there must be some means of storing power. This means bulky and expensive equipment, chiefly storage batteries. Of course, wind-driven fans are also inactive if the train is not in motion and the wind is not blowing or if the train is moving at the same rate as a tail wind, but such a combination of conditions is rarely met.

These experiments indicated that when wind-activated rotors were used as the source of power it was desirable to use a fan within the
APPLES AND Pears IN TRANSIT DURING WINTER

car of relatively large area and relatively low discharge velocity rather than a fan of small area and high velocity. Consequently, fans of this type were constructed and used in further tests which were conducted in loaded cars in actual service. Two four-blade propeller-type fans, each 30 inches in diameter, were installed in a car, suspended from the ceiling between the doors, and each was activated by a 10-inch rotor on the roof outside the car.

A diagrammatic drawing of the fan installation showing the arrangements of the rotors, fans, shafts, and ceiling ducts as developed in these experiments is given in figure 18. These fans are covered by a public-service patent (β) and may be used by anyone, since the patent is dedicated to the free use of the public.

These fans were used without ceiling ducts during the Washington 1933-1 and 1934-1 tests from Wenatchee, Wash., to Jersey City, N. J., the rotors and fans being located between the doors. The results of one of these tests (Washington 1933-1) in which extremely cold weather was encountered show that in the fan car the average temperature of the top layer was from 5° to 10° lower during the time the heaters were burning, while the bottom-layer temperature averaged 1.5° to 2° higher than in the check car. The average difference between the temperature of the top and bottom layers of the two cars was about 13° in the check car and just half that, or 6.5°, in the car equipped with fans, showing the effectiveness of the fans in equalizing the temperatures in the load.

During the Washington 1935-1 and 1935-2 tests, for the first time it was possible to obtain results with the fans combined with air
ducts in the ceiling of refrigerator cars under heater service. In three cars a false ceiling was installed, above which were placed air ducts leading from each bunker to openings at the doorway in which the propeller fans were located (fig. 18). The top bulkhead openings were closed with building paper, so as to direct all movement of heated air through the air ducts. The heated air was thus carried direct to the doorway and was not in contact with the top layer of the load, being blown downward by the fans, thence returning to the bunkers under the floor racks.

In table 7 is given a summary of the results obtained during the Washington 1935-1 test in cars equipped with fans and ducts and in which charcoal heaters were operated under Carriers' Protective Service rules and inside control. It will be noted that the use of the fans decreased the maximum difference in temperatures between the top and bottom layers by 6° to 7.8°. The more even distribution of the heat with the fans and ducts made it possible to reduce the number of heater hours as compared with Carriers' Protective Service or inside control without fans and still give sufficient protection against freezing.

Figure 19 shows the fruit and air temperatures obtained in a car in the Washington 1935-1 test with rotors, fans, and ducts installed as shown in figure 18. The heaters were not lighted or extinguished according to any regular procedure, but were operated so as to observe the effect of having the front and rear heaters burning individually and together. Outside temperatures were low on January 21 and 22 during the time that the front heater was not burning, but their influence on the fruit temperatures was slight. The fruit temperatures remained fairly constant throughout the trip, and there was not as great a spread between the top and bottom layers as in the other cars of the test that were not equipped with the fans.

It is obvious from the data that it is possible by means of forced-air circulation within a refrigerator car under heater service, to establish more uniform temperatures throughout the load and reduce the amount of heat necessary to protect it.

Table 7.—Average maximum and minimum fruit temperatures during Washington 1935-1 test from Winchester, Wash., to Chicago, Ill., Jan. 18 to 28, 1935

<table>
<thead>
<tr>
<th>Items of comparison</th>
<th>Carriers' Protective Service</th>
<th>Inside control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Car A, no fans</td>
<td>Car B, fans</td>
</tr>
<tr>
<td>Maximum temperatures in top layer</td>
<td>42.7°F</td>
<td>44.0°F</td>
</tr>
<tr>
<td>Minimum temperatures in bottom layer</td>
<td>38.2°F</td>
<td>38.5°F</td>
</tr>
<tr>
<td>Difference</td>
<td>4.5°F</td>
<td>10.5°F</td>
</tr>
</tbody>
</table>
Prewarming refrigerator cars is the warming of its interior by charcoal, wood, or kerosene heaters prior to or during loading. This is done only during the coldest periods of the winter, to protect the fruit from freezing during loading and until the car is placed under regular heater service after loading.

A large percentage of the fruit shipped from the Pacific Northwest during the winter months is loaded from cold storage, with an average temperature generally ranging between 31° and 34° F. Obviously, this fruit does not have a great deal of reserve heat and unless given adequate protection will soon freeze when outside temperatures are below 20°.

![Graph](image)

**Figure 19.** Fruit and air temperature in the top and bottom layers of a car equipped with wind-driven fans and electric heaters in the Washington 1932 test.

While prewarming the cars was not commonly practiced prior to 1930, when done it was with standard charcoal heaters (fig. 9, B and C) used in Carriers' Protective Service. However, these were objectionable on account of the dangerous quantities of carbon-monoxide gas which they give off. To avoid such danger the car loaders thoroughly ventilate the cars prior to loading, so that most of the effect of prewarming is lost before it can be utilized.

Wood-burning heaters placed between the doors are seldom used, since they are not only difficult to set up but are in the way of the men loading the cars.

Kerosene heaters (fig. 9, A), which were used in the two prewarming tests conducted at Wenatchee, Wash., in January 1930, proved to be satisfactory. There was sufficient oxygen in the cars to permit the heaters to burn without odor or smoke during the relatively short time they were used, and the men working in the cars felt no ill effects from combustion gases.
In extremely cold weather it is desirable to provide some protection at the doorway to prevent too rapid loss of heat from prewarmed cars and from the fruit during loading. This may be done by use of a canvas tunnel between car and warehouse or by a split canvas curtain hung over the car doorway.

When roller conveyors are used to move the fruit into the car, a split canvas curtain may be hung across the open door, the conveyor passing through a hole in the curtain with a flap left hanging down. A metal rod is placed in the bottom of the curtain to hold it down. When fruit is trucked into the car a canvas tunnel may be used between the storage house and the open car door.

In the tests in January 1930 fruit and air temperatures were taken in various parts of the load at short intervals during the time the cars were being loaded and for a few hours afterwards. Records secured from the bottom-layer boxes a few hours after loading had been completed in the first prewarming test are shown in table 8. This table shows that in cars G and H air temperatures below the average freezing point of apples and pears (approximately 28.5° F.) (25) prevailed in the nonpreamermed cars despite the fact that the temperature of the fruit in the two cars averaged 38.5° and 41.7° at the time of loading. The minimum fruit temperature in car G, which was without any protection, was 28.1°; and in car H, which had a curtain at the doorway but not heaters, it was 30.6°. The outside temperatures during loading were between 8° and 10°.

Table 8.—Fruit and air temperatures in bottom layers of cars preceded with kerosene heaters, with and without doorway protection, at Woodinville, Wash., Jan. 7-8, 1930, with the outside temperature between 8° and 10°, during loading

<table>
<thead>
<tr>
<th>Test car</th>
<th>Treatment</th>
<th>Car-door protection</th>
<th>Hours open for loading</th>
<th>Average fruit temperature</th>
<th>Front bunker</th>
<th>Doorway</th>
<th>Rear bunker</th>
<th>Fruit</th>
<th>Air</th>
<th>Fruit</th>
<th>Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Protected</td>
<td>Curtain 1</td>
<td>3 4</td>
<td>42.1 38.4 38.5 38.7 38.3 38.0</td>
<td>40.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>do</td>
<td>None</td>
<td>2 5</td>
<td>38.1 31.5 31.8 31.6 31.4 31.4</td>
<td>31.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>do</td>
<td>Tunnel 2</td>
<td>3 7</td>
<td>31.6 32.1 32.3 32.3 32.4 32.4</td>
<td>32.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>do</td>
<td>Tunnel 2</td>
<td>3 7</td>
<td>38.1 31.5 31.8 31.6 31.4 31.4</td>
<td>31.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>do</td>
<td>Tunnel 2</td>
<td>3 7</td>
<td>38.1 31.5 31.8 31.6 31.4 31.4</td>
<td>31.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>do</td>
<td>Tunnel 2</td>
<td>3 7</td>
<td>38.1 31.5 31.8 31.6 31.4 31.4</td>
<td>31.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Not protected</td>
<td>Curtain 1</td>
<td>4 0</td>
<td>41.7 31.3 31.7 31.5 31.4 31.4</td>
<td>31.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 At time of loading test cars.
2 Canvas curtain hanging across the open door.
3 Curtain tunnel between storage house and the open door.

Table 9 gives a record of the second prewarming tests when outside temperatures were between —1° and 14° F. during loading. A comparison of records from cars A, F, and H, in which the fruit temperatures were about the same at time of loading, indicates that the use of a tunnel or a curtain in loading prewarmed cars prevented freezing temperatures in the fruit in the bottom-layer boxes, whereas freezing temperatures occurred in the absence of these facilities. Car A, without protection at the doorway, was the only car in which
freezing temperatures were recorded several hours after the doors were closed.

TABLE 9.—Fruit and air temperatures in bottom layers of preheated cars, with and without doorway protection, at Wenatchee, Wash., Jan. 23, 1930, with the outside temperature between -1° and 14° F. during loading

<table>
<thead>
<tr>
<th>Test car</th>
<th>Treatment</th>
<th>Front door protection</th>
<th>'Hours'</th>
<th>Average fruit temperature</th>
<th>Temperatures in bottom layers, north side, 6 to 9 hours after loading was completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Preheated</td>
<td>None</td>
<td>2.00</td>
<td>30.3, 29.8, 29.4, 29.2</td>
<td>28.1, 28.0, 28.8</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>Tunnel</td>
<td>2.00</td>
<td>36.0, 35.1, 34.2, 33.0</td>
<td>32.0, 31.7, 31.4, 31.1, 30.7, 30.4, 30.1, 29.8</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>None</td>
<td>2.00</td>
<td>34.0, 33.1, 32.2, 31.3</td>
<td>30.3, 29.9, 29.5, 29.3, 28.9, 28.6, 28.3, 27.9</td>
</tr>
<tr>
<td>D</td>
<td>10</td>
<td>Tunnel</td>
<td>2.00</td>
<td>32.0, 31.1, 30.2, 29.3</td>
<td>28.3, 27.9, 27.6, 27.3, 26.9, 26.6, 26.3, 25.9</td>
</tr>
<tr>
<td>E</td>
<td>10</td>
<td>Curtain</td>
<td>2.00</td>
<td>30.0, 29.1, 28.2, 27.3</td>
<td>26.3, 25.9, 25.6, 25.3, 24.9, 24.6, 24.3, 23.9</td>
</tr>
<tr>
<td>F</td>
<td>10</td>
<td>Tunnel</td>
<td>2.00</td>
<td>30.0, 29.1, 28.2, 27.3</td>
<td>26.3, 25.9, 25.6, 25.3, 24.9, 24.6, 24.3, 23.9</td>
</tr>
<tr>
<td>G</td>
<td>10</td>
<td>Curtain</td>
<td>2.00</td>
<td>30.0, 29.1, 28.2, 27.3</td>
<td>26.3, 25.9, 25.6, 25.3, 24.9, 24.6, 24.3, 23.9</td>
</tr>
<tr>
<td>H</td>
<td>10</td>
<td>Curtain</td>
<td>2.00</td>
<td>30.0, 29.1, 28.2, 27.3</td>
<td>26.3, 25.9, 25.6, 25.3, 24.9, 24.6, 24.3, 23.9</td>
</tr>
</tbody>
</table>

1 At time of loading test cars.
2 Canvas tunnel between storage house and the open end door.
3 Proven door in open doorway of car.
4 Preheated with wood stove—all others with kerosene heaters.

The information developed in these tests shows that when cars are loaded in an outside temperature of 10° F. or below, prewarming and proper protection at the doorway is desirable to prevent freezing of the fruit at the time of loading or shortly thereafter. Although no data were obtained as to the need of prewarming and protecting the doorway during loading of cars when the outside temperature is above 16°, it would seem advisable to provide this protection whenever the outside temperature is more than 3° or 4° below the freezing point of the fruit.

DISCUSSION OF RESULTS

The term “overheating”, as pertaining to fruit, is not always clearly understood. As used in this bulletin it means the exposure of fruit to temperatures high enough to result in an accelerated rate of ripening. The extent of this acceleration depends on the temperature and the duration of the exposure. Overheating of fruit in transit may be caused by too much artificial heat from car heaters or by the injudicious ventilation of the cars. Overheating from either or both of these causes was possible under the heating and ventilating rules of Carriers’ Protective Service which were in effect at the time of this investigation. Overheating from either cause would have the same deleterious effect on the fruit, provided the temperature was the same.

The rate of ripening of a fruit varies with its temperature. Magness et al. (14) found that with apples—

at 70° F. softening proceeds approximately twice as fast as at 50°. At 50° it is almost double the rate at 40°, while at the latter temperature softening proceeds fully twice as rapidly as at 32°. About 25 percent longer time was required for fruit to ripen at 30° than was required at 32°. In other words, 1 day at 70° will soften the fruit approximately as much as 2 days at 50°, 4 days at 40°, 8 to 10 days at 32°, or 12 days at 30° F.

Magness and Diehl (13) found that Winesap and Rome Beauty apples softened as much in 12 days at 70° as in 3 to 4 months at 32° F.,
while Delicious apples were softer at the end of 12 days at 70° than they were at the end of 6 months at 32°.

Working with pears, Pentzer, Magness, Diehl, and Haller (19) demonstrated the desirability of using temperatures low enough (30° to 31° F.) nearly to suspend physiological activities rather than temperatures only low enough to retard ripening. Gore (5) found that for every increase of 18° in temperature, the respiration rate increased 2.23 times for Seckel pears and 2.24 times with Kieffer pears. Hartman and others (8) state that Bose pears harvested at the proper time and stored immediately at 30° to 32° for 80 to 120 days reach prime maturity in 8 to 12 days after removal to a temperature of 66°.

Overheating in transit causes an injury that is generally masked until possibly several weeks after it has occurred and may not become apparent until the fruit is in storage at destination or in the process of marketing. This injury is generally manifested by a shortening of the storage life and premature break-down of the fruit. Such injury therefore is often not readily discernible at time of unloading. The extent of the loss caused by overheating is determined by the subsequent disposition of the fruit. If it goes into immediate consumption the loss, if any, may be small, but is most likely to occur in such fruits as the Delicious apple and winter pears, which are so responsive to overheating. However, if the fruit is placed in cold storage or if sale is delayed the loss may be large.

The time of selling is largely determined by market conditions except as the condition of the fruit may require earlier disposal. When the latter is the determining factor, the weakest or most mature fruit in the lot becomes the criterion for all of it, since in the wholesale trade dealings are generally upon a carlot basis. Thus, if any portion of a carload has been overheated the entire consignment may be sold at a loss. However, even though the wholesaler or jobber may be able to avoid a loss in such sales, there may still be a loss from the reaction of consumers, the extent of which it is impossible to estimate. If the fruit reaches the consumer in an overripe, mealy, or mushy condition he is discouraged from buying and demand falls off, causing a serious loss to everyone interested in the growing and marketing of the fruit. Any decrease in the consumption of fruit also reacts against the carriers and affects their revenue so that they too suffer in this indirect way. In addition, they are subject to direct claims for damage from faulty heater service.

Fruit may be frozen for a short time but if carefully thawed the resulting injury may be so slight as to be practically unnoticeable, especially in pears. Hartman (7) found that when pears are "frozen for short periods—namely, 48 hours, one week, and two weeks—at temperatures of 27° to 23° F. the fruit usually recovers fairly well." On the other hand, badly frozen pears when thawed usually show such severe injury that they are either unsalable or unfit for subsequent storage. However, observations have generally shown that losses from freezing damage in pears are less serious than the direct and indirect effects of overheating.

Although frozen fruit usually can be readily recognized by its condition and appearance, certain other types of injury have been mistakenly diagnosed as having been caused by freezing. Rose and Lutz (21) have shown that certain types of bruises, formerly considered as indicating that freezing has occurred, may in reality be
caused by continued jolting against a hard surface in the absence of freezing temperatures. Such injury is frequently found on fruit after transcontinental shipment. It was also found that the bruised portions of apples tend to freeze at a slightly higher temperature than the unbruised portions.

The tendency in the past has been to stress protection against freezing and to overlook the adverse effects of using too much heat. This is no doubt largely because injury caused by low temperature is much more quickly apparent than that caused by high temperature. This is reflected in the fact that more claims are filed for damage from freezing in transit than for damage from overheating.

The presence of frost on the inner walls of the car cannot be considered an indication that freezing of the fruit has occurred during the transit period. Frost is formed by the condensation of moisture from the warmer air in the car onto the colder walls and may form at 32° F., while fruit freezes at an average temperature of about 28.5° (26). Frost was noticed on the side walls of many of the experimental cars in which no frozen fruit was found.

The results of these investigations have shown that, with methods now in use for heating cars, it is impossible to maintain optimum storage temperatures in all parts of the load. Other methods of heater service, such as circulating a heated liquid (the temperature being thermostatically controlled) under the floor racks or heating the floor, gave the best results, but they do not appear to be economically practical at the present time. Therefore, a compromise between what is needed and what is feasible should be adopted. The primary objective here must be a heater-protective service that will preserve the quality and condition of the fruit, since a heater service operated merely upon the basis of weather conditions is inadequate.

Mallison and Powell (16) found that Bartlett pears in a hard-ripe condition could be transported from Medford, Oreg., to New York City during August and September at an average temperature as high as 43° F. and be in good marketable condition at the end of their normal storage life of 60 days, but that comparable fruit transported at an average temperature 10° higher ripened prematurely, soon after being placed in cold storage. Pentzer, Magness, and Dierk (19), in studying the effects of transit conditions on hard-ripe pears, found that in reducing the temperature from 53° to 43° for 12 days, which corresponded roughly to the time shipments were in transit from the Pacific coast, the subsequent storage life of most varieties at 31° was prolonged as much as 2 months. Results secured in this investigation, as shown in figure 12, indicate that with Anjou pears an average temperature in transit of 44.5° during February caused the fruit which was firm at time of shipping to ripen within 30 days, whereas that transported at an average temperature of 30° to 37° was still in firm condition after 60 days' storage. Although average transit temperatures of 36° to 37° are higher than the optimum storage temperature, these experiments proved that they could be safely used for a 10- to 12-day transit period without unduly affecting the marketability of pears that are in good firm condition when shipped. While it appears that most fruit, if not overmature at time of shipping, can be transported safely at temperatures somewhat above its optimum storage temperature, this temperature should be approached as closely as possible.
The condition of the fruit at time of shipment has a very decided influence on its susceptibility to injury from overheating. Fruit of advanced maturity must be transported at a temperature near its optimum storage temperature to avoid severe loss. With this class of fruit which is generally marketed on arrival there is likely to be less deterioration from slight freezing injury than from overheating in transit. With pears, especially, it would be better to ship such fruit without heat, as, for example, by utilizing the latent heat of fusion of water (i.e., wet sawdust under the floor racks). On the other hand, most varieties of apples in good shipping condition are not injured so much by overheating, but are readily injured by freezing.

The operation of the heaters by inside control reduced the amount of heat released, as measured by the number of heater hours, an average of 25 percent below that provided in comparable cars under Carriers' Protective Service. At the same time it lessened the danger of overheating by lowering the average temperature of the fruit in the top layer by 8° to 11°. The fruit in the bottom layer of cars shipped under inside control likewise was kept from freezing while in heater territory. However, this method does not provide much reserve heat in the load; hence if it is used, heater service should be extended to destination, particularly in territory east of the Illinois-Indiana State line, the present eastern boundary of heater territory.

During these tests it was found that the heaters burning charcoal were still warm 6 to 9 hours after the fuel shut-off slide had been closed. There was sufficient heat in the cars at the time of the closing of the shut-off slide so that the burning of the fuel remaining in the fire pots of the heaters gave unnecessary heat, thus increasing the hazard of overheating. Efforts should be made to extinguish the heaters more quickly or to remove the burning heaters from the car when heat is no longer required.

While none of the methods tested gave the desired optimum temperatures during severe weather, it was found that inside control afforded an improvement over present methods of operating heaters. The installation or use of distance thermometers, automatic heaters, improved charcoal heaters, or other new devices for the improvement of heater service necessarily involves additional costs for equipment. Likewise these improvements may increase labor costs. All of these costs must be considered in any effort to evaluate the practical benefit of the improvements suggested. Since the purpose of this investigation was to find means of improving temperature conditions inside the cars in shipments of fruit during cold weather, no efforts were made to determine the costs or benefits in dollars and cents to the carriers and shippers. However, the methods tested were largely confined to those that seemed economically feasible, recognizing that any improvement in heater service might involve additional costs.

With the tendency in the Pacific Northwest to increase production of winter pears and Delicious apples, the situation as to overheating becomes increasingly serious because these fruits are so responsive to high temperatures and therefore often arrive overripe and in poor condition for subsequent merchandizing.

Excess heat in the cars while en route to eastern destinations is not the only factor involved in the overripe and mealy condition of so many of the northwestern apples and pears obtainable on eastern markets, but it is an important one. Picking at the right stage of
maturity and prompt cold storage at the production end and proper handling after arrival at destination are also important, as stressed in other reports (2, 3, 8, 9, 10, 13, 14, 16, 19, 20, 21).

SUMMARY

Thirty-five transportation tests, using 217 cars, over a period of 14 shipping seasons have been made under varying weather conditions from the Pacific Northwest to eastern destinations to determine means of improving the methods of protecting fruits from freezing and overheating while in transit. In addition, two stationary tests were made—one at Roseville, Calif., and the other at Havre, Mont. These 37 tests have involved experimental work with different types of heaters, methods of lighting and extinguishing heaters, various heating systems, various methods of protection without heaters, ventilation, forced air circulation, refrigeration, and prewarming of cars with commercial shipments of apples and pears.

The results of this investigation in general have shown the need for improvement in the methods used in the transportation of pears and apples from the Pacific Northwest during the winter months and have indicated some of the methods by which improvement can be brought about.

None of the methods of heating refrigerator cars by means of heaters in the bunkers that depend for the distribution of heat upon the natural circulation of air alone maintained uniform temperatures throughout the load.

The use of wind-activated fans to increase the circulation of air served to create more nearly uniform temperature conditions in the car and reduced by several degrees the difference between the temperatures in the top and the bottom of the load and between the ends of the car.

Henceforward more effort has been made to prevent freezing than overheating of the fruit while in transit. This situation has been brought about chiefly by the fact that freezing injury is apparent at time of unloading, whereas injury from overheating may not become apparent until some time thereafter.

When the heaters were lighted and extinguished according to the temperature of the air outside the car, as in Carriers' Protective Service, temperatures inside the car could not be satisfactorily regulated.

Ordinarily, the only part of the load requiring heat is that near the floor. The maintenance of a uniform temperature at about 30° or 32° F. in the bottom layers without materially increasing the temperature near the top of the load would be ideal.

Burning one heater in the front bunker of a refrigerator car was found to give high temperatures in the top layer of fruit in the end of the car in which the heater was located, whereas the temperatures in the bottom layer of the opposite end of the car were not materially affected. More uniform and satisfactory temperatures were obtained when one heater was operated in each bunker of the car.

It was found that operating two heaters through heater territory according to the need for heat within the car resulted not only in the prevention of freezing but also in the avoidance of excessively high temperatures in the top-layer fruit packages. Pears in that layer
were in good marketable condition 30 days longer than comparable fruit shipped under Carriers' Protective Service.

During periods of high outside temperatures when the ventilators were operated according to the rules of Carriers' Protective Service it was not possible to maintain uniform temperatures near the optimum for fruit. The results indicate that there is no need for ventilation with shipments of apples and pears loaded at temperatures of 30° to 35° F. from storage in the Pacific Northwest during the period when Carriers' Protective Service is available. With such fruit desirable temperatures can be better maintained by keeping the ventilators closed, and shipments should be so handled.

When outside temperatures of 20° F. or lower prevail, prewarming of cars and the use of some means of retaining the heat during loading is desirable to prevent freezing of the fruit during loading or shortly afterward.

Ice in the bunkers was found to be of no benefit during winter months. The use of ice did not prevent or retard freezing; on the contrary, the presence of the ice caused the fruit to freeze more quickly.

It was found that dry insulating materials, such as sawdust, shavings, straw, or paper around the load not only did not give satisfactory protection against freezing but actually increased the hazard of freezing because they blocked the air channels and prevented air circulation.

The use of wet sawdust under the floor racks of the car and on the floor of the bunkers proved beneficial in delaying or preventing freezing of fruit by utilizing the latent heat of fusion of water when outside temperatures were not below zero for prolonged periods. This method is especially applicable with pears and with apples of advanced maturity that are severely affected by overheating. It is not recommended for general use over northern routes during periods of extremely cold weather.

It was found that the efficiency of heater service using present type charcoal heaters can be greatly improved by operating the heaters by inside control; that is, by releasing heat inside the cars when the minimum temperature of the air inside the car drops to slightly above the freezing point of fruit and then releasing only sufficient heat to prevent freezing injury. Success in operating charcoal heaters under inside control depends on providing relatively short periods between times of heater inspection, use of heaters in which combustion can be stopped within a comparatively short time after closing the fuel shut-off slide, or their removal from the car and replacement with cold heaters, and extension of heater territory. As manually operated heaters are serviced only at regular heater inspection stations, the development of a satisfactory automatic or thermostatically controlled heater would be an added improvement. However, uniform and optimum storage temperatures for fruit cannot be obtained throughout the load when heaters that depend on the natural circulation of air alone are used.

Various types of distance temperature-indicating devices were tested, and it was found that the bimetallic thermostat, electric resistance thermometers, and liquid-expansion thermometers are adaptable for use with inside control of manually operated charcoal heaters.
The favorable results obtained from use of inside control justify the recommendation of the general principle of protection upon which this method is based. The details of application and servicing arrangements can best be worked out by each carrier to suit its own individual conditions.

**LITERATURE CITED**

1. **Anonymous.**


3. **Cooley, J. S., and Fisher, D. F.**

4. **Miller, E. V., Brailey, C. O., Cooley, J. S., Monk, P. V., and Johnson, H. B.**

5. **Gore, H. C.**

6. **Colman, E. A.**

7. **Hartman, H.**

8. **Magness, J. R., Reimer, F. C., and Haller, M. H.**


10. **Herrick, W. V.**

11. **McKee, A. W.**

12. **——**

13. **Magness, J. R., and DiBula, H. C.**
    1924. PHYSIOLOGICAL STUDIES ON APPLES IN STORAGE. *Jour. Agr. Research* 27: 1 38, Illus.

14. **DiBula, H. C., Haller, M. H., Graham, W. S., and others.**

15. **—— and Taylor, C. F.**

16. **Mallison, E. D., and Powers, C. L.**


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