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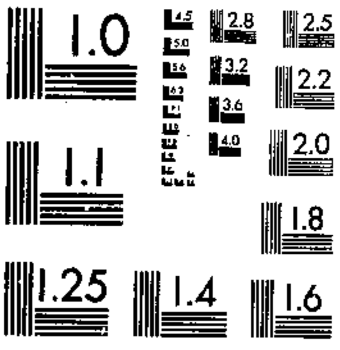

MICROCOPY RESOLUTION TEST CHART
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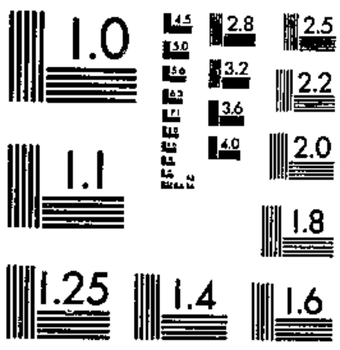

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REFRIGERATION OF ORANGES IN TRANSIT FROM CALIFORNIA

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CONTENTS

INTRODUCTION

The investigations forming the subject of this bulletin were concerned with the refrigeration of oranges during transportation from California to markets in the eastern part of the United States. This work was undertaken by the Bureau of Plant Industry in 1928 at

[1] The experimental work during 1928 and 1929 was under the general direction of Lon A. Hawkins, but after April 1930 was directed by D. F. Fisher. The authors were assisted in the transportation tests by R. J. Allan, W. R. Barger, C. O. Bratley, F. T. Engan, E. A. Gorman, Jr., J. G. Gray, Jr., E. M. Harvey, J. M. Lutz, E. D. Mallison, F. A. McKim, J. C. Moore, J. J. Moynihan, Jr., R. L. Newton, C. L. Powell, D. H. Rose, G. L. Rygg, J. S. Wiant, J. R. Winston, and R. C. Wright of the staff of the Division of Fruit and Vegetable Crops and Diseases of the Bureau of Plant Industry, and W. V. Hukill of the Bureau of Agricultural Engineering. They were assisted in the preparation of this report generally by E. M. Harvey and in the preparation of the sections dealing with experimental fruit and fruit inspections by C. O. Bratley and J. S. Wiant. Representatives of the Interstate Commerce Commission accompanied some of the test trips as observers. The generous cooperation of the California Fruit Growers Exchange in forwarding carload shipments of oranges under various experimental methods of refrigeration is acknowledged as well as that of the Pacific Fruit Express Co., the Santa Fe Refrigerator Department, the Atchison, Topeka & Santa Fe Ry., the Erie R. R., the Southern Pacific R. R., the Union Pacific R. R., and connecting lines over which the transportation tests were routed and without whose assistance the work could not have been carried on. Acknowledgments are due many officials of these companies who participated in these tests and rendered material assistance in the handling of test cars en route, but especially to C. A. Richardson of the Pacific Fruit Express Co. and W. F. Kerns of the Santa Fe Refrigerator Department.

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the request of the California Citrus League, an organization of growers and shippers representing about 95 percent of the citrus interests of the State.

REASONS FOR THE INVESTIGATION

A brief account of some of the conditions that have largely determined the methods used in the handling and shipment of citrus fruit will be helpful in understanding the purpose of the investigation discussed in this bulletin.

Citrus fruits, including oranges, lemons, and grapefruit, are picked and shipped from California throughout the year. The commercial production of oranges, as indicated by the carload shipments, has shown a substantial increase during each 5-year period since 1886 (*8*).[2] Oranges, which comprise about 80 percent of the citrus fruit, are chiefly of two varieties, the Washington Navel, which ripens during the winter and is marketed in the period November to May, and the Valencia, which matures and is shipped from April or May to November. A number of other varieties are grown but they are now of minor commercial importance (*15*). Between 1912 and 1917 Washington Navel orange shipments were 2.7 times as large as Valencia shipments; after 1918, however, shipments of Valencias increased at a faster rate, and since 1926 have exceeded Washington Navel shipments. About 90 percent of the acreage in young groves in 1928 was in Valencia oranges (*17*).

Shipments of Washington Navel oranges usually begin to move from northern and central California in November, and from southern California the latter part of December. These shipments go forward under standard ventilation until about February 15. After that date, due to the riper condition of the fruit and to warmer weather in the citrus districts, refrigeration is used on a large proportion of the shipments of Washington Navel oranges. Valencia oranges move almost entirely under some type of refrigerated service. The increase in the shipment of Valencias in recent years has accordingly resulted in an increased use of refrigerated service in the transportation of the fruit.

This investigation was begun during a period of relatively good prices for oranges, but the heavy prospective production faced by the industry made it seem desirable, if not essential, to develop and adopt methods of handling and transportation that would deliver the fruit to eastern markets in good condition but at less cost than prevailing methods. It was therefore decided to study the possibility of effecting savings in transit refrigeration which might enable the producers to market profitably.

A number of other factors relating to the handling and shipment of citrus fruit apparently made the investigation desirable. Progress recently made in applying various fruit-treating processes to improve the keeping quality of the fruit (*1*) caused refrigeration to be regarded as less effective in the control of decay and deterioration in transit than the preservative treatments used in connection with the cleaning and polishing of the fruit. Conditions under which the fruit was transported also had been materially improved

[2] Italic numbers in parentheses refer to Literature Cited, p. 86.

through the replacement of most of the older refrigerator cars with more efficient equipment. The shortening of freight-train schedules had contributed to the same end. Faster movement of trains had the effect of reducing the time elapsing between car reicings in transit. Shipments under standard refrigeration moving on a schedule of 9 days between California and Jersey City were being reiced at the same number of icing stations as were formerly used when the schedule was 12 days. Citrus fruit now reaches the auction piers in New York 71 hours earlier than in 1920. Many shippers also regarded the methods of refrigeration employed for citrus fruits as unnecessarily expensive.

EARLIER REFRIGERATION INVESTIGATIONS

In some of the former investigations of the Bureau, studies were made of the effect of refrigeration on the decay of oranges in transit. Powell (*13*) found in 1905–9 that precooling and shipment of the fruit at the lowest temperatures secured by reicing of the cars in transit reduced decay due to green mold and blue mold during the period of shipment. Refrigeration was effective temporarily in retarding the growth of these decay organisms which usually enter and attack the fruit through mechanical injuries. However, the decay again became active after the fruit was unloaded from the iced car and exposed to higher temperatures. It was noted also in these experiments that precooling provided a method of refrigeration by which oranges could be forwarded under initial icing only, or at least with less reicing in transit than had ordinarily been used, and permitted heavier loading of refrigerator cars.

Refrigerator cars in use at that time contained less than 1 inch of insulating materials in the walls, floor, and roof. In cars so constructed there was excessive meltage of ice in the bunkers by heat that penetrated to the interior of the car. Under these conditions it was usually necessary during warm weather frequently to reice precooled shipments in transit.

Following the work just discussed in which a study was made of the relation of refrigeration to the decay of oranges in transit, the factors influencing the efficiency of the refrigerator car were investigated by Pennington (*12*) and Ramsey[3] from 1912 to 1918. These investigations had reference chiefly to the refrigeration of fruits and other perishable food products in transit as influenced by the insulation of the car, the design and arrangement of the ice bunkers, and the use of the floor rack.

Results of this work were summed up in certain specific recommendations for the improvement of the refrigerator car. Chief importance was attached to the following details:

(1) The amount and distribution of the insulation.

(2) The basket form of ice bunker which had been found to enhance the circulation of air in contact with the ice.

(3) A solid, insulated bulkhead with openings at top and bottom, which aided in directing the movement of the air in the car.

(4) A floor rack 4 inches above the car floor formed by lengthwise stringers and cross slats. The floor rack provided a means of distributing the air from the bunkers and resulted in a marked acceleration of cooling. This especially

[3] RAMSEY, H. J. PERFORMANCE OF REFRIGERATOR CARS. Unpublished work. 1919.

affected the lowering of the temperature of the fruit in the upper portion of the lading and in parts farthest removed from the ice bunkers.

These and other features relating to the structure were made the basis of specifications of an improved refrigerator car, which were prepared in conjunction with engineers of various car lines and railroads and issued by the United States Railroad Administration in 1918.[4] Most of the refrigerator cars since built or rebuilt are of this general type. A relatively small proportion of the newer refrigerator cars contained less than the minimum amount of insulation recommended in the specifications of the "standard car."

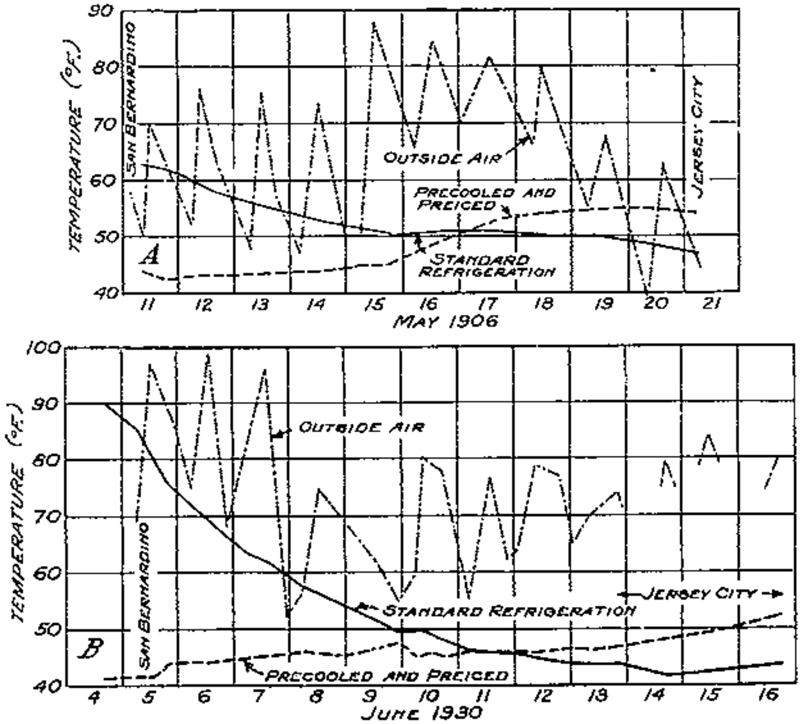

FIGURE 1.—Comparison of fruit temperatures (top quarter-length positions) in refrigerator cars of (*A*) former and (*B*) recent types. The minimum outside temperature was not recorded from the 14th to the 16th day.

COMPARISON OF FRUIT TEMPERATURES IN REFRIGERATOR CARS OF FORMER AND RECENT TYPES

The temperature graphs of figure 1 are presented to illustrate the performance of refrigerator cars of the improved type compared with those of earlier construction used in the precooling experiments mentioned previously.

Figure 1, *A*, shows the temperature of the fruit in two comparable shipments, in cars of the former type including warm fruit for-

[4] U. S. Railroad Administration, Mechanical Department Circular 7, provided that "In order to insure the greatest possible degree of efficiency in refrigeration and conservation of foodstuffs, refrigerator cars having trucks of 60,000 pounds capacity or over will, when receiving general repairs or being rebuilt, be made to conform to the following United States standard refrigerator car requirements", reference being made to drawings and specifications relating to various details of construction of the refrigerator car as developed in the investigations referred to.

warded under standard refrigeration and precooled fruit forwarded in a preiced car which was reiced at San Bernardino and not again reiced during the trip to New York. The two cars moved in the same train and therefore were subject to the same outside temperatures en route.

The solid line records the temperature of the fruit resulting from reicing at all regular icing stations en route under standard refrigeration. The temperature of the oranges before the car was iced at San Bernardino was 63° F., which is comparatively cool. The temperature of the fruit reached 50° on the fifth day, remained about stationary until the tenth day while outside temperatures were relatively high, and was about 47° at Jersey City.

The line of dashes shows the temperature of oranges precooled to 42° F. before loading in a preiced car which was reiced at San Bernardino before leaving California. The car was not reiced during the rest of the trip. It arrived in Jersey City on the twelfth day with about 700 pounds of ice in the two bunkers. The line of fruit temperature shows the effect of a rise in the outside temperature on the sixth day en route. As the mean outside temperature rose about 15° there was a gradual rise in the temperature of the fruit from 45° to 55°.

Figure 1, *B*, presents the record of the temperature of the oranges in one of the tests in 1930, the refrigerator cars in this case having much heavier insulation and larger ice bunkers than those illustrated in *A*. This test was conducted in much warmer weather than the earlier one.

The solid line in *B* records the temperature of the fruit in a shipment under standard refrigeration. The oranges were loaded at a temperature of about 90° F. The temperature of the fruit reached 51° on the fifth day, 46° on the seventh day, and dropped to about 43° on the twelfth day.

The line of dashes shows the temperature of a shipment of precooled oranges in the same trip. The oranges were precooled to 41° F., were loaded in a car preiced with block ice by the shipper, and were not reiced en route. There was a gradual rise in fruit temperature to 45° on the third day. The fruit temperature remained at about 45° until the eighth day and rose to 50° on the twelfth day after the car had been held for 3 days at Jersey City. When the car was unloaded on the twelfth day the bunkers contained 4,260 pounds of ice.

The cars in this test were representative of the more effectively insulated refrigerator cars now in use, which make it possible to forward shipments of precooled oranges to eastern destinations under initial icing during the warmer part of the year and which afford satisfactory refrigeration of nonprecooled oranges under the various methods of modified refrigeration service studied experimentally in this investigation.

REFRIGERATION SERVICES USED FOR CITRUS FRUIT AT BEGINNING OF INVESTIGATION

The methods of refrigeration in use in 1928 when the present investigation was started had long been the basis of refrigeration service on citrus fruit. Two types of refrigeration—standard refrigeration and initial icing only—were provided and are still used.

STANDARD REFRIGERATION

Standard refrigeration is a protective service against heat by the use of ice in the bunkers of refrigerator cars at a stated charge per trip. As applied to oranges in California, the carrier is not required to initially ice the cars until after they are loaded and are moved to the first icing station [5] but must then ice to full bunker capacity and reice at all regular icing stations en route, at all "hold" points, and at final destination until delivery is taken by consignee; and to assume all responsibility therefor. In the icing of refrigerator cars by the railroad the ice is broken into chunks weighing a few pounds to 100 pounds or more. As a rule the lower quarter to one-third of the bunker is filled with larger chunks weighing 75 to 150 pounds. The ice in the upper part is chopped into smaller pieces. The term "standard refrigeration" refers to the system of regular reicing of the cars in transit rather than to the degree of refrigeration afforded by the ice itself.

INITIAL ICING ONLY

Initial icing only became established (*14*) in connection with the method of precooling previously discussed and has been most extensively used on oranges precooled in the warehouses operated by fruit growers' associations. Precooled fruit was usually shipped in refrigerator cars that were initially iced by shippers before loading; i. e., preiced. Car icing as performed by the citrus associations differs from the usual procedure followed at railroad icing stations. The method is to fill the bunkers with block ice corded or laid in such manner as to form practically a solid mass. In this way it is possible to place 15,000 to 16,000 pounds of block ice in bunkers of refrigerator cars which have a rated capacity of 11,000 pounds of chunk ice. Oranges that are precooled and preiced by the shippers are usually forwarded under instructions to the carriers not to reice in transit.

A considerable number of nonprecooled shipments are forwarded under initial icing only by the carrier. This type of icing service is also used on oranges that are precooled at the car-precooling plants maintained by the railroads at Colton and San Bernardino. A modification of the "initial icing only" method is one by which shipments are precooled with portable fans,[6] placed in the cars, and require replenishment of the ice in the bunkers to replace the ice melted in precooling the fruit.

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[5] Car icing in southern California is done chiefly at Los Angeles and Colton on the Southern Pacific; at Colton on the Union Pacific, and at Los Angeles and San Bernardino on the Santa Fe railways. The delay between loading and initial icing under standard refrigeration service depends on the distance of the packing house from the icing station, and the switching service thereto. It rarely exceeds 12 hours but in some instances is as much as 24 hours. Extensive plants for the manufacture of ice and the icing of refrigerator cars and for fruit precooling are maintained by the Pacific Fruit Express Co. at Colton and by the refrigerator department of the Santa Fe at San Bernardino, both being located in the principal freight-consolidation yards of the railroads.

[6] GALLOWAY, A. G.: A PORTABLE PRECOOLING APPARATUS. U. S. Dept. Agr., Bur. Plant Indus., July 15, 1929. [Mimeographed.]

Practically the entire movement of citrus fruit is in cars of the originating railway lines, which are adapted for the standard load of 462 boxes of oranges or grapefruit.

EXTENT OF USE OF VARIOUS TYPES OF PROTECTIVE SERVICE AT BEGINNING OF INVESTIGATION[7]

Table 1 indicates the proportion of the total shipments of oranges and grapefruit forwarded in different months of the year under refrigeration and under ventilation during the 5-year period ended October 31, 1931, by the California Fruit Growers Exchange.[8] As shown by this record, 65.97 percent of the shipments moved under some form of refrigeration and 34.03 percent under ventilation.

In December and January practically all shipments were handled under ventilation. During the 5-year period only 64 cars in December and 11 cars in January were refrigerated. February shipments under refrigeration amounted to 22 percent and November shipments to 20 percent of the fruit shipped. During the rest of the year all but a relatively small portion of the fruit moved under refrigeration.

Table 2 shows the proportion in which various methods of refrigeration were used on oranges and grapefruit during the period 1926 to 1929, and is indicative of the practices in vogue before this investigation. The statement includes the shipments of three of the largest groups of shippers (California Fruit Growers Exchange, Mutual Orange Distributors, and American Fruit Growers, Inc.), and represents about 93 percent of the total shipments of citrus fruit from California and Arizona.

TABLE 1.—*Monthly and annual data on car-lot shipments of oranges and grapefruit under ventilation and refrigeration by the California Fruit Growers Exchange for the 5-year period ended Oct. 31, 1931*

[Standard carloads of 462 boxes]

Month	Standard ventilation	Refrigeration of all types	Total shipments	Month	Standard ventilation	Refrigeration of all types	Total shipments
	Cars	*Cars*	*Cars*		*Cars*	*Cars*	*Cars*
January	13,751	11	13,762	October	870	12,402	13,272
February	11,152	3,174	14,326	November	9,122	2,293	11,415
March	3,769	17,496	21,265	December	16,167	64	16,231
April	2,862	18,982	21,844				
May	4,281	18,950	23,231	Total	69,578	134,849	204,427
June	2,731	16,907	19,638				
July	1,842	16,830	18,672	Yearly average	13,916	26,970	40,885
August	1,622	14,877	16,499	Percentage	34.03	65.97	100.00
September	1,409	12,863	14,272				

[7] Reported by California Fruit Growers Exchange.

[8] Exchange shipments during the period 1926–31 included about 73 percent of all oranges and grapefruit shipped from California. Grapefruit represents only a relatively small portion of the total shipments appearing in table 1, ranging from 615 carloads in 1927 to 1,606 carloads in 1931.

TABLE 2.—*Car-lot shipments of oranges and grapefruit under different types of refrigeration service by the three largest groups of shippers, comprising about 93 percent of the total movement, for the 3 years ended Oct. 31, 1929*

[Standard carloads of 462 boxes. Based on record of shipments compiled by California Citrus League]

Year	Standard refrigeration		Initially iced only		
	Preiced car [1]	Dry car loaded [2]	Fruit precooled; preiced by shipper	Fruit precooled; initially iced by railway [3]	Fruit nonprecooled; initially iced by railway [4]
	Cars	*Cars*	*Cars*	*Cars*	*Cars*
1926-27	1,071	26,008	5,307	107	1,268
1927-28	732	17,865	4,188	64	2,209
1928-29	1,171	30,861	7,170	150	2,828
Percentage of total shipments under refrigeration	2.94	73.95	16.49	0.32	6.30

[1] Bunkers iced before loading.
[2] No ice in bunkers at time of loading.
[3] Iced by railroad at first regular icing station after loading.

Standard refrigeration was applied on 76.89 percent of all shipments moving under refrigeration (table 2). Precooling and preicing by the shipper accounted for 16.49 percent. Initial icing only as supplied by the railroads was used on 6.62 percent of the fruit, including oranges that were precooled at carrier plants at Colton and San Bernardino, and nonprecooled oranges and grapefruit.

The various methods of refrigeration that were tested experimentally in the investigation and for which provision has since been made in the National Perishable Protective Tariff are discussed elsewhere (p. 83) in this bulletin. The refrigeration rates which apply on shipments forwarded under the various types of refrigeration service are illustrated by the comparative rates between California and Chicago and New York shown in table 25.

METHODS AND MATERIALS

TRANSPORTATION TESTS

The experimental work consisted of a series of 29 transit refrigeration tests from southern California to Chicago and New York City during the years 1928 to 1933. These tests were conducted by observers who accompanied the shipments and made records en route. In each of these test trips there were from 2 to 16 carloads of oranges handled under various methods of refrigeration. The cars were loaded at the same or nearby shipping points and moved eastward in the same train, so that all shipments in any one test were subject to the same weather conditions.

The test cars were attached to a regular fruit train moving under the usual freight schedule, which requires delivery at the auction in New York City on the tenth morning after departure from the loading point in California, regardless of routing.

Outside atmospheric temperatures en route were taken every 2 to 4 hours on the shaded side of the experimental cars, and these temperatures were used as an index of conditions encountered in comparing one test with another.

DESCRIPTION OF EXPERIMENTAL CARS

Refrigerator cars of Pacific Fruit Express and Santa Fe construction were used in all tests. These cars were equipped with basket-type ice bunkers having either a wire screen or a perforated metal front, solid insulated bulkheads, permanent floor racks, 1½ to 2¼ inches of insulation in the sides and ends, and 2 to 2½ inches of insulation in the roof and floor. The inside dimensions of the loading space were approximately as follows: 33 feet 2¾ inches long, 8 feet 2¾ inches wide, and from 7 to 7 feet 7¼ inches high.

Tests were conducted with both newly built cars and with some that had been in service from 1 to 10 years to obtain data that would

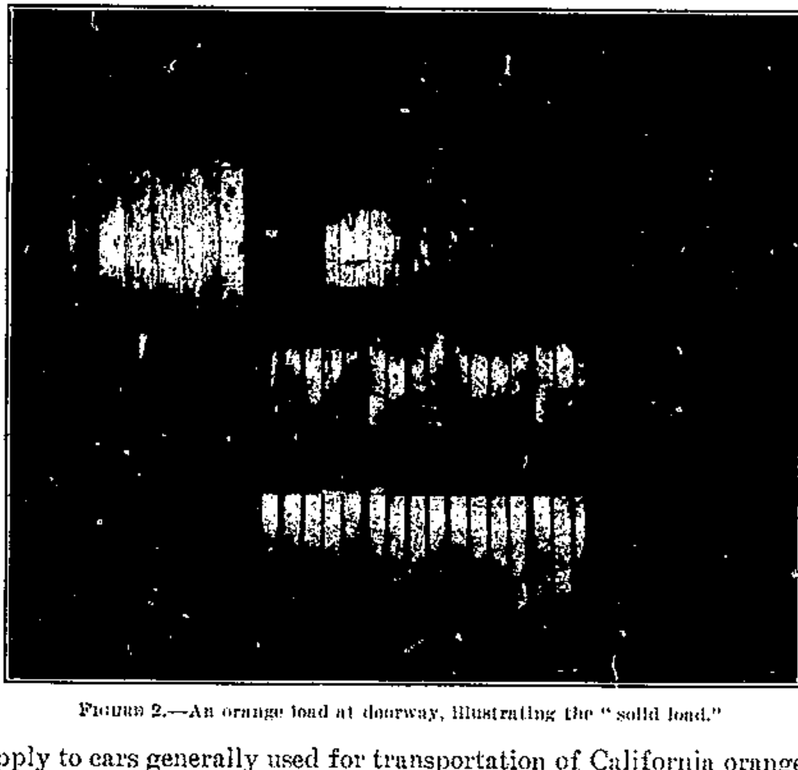

FIGURE 2.—An orange load at doorway, illustrating the "solid load."

apply to cars generally used for transportation of California oranges. However, in each experimental trip cars of the same age, construction, design, and insulation were used for comparing the different methods of refrigeration.

DESCRIPTION OF LOAD USED IN EXPERIMENTAL CARS

All test shipments were of the standard orange load containing 462 packed boxes, stowed 7 rows wide, 2 layers high on end, and 33 stacks long. This load extends from end to end of the car, no space being left at the doorway, as is the common practice in shipping other fruits. This type of "solid" load is illustrated in figure 2.

In the tests made during 1928 to 1931, inclusive, the boxes were loaded in the usual manner; i. e., with the bulge or lid side of the box against one side wall and the bottom of the boxes against the other side wall. An improved method of loading was used in the tests made during 1932 and 1933. In this method the row formerly loaded bottom to wall was reversed and the bulge was placed to the wall. Both methods of loading are discussed on page 41 and are illustrated in figure 15.

GENERAL OUTLINE OF EXPERIMENTAL WORK

The first test trip was made with Valencia oranges in November 1928. Preliminary information was obtained on the refrigeration of the fruit afforded by the two forms of service then in use, namely, standard refrigeration and initial icing only. Standard refrigeration was used on nonprecooled shipments, and initial icing only on both precooled and nonprecooled shipments.

Following this a series of 28 transportation tests was conducted during the years 1929 to 1933. These studies dealt with various modifications of the methods in general use and with various new or experimental methods of refrigeration. The date, routing, destination of shipments, variety of fruit, number of cars, and methods of refrigeration used in each test are given in table 3. The various routings used for the test trips, scheduled portion of route covered per day, and location of icing stations are illustrated graphically in figure 3. The test trips were conducted during every month of the year except December, January, and February, in order to determine the most economical types of refrigeration service that could be used satisfactorily in each season. Some of the tests were repeated over a period of 5 years in order to obtain significant and conclusive results. In the 29 test trips complete refrigeration records were secured on a total of 190 carloads of oranges, and supplemental data were secured on many additional shipments which were not observed en route.

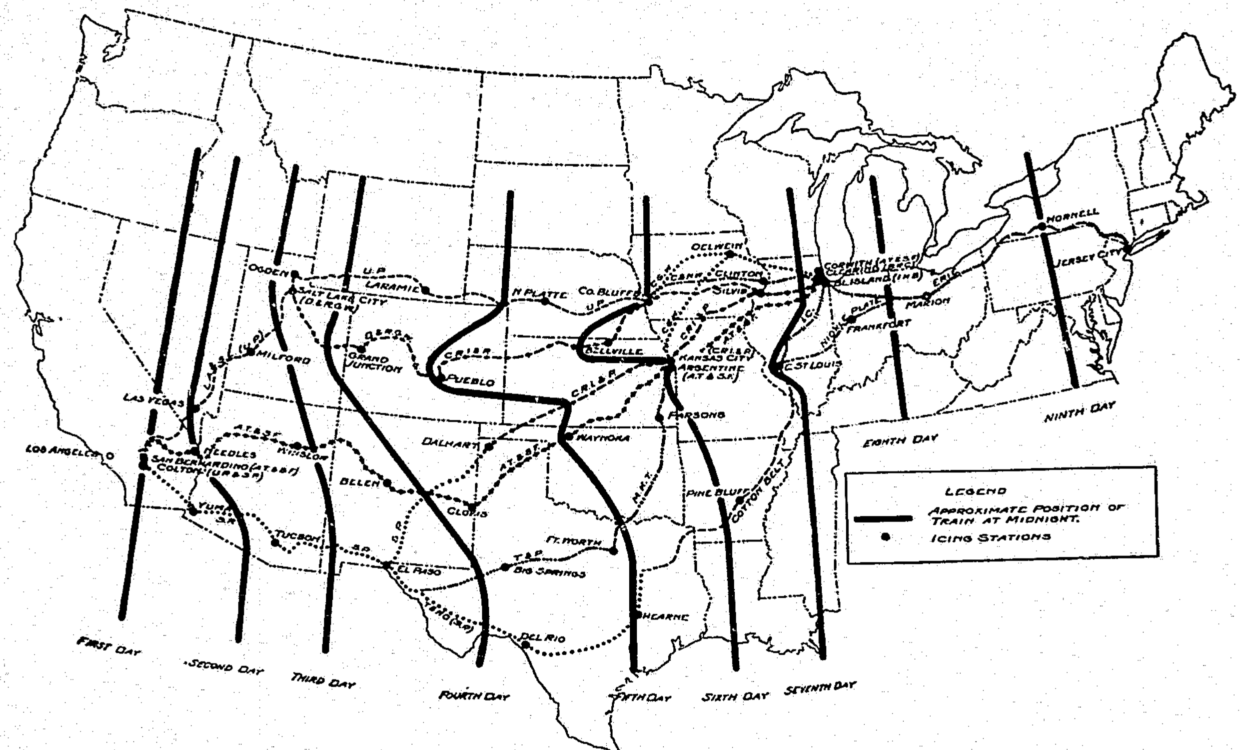

FIGURE 3.—Scheduled portion of route covered per day and location of icing stations. (Erratum: "Bellville" in Kansas should be "Belleville."

TABLE 3.—*Shipments of test cars in orange transportation investigations, 1928–33*

Test trip no.[1]	Date	Routing	Destination	Variety	Cars	Precooled or nonprecooled at time of loading	Method of refrigeration
					Number		
1928-1	Oct. 30–Nov. 7	Santa Fe	Chicago	Valencia	2	Nonprecooled	Standard refrigeration.
					2	do	Initially iced [2] San Bernardino, Calif.; not reiced [3] in transit.
					2	Precooled	Preiced [4] only.
1929-1	May 2–12	Santa Fe; Erie	New York	Washington Navel.	2	Nonprecooled	Standard refrigeration.
					2	do	Initially iced San Bernardino; not reiced in transit.
					2	Precooled	Preiced only.
1929-2	May 15–27	Southern Pacific; Rock Island; Erie.	do	Valencia	2	Nonprecooled	Standard refrigeration.
					2	do	Initially iced Colton, Calif.; reiced Silvis, Ill.
					2	do	Half-tank standard refrigeration.[5]
					4	Precooled	Preiced only.
1929-3	May 29–June 10	Union Pacific; Chicago & North Western; Erie.	do	do	2	Nonprecooled	Standard refrigeration.
					2	do	Initially iced Colton, Calif.; reiced North Platte, Nebr.
					4	Precooled	Preiced only.
1929-4	July 6–17	Southern Pacific; Cotton Belt; Nickel Plate; Erie.	do	do	2	Nonprecooled	Standard refrigeration.
					2	do	Initially iced Colton, Calif.; reiced El Paso, Tex
					2	do	Half-tank standard refrigeration.
					2	Precooled	Preiced only.
1929-5	July 20–31	Union Pacific; Chicago & North Western; Erie.	do	do	1	Nonprecooled	Standard refrigeration.
					2	do	Initially iced Colton, Calif.; reiced North Platte, Nebr.
					2	do	Half-tank standard refrigeration.
					2	Precooled	Preiced only.
1929-6	Aug. 8–26	Santa Fe; Erie	do	do	2	Nonprecooled	Standard refrigeration.
					2	do	Initially iced San Bernardino; reiced Belen, N. Mex.
					2	do	Half-tank standard refrigeration.
					2	Precooled	Preiced only.
1929-7	Aug. 30–Sept. 16	do	do	do	2	Nonprecooled	Standard refrigeration.
					1	do	Initially iced San Bernardino; reiced Clovis, N. Mex.
					2	Precooled	Preiced only.
					1	do	No ice; vents closed to destination.
1929-8	Sept. 20–Oct. 8	Southern Pacific; Rock Island; Erie.	do	do	2	Nonprecooled	Standard refrigeration.
					3	do	Initially iced Colton; not reiced in transit.
					2	do	Initially iced Colton; reiced Silvis, Ill.—2 tons.
					2	do	Initially iced Colton; reiced Silvis—1 ton.
1929-9	Oct. 15–29	Union Pacific; Chicago & North Western; Erie.	do	do	1	do	Standard refrigeration.
					5	do	Initially iced Colton; not reiced in transit.
					2	Precooled	Preiced only.

1930-1	June 4-17	Santa Fe; Erie	do	do	1	Nonprecooled	Standard refrigeration.
					2	do	Initially iced San Bernardino; reiced Clovis, N. Mex., and Clearing, Ill.
					2	do	Initially iced San Bernardino; reiced Argentine, Kans.
					1	do	Precooled [6] in car with fans; replenished [7] after precooled; not reiced in transit.
					2	Precooled	Preiced only.
1930-2	July 9-21	Southern Pacific; Rock Island; Erie	do	do	1	Nonprecooled	Standard refrigeration.
					1	do	Initially iced Colton; reiced Kansas City.
					1	do	Initially iced Colton; reiced El Paso, Tex., and Blue Island, Ill.
					1	do	Preiced; replenished Colton; reiced Kansas City.
					1	do	Preiced; replenished Colton; reiced El Paso and Blue Island.
					2	do	Preiced + salt; replenished Colton; reiced El Paso and Blue Island.
					1	do	Preiced; standard refrigeration.
					2	Precooled	Preiced only.
1930-3	Aug. 13-26	Union Pacific; Denver & Rio Grande Western; Rock Island; Erie.	do	do	2	Nonprecooled	Standard refrigeration.
					1	do	Initially iced Colton; reiced Salt Lake City, Utah.
					1	do	Initially iced Colton; reiced Grand Junction, Colo.
					2	do	Initially iced Colton; reiced Chicago.
					1	do	Preiced; replenished Colton; reiced Chicago.
					1	do	Preiced + salt; replenished Colton; reiced Chicago.
1930-4	Sept. 15-29	Union Pacific; Chicago Great Western; Erie.	do	do	2	do	Standard refrigeration.
					1	do	Initially iced Colton; reiced Council Bluffs, Iowa.
					1	do	Preiced; replenished Colton; not reiced in transit.
					1	do	Dry car [8]; precooled by carrier at San Bernardino; initially iced after precooled; not reiced in transit.
1930-5	Oct. 28-Nov. 9	Southern Pacific; Cotton Belt; Illinois Central.	Chicago	do	2	do	Standard refrigeration.
1931-1	Ventilation test [9].						
1931-2	Mar. 11-22	Southern Pacific; Texas & Pacific; Missouri, Kansas & Texas; Chicago Great Western; Erie.	New York	Washington Navel.	3	do	Do.
					1	do	Initially iced Colton; not reiced in transit.
					3	do	Preiced; replenished by shipper after loading; not reiced in transit.
					1	Precooled	Preiced only.
					1	do	No ice; vents closed to destination.

1 The first unit of the test trip number refers to the year of the test; the second unit to the particular test in that year. This manner of designation is uniformly used in this report.
2 Initially iced, as used in this bulletin, refers to first icing given car after it has been loaded, usually occurring at the first icing station en route.
3 Reiced, bunkers refilled at any other icing station en route.
4 Preiced, car iced prior to loading.
5 Half-tank standard refrigeration, bunkers filled to half capacity only at regular reicing stations.
6 Precooled; fruit cooled before start of transcontinental trip.
7 Replenished, when done by carrier refers to refilling bunkers of preiced cars at first icing station; when done by shipper, refilling of bunkers of preiced cars at packing house.
8 Dry car, no ice in bunkers.
9 Not discussed in this bulletin.

TABLE 3.—*Shipments of test cars in orange transportation investigations, 1928–33*—Continued

Test trip no.	Date	Routing	Destination	Variety	Cars	Precooled or nonprecooled at time of loading	Method of refrigeration
					Number		
1931-3	May 12-25	Southern Pacific; Rock Island; Erie.	New York	Valencia	2	Nonprecooled	Standard refrigeration.
					1	do	Initially iced Colton; reiced El Paso.
					1	do	Initially iced Colton; reiced Dalhart, Tex.
					1	do	Initially iced Colton; reiced Kansas City.
					1	do	Initially iced Colton; reiced El Paso and Blue Island.
					2	do	Preiced; replenished by shipper after loading; reiced Dalhart.
1931-4	July 8-19	Union Pacific; Chicago Great Western; Erie.	do	do	3	do	Standard refrigeration.
					1	do	Preiced; standard refrigeration.
					2	do	Initially iced Colton; reiced Ogden, Utah, and Blue Island.
					2	do	Preiced; replenished Colton; reiced North Platte.
					1	do	Dry car; precooled by carrier at Colton; initially iced after precooled; reiced Laramie, Wyo.
					1	do	Dry car; precooled by carrier at Colton; initially iced after precooled; reiced Ogden and Blue Island.
1931-5	July 29-Aug. 11	Southern Pacific; Rock Island; Erie.	do	do	1	do	Standard refrigeration.
					2	do	Preiced; replenished by shipper day after loading; reiced Dalhart.
					2	do	Initially iced at time of loading; replenished by shipper next day; reiced Dalhart.
					3	do	Preiced; replenished by shipper day of loading; reiced Dalhart.
					1	do	Dry car; precooled by carrier at Colton; initially iced after precooled; reiced Dalhart.
1931-6	Sept. 14-Oct. 19	Santa Fe; Erie	do	do	1	do	Standard refrigeration.
					1	do	Preiced; reiced Winslow, Ariz.
					4	do	Preiced; replenished by shipper day after loading; reiced Waynoka, Okla.
					2	do	Reiced; replenished by shipper day of loading; reiced at Waynoka.
1931-7	Oct. 14-26	do	do	do	3	do	Standard refrigeration.
					2	do	Preiced; reiced at Winslow.
					1	do	Preiced; replenished by shipper day of loading; reiced at Waynoka.
					1	do	Preiced; replenished by shipper day of loading; reiced at Clovis.

1932-1	Mar. 7-9	Santa Fe	Needles, Calif.	Washington Navel.	1	Nonprecooled	Preiced; replenished 10 hours after loading.
					1	do	Not reiced in transit. Preiced; precooled with fans for 9 hours; replenished after precooled; not reiced in transit.
1932-2	Mar. 16-18	Southern Pacific	Yuma, Ariz.	do	1	do	Preiced; replenished 10 hours after loading; not reiced in transit.
					2	do	Preiced; precooled with fans for 9 hours; replenished after precooled; not reiced in transit.
					1	do	Preiced; replenished 20 hours after loading; not reiced in transit.
1932-3	Mar. 28-Apr. 1	do	Tucson, Ariz.	do	1	do	Preiced; precooled 16 hours with fans; replenished after precooled; not reiced in transit.
					1	do	Dry car; precooled 4 hours by carrier at Colton; initially iced after precooled; not reiced in transit.
1932-4	May 11-27	Santa Fe; Erie	New York	Valencia	1	do	Standard refrigeration.
					1	do	Preiced; replenished day after loading by shipper; reiced Clovis.
					1	do	Dry car; precooled 8 hours by carrier at San Bernardino; initially iced after precooled; not reiced in transit.
					1	do	Preiced; precooled with fans for 16 hours; replenished after precooling; not reiced in transit.
					1	Precooled	Preiced only.
1932-5	June 14-29	Southern Pacific; Rock Island; Erie	do	do	3	Nonprecooled	Standard refrigeration.
					1	do	Dry car; precooled by carrier at Colton 4 hours; initially iced after precooled; reiced at Dalhart.
					1	do	Dry car; precooled by carrier at Colton 6 hours; initially iced after precooled; not reiced in transit.
					1	do	Dry car; precooled by carrier at Colton 8 hours; initially iced after precooled; reiced at Dalhart.
					1	Precooled	Preiced only (block ice).
					1	do	Preiced only (crushed ice).
1932-6	Aug. 17-30	Southern Pacific; Rock Island; Erie.	do	do	1	Nonprecooled	Standard refrigeration.
					1	do	Dry car; precooled by carrier at Colton 8 hours; initially iced after precooled; reiced at Kansas City.
						do	Preiced; precooled by carrier at Colton 8 hours; replenished after precooled; reiced at Kansas City.
					1	do	Preiced; precooled by carrier at Colton 8 hours; replenished after precooled; not reiced in transit.
					1	do	Preiced; replenished Colton; reiced Kansas City.
1933-1	June 21-24	Southern Pacific	Tucson, Ariz.	do	1	do	Dry car; precooled 8 hours by carrier at Colton; initially iced after precooled; not reiced in transit.
					1	do	Preiced; precooled 8 hours by carrier at Colton; replenished after precooled; not reiced in transit.
1933-2	July 11-13	Santa Fe	Needles, Calif.	do	1	do	Dry car; precooled 8 hours by carrier at San Bernardino; initially iced after precooled; not reiced in transit.
					1	do	Preiced; precooled 8 hours by carrier at San Bernardino; replenished after precooled; not reiced in transit.

DETERMINATION OF FRUIT AND AIR TEMPERATURES

In order to compare the effectiveness of refrigeration of the fruit under the different methods it was necessary to secure temperatures of the fruit and air inside the cars while in transit. These temperatures were measured by means of electrical resistance thermometers. The sensitive part or bulb of the instrument was inserted into a fruit or hung in the air at desired locations in the car. Leads from these bulbs were connected to a master cable, which was carried out of the car through a thin doorplate placed at the top of the doorway and thence to the running board on the top of the car, as shown in figure 4. Readings were made by connecting the end of the master cable to

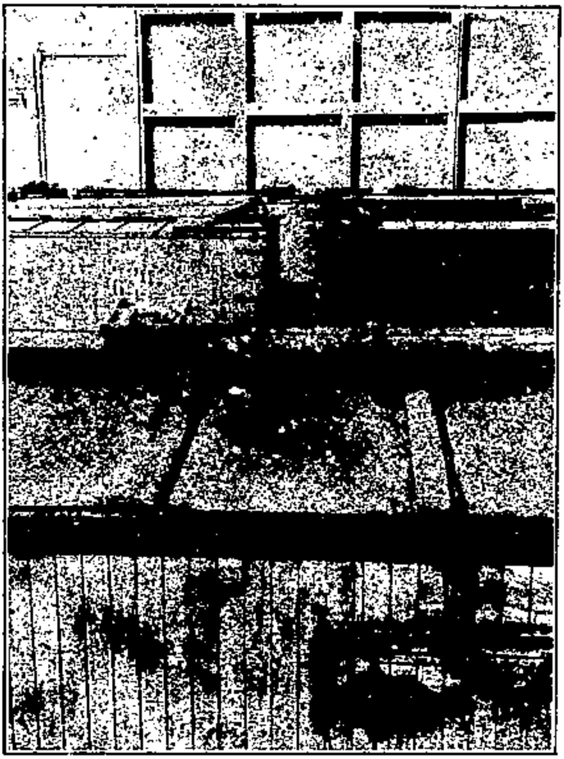

FIGURE 4.—Doorplate, outer end of master cable, and temperature-indicator box of apparatus for reading air and fruit temperatures in railroad cars.

an indicator or reading box equipped with a suitable selector switch by which the electrical resistance in any of the 12 bulbs could be determined. The indicator box is a modified Wheatstone bridge utilizing a sensitive galvanometer. Changes in the temperature of the bulb produce a corresponding change in the resistance of the coil in the bulb, which the reading box indicates directly in degrees Fahrenheit. As a slight variation exists in the different instruments, calibrations of individual bulbs and of individual indicators are necessary for accuracy. It will thus be seen that the instruments are so constructed and placed that temperature readings may be obtained at a number of places within the car without opening the doors. In the tests under discussion, readings were made at intervals of 4 to 8 hours. Outside air temperatures were obtained at the same time with a mercury thermometer.

At least 1 set of 12 thermometers was used in each test car. The usual positions in the load selected for the location of these thermometers in most of the tests were as follows:

Fruit in top layer of center row in stack next to bunker.
Fruit in bottom layer of center row in stack next to bunker.
Air at top opening of bulkhead at bunker.
Air at bottom opening of bulkhead at bunker.
Fruit in top layer of center row in eighth stack from bunker (quarter-length position).
Fruit in bottom layer of center row in eighth stack from bunker (quarter-length position).
Fruit in top layer of center row in seventeenth stack from bunker (doorway position).
Fruit in bottom layer of center row in seventeenth stack from bunker (doorway position).
Fruit in top layer of row next to the south door of car in seventeenth stack.
Fruit in bottom layer of row next to the south door of car in seventeenth stack.
Air at level of floor racks at doorway position.
Air 2 to 3 inches above load at doorway position.

Thermometers were located in only one end of each car, since other work of the Department had proved that the refrigeration is practically the same at similar points in opposite ends of the car, provided both ends are loaded in the same manner.

In each instance the fruit temperature was secured by inserting the thermometer directly into the pulp of an orange located midway between the center and outside of the top half of the box for the top-layer positions, and in a similar position in the bottom half of the box for the bottom-layer positions.

In tests 1931–6, 1931–7, and in all tests made in 1932 and 1933, 2 to 4 sets of 12 thermometers each were used in some of the cars to obtain temperatures at certain positions in the load other than at the regular positions mentioned above. The location of these thermometers and the results obtained are presented on pages 431 to 461 and 681 to 761.

METHODS OF ANALYZING TEMPERATURE DATA

In analyzing the results in any particular car it is of much interest to determine the average fruit temperature maintained in that car. A study of the temperatures obtained in the cars in which thermometers were located at 24 to 48 different positions indicated that the fruit temperature obtained at the 8 regular positions used in all cars did not represent equal amounts of fruit, and that an arithmetical average of these 8 temperatures would not give the correct figure for the average temperature of the load. As shown later, it was found that in cars under ordinary ice refrigeration[9] the bunker position represented the temperature of only about 6 percent of each layer, the doorway position about 12 percent, and the quarter-length position 82 percent.

[9] Ordinary ice refrigeration as used above refers to all methods reported on in this bulletin except fan and carrier precooling.

When it was determined that the quarter-length temperatures represented the temperature of so much fruit, it appeared that an average of the top and bottom quarter-length temperatures would give a value approximately representative of the average temperature of the entire load. Accordingly, an average thus obtained was compared in several cars with the weighted average derived by taking into consideration 24 temperatures throughout the load and giving a definite weight to each temperature, depending upon the percentage of fruit it represented. The results of two such comparisons obtained in test 1932–4 are shown in table 4. It is apparent from this table that an average of the 2 quarter-length temperatures agrees very closely with the weighted average of the 24 temperatures. Throughout this bulletin, therefore, unless otherwise noted, an average of the top and bottom center quarter-length fruit temperatures will be used to represent the average temperature of the load in cars under refrigeration.

In some instances the mean temperature for each day in transit was also computed. Since the temperature readings were secured at irregular intervals, a planimeter was used in determining the daily mean temperature.

TABLE 4.—*Comparison of weighted average of all fruit temperatures with average of top and bottom quarter-length fruit temperatures in test 1932–4*

Station at which temperature was taken	Date	Time	Car A[1]		Car B[2]	
			Weighted average	Average top and bottom quarter-length	Weighted average	Average top and bottom quarter-length
			° F.	° F.	° F.	° F.
Placentia, Calif.	May 10	5 p. m.			74.7	72.7
		11 p. m.			70.3	67.7
Do.	May 11	4 a. m.			66.8	64.7
		7 a. m.			65.4	63.4
		4 p. m.	72.1	71.9	61.6	60.3
San Bernardino, Calif.	May 12	7 a. m.			55.8	55.4
Do.		11 a. m.	72.4	72.5		
Barstow, Calif.		8 p. m.	67.0	67.0	52.8	52.8
Needles, Calif.	May 13	5 a. m.	62.1	62.1	50.7	50.9
Seligman, Ariz.		1 p. m.	59.3	59.2	49.7	49.8
Winslow, Ariz.		10 p. m.	56.8	56.9	49.2	49.6
Gallup, N. Mex.	May 14	6 a. m.	54.4	54.3	48.1	48.0
Belen, N. Mex.		1 p. m.	52.6	52.7	47.7	48.2
Vaughn, N. Mex.		8 p. m.	51.4	51.6	47.5	47.9
Clovis, N. Mex.	May 15	1 a. m.	50.2	50.3	47.0	47.3
Canadian, Tex.		12 m.	48.7	48.9	45.8	46.4
Waynoka, Okla.		5 p. m.	48.0	48.4	45.4	46.0
Emporia, Kans.	May 16	5 a. m.	46.1	46.3	43.8	44.1
Argentine, Kans.		2 p. m.	44.8	44.9	43.0	43.5
Do.		10 p. m.	44.0	44.2	42.3	42.8
Shopton, Iowa	May 17	9 a. m.	43.1	43.0	41.7	42.2
Chillicothe, Ill.		4 p. m.	42.6	42.7	41.5	42.0
Corwith, Ill.		9 p. m.	42.5	42.6	41.3	41.7
Hammond, Ind.	May 18	7 a. m.	41.7	41.9	40.8	41.0
Do.		2 p. m.	41.5	41.6	40.6	41.4
Huntington, Ind.		8 p. m.	41.4	41.0	40.6	40.7
Marion, Ohio	May 19	3 a. m.	40.8	40.8	40.1	40.3
Meadville, Pa.		1 p. m.	40.5	40.4	40.1	40.2
Cuba Junction, N. Y.		7 p. m.	40.5	40.5	40.0	40.2
Susquehanna, Pa.	May 20	6 a. m.	40.4	40.3	40.0	40.1
Jersey City, N. J.		3 p. m.	40.2	40.2	40.2	40.2

[1] Standard refrigeration.
[2] Preiced, replenished, reiced once in transit (at Clovis, N. Mex.).

ICING OF EXPERIMENTAL CARS

All icing of experimental cars during transit was done by the railroads over whose lines the cars were routed. A typical railroad icing

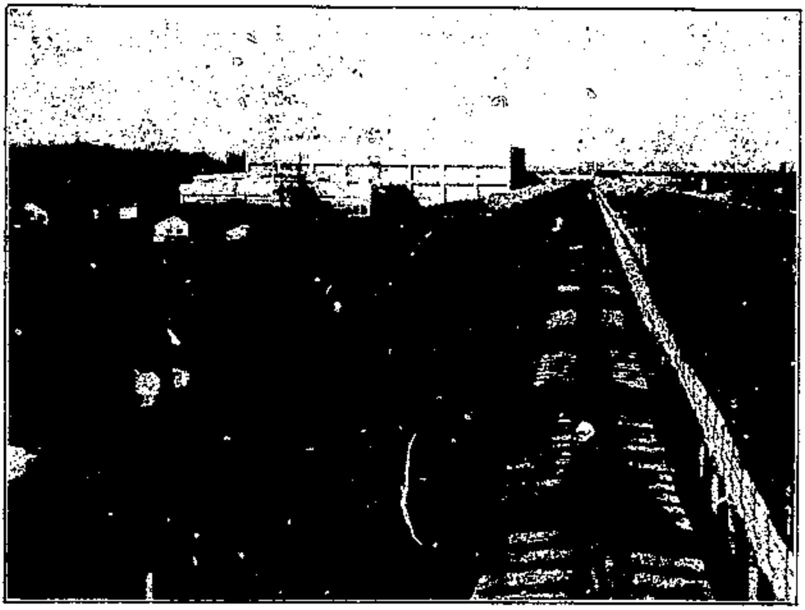

FIGURE 5.—The Pacific Fruit Express Co. icing station at Ogden, Utah.

station is shown in figure 5. An icing station usually consists of an ice-manufacturing plant, ice-storage rooms, and an icing platform.

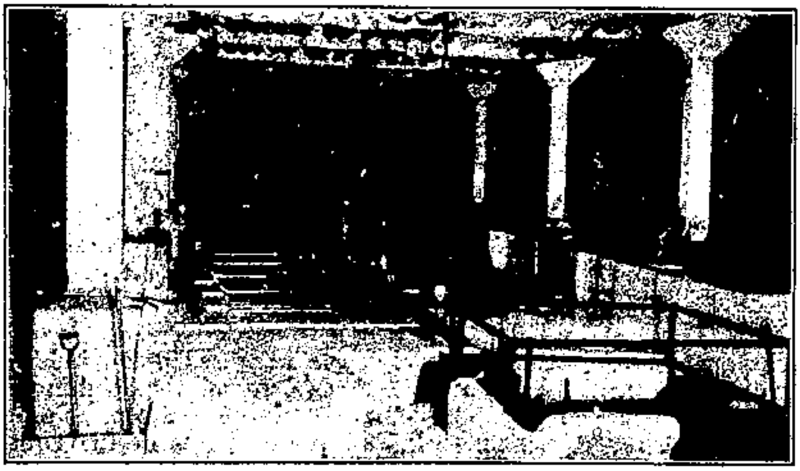

FIGURE 6.—Interior of the storage room of the San Bernardino ice plant of the Santa Fe Railway. The men in the picture are placing ice on conveyor chains which carry it to the icing platform.

Figure 6 is an interior view of an ice-storage room showing ice being placed on a conveyor chain preparatory to its removal to the icing platform. On reaching the platform the ice is usually distributed at convenient intervals for the icing of cars, this operation usually taking place before arrival of trains so as to avoid delay in icing of cars. However, in some instances, especially on the Santa Fe Railway, the ice is transferred directly from the conveyor chain to the bunkers of the car. In all cases as soon as the train has been spotted at the platform, hatch covers and plugs are opened and the bunkers are filled with ice as illustrated in figure 7. At the first or initial icing the lower parts of the bunkers are filled with chunks of ice varying from 75 to 150 pounds, and the ice in the upper part is always barred down into smaller pieces by means of long steel bars (fig. 7). Bunkers are usually filled well up into the hatches, leaving only enough space for the plugs and hatch covers to fit properly. In

FIGURE 7.—A crew of men icing refrigerator cars at the San Bernardino icing station of the Santa Fe Railway. Note that the ice is taken directly from the conveyor chain at left and is not spotted on the platform.

reicing, the old ice is barred down to fill in any large spaces before the bunkers are refilled.

When test cars of nonprecooled fruit were iced by the shipper at packing houses, the ice was broken up in the same manner as was done by the railroads, unless otherwise stated.

In shipping warehouse precooled fruit the cars are nearly always initially iced with block ice by the shipper several hours before loading, as described on page 65.

DETERMINATION OF ICE MELTAGE

The amount of ice melted in each car was used as an index of refrigeration furnished. This record was obtained by weighing the ice supplied at all icing stations. In each instance, except as otherwise noted, this ice was weighed by representatives of the United States Department of Agriculture accompanying the test.

In using these ice records it must be understood that at different icing stations there is commonly a difference in the point to which the bunkers are filled and also in the extent to which the ice is barred down. Too much significance, therefore, should not be given to the amount of ice supplied at the individual station, for while this is the actual amount of ice added, it is not necessarily the amount of ice melted since the preceding reicing. However, by measuring the ice remaining in the bunkers on arrival at Jersey City, N. J., and subtracting this amount from the total ice supplied, it is possible to secure an approximately correct figure for total ice melted in transit.

DETERMINATION OF TEMPERATURE OF ICE

Although the greater part of the refrigeration of oranges in transit is effected by the melting of ice, some refrigeration is secured from the ice before it melts if it is at a temperature lower than the melting point (32° F.) when supplied to the bunkers. Heat absorbed by the ice before melting is calculated on the assumption that ice at a temperature ranging from 20° to 32° F. has a specific heat of 0.5.

In tests 1931–7 and 1932–4 over the Santa Fe and test 1932–5 over the Southern Pacific and Rock Island, the temperature of ice supplied at all icing stations was secured. For this purpose two holes were bored into the cake of ice being tested, one in the center and the other 1 inch from the outside. The temperature at each position was obtained by inserting a long mercury thermometer into each hole. The average of these two temperatures was used to represent the temperature of that cake of ice.

FRUIT INSPECTION

In the 1929 and 1930 tests the fruit taken from the regular thermometer locations in each car was inspected at destination, and a record was made of the amount of decay and other changes which had occurred during transit. However, since the test cars often originated at different packing houses and also contained fruit from different groves which had not been uniformly treated it was apparent that this inspection could at best afford only a rough comparison from which no conclusion could be drawn.

Accordingly, in the 1931 and 1932 tests comparable lots of fruits from the same grove, picked the same day and given the same packing-house treatment, were placed at certain positions in the cars. These lots were inspected in New York City at the time of unloading and from 7 to 21 days after unloading. During the 21-day holding period the fruit, unless otherwise noted, was stored alongside other fruit on the wholesale market. The history, description, and locations of these experimental lots are given in connection with the results. Records were secured in several tests of loss in weight of the experimental fruit during transit and during the 21-day holding period, as well as the development of decay and various spots and other rind blemishes which affect the sales value of the fruit.

UNLOADING AND SALE OF FRUIT

On arrival in Jersey City, N. J., where the terminal train yard for cars in transit to New York is located, the test cars of oranges were held in the railroad yards for a period varying from 2 to 10 days in the different tests. When ordered to New York by the consignee the cars were ferried across the Hudson River on floats and unloaded on Erie Pier 21. These floats, as illustrated in figure 8,

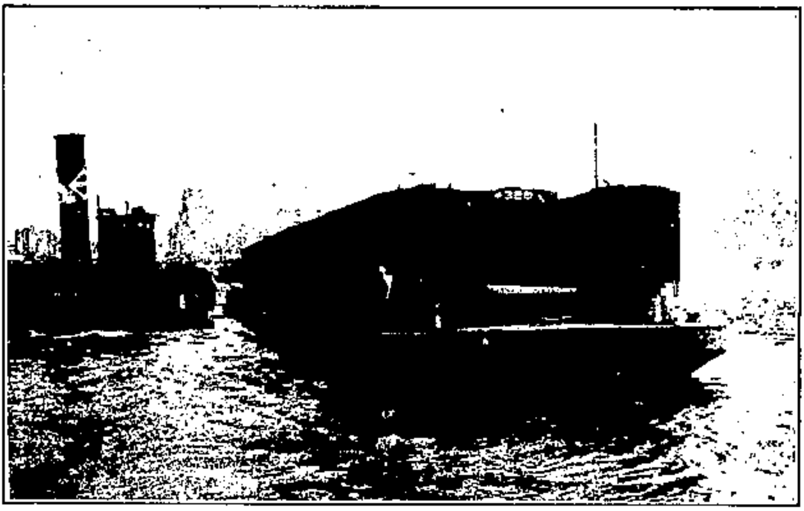

FIGURE 8.—A railroad float ferrying carloads of oranges across the Hudson River from Jersey City, N. J., to New York City.

are flat barges with 2 tracks which have space for 14 to 16 cars, and are towed across the river by tugs.

The fruit in the test cars, with the exception of the experimental lots, was sold at auction by the consignee on the day after unloading. Following is the usual practice in the unloading and auctioning of oranges: The fruit is "trucked" from the car to the pier warehouse by stevedores, where it is stacked in lots according to brands and sizes and displayed as illustrated in figure 9. The auction company catalogs each lot and furnishes each buyer with a complete list of the varieties, grades, sizes, and brands of the fruit to be sold. The buyers may inspect the fruit, making notes as to the condition of each lot. The auction sale occurs the morning after unloading in a separate room from that in which the fruit is displayed, and the buyers depend entirely upon their notes when bidding.

RESULTS AND DISCUSSION

SOURCES OF HEAT

In the refrigeration of perishable commodities in transit there are four sources of heat to be reckoned with, namely, field heat, vital heat, internal heat of car, and heat leakage. A consideration of each of these is necessary to obtain a clear understanding of the refrigeration and ice-meltage data.

FIELD HEAT

The heat contained in the load as indicated by its temperature is referred to as "field" or sensible heat. It is calculated by multiplying the specific heat of the lading by the weight of the lading times the degrees of actual cooling. In considering the field heat it should be noted that the standard orange load consists of approximately 34,000 pounds of fruit, 3,350 pounds of wood, and 350 pounds of paper wraps. In this bulletin the field heat was calculated sepa-

FIGURE 9.—An auction display of California oranges on Erie Pier 21, New York City.

rately for the fruit, wood, and paper, and the sum of these separate items constitutes the total field heat of the load.

Investigators are not agreed as to the correct value for the specific heat of oranges and other fruits and vegetables. Rose [10] suggested

[10] Personal correspondence.

that in the absence of actual measurements probably the best method of calculating the specific heat is by using Siebel's (*16*) formula which takes into consideration the moisture content of the fruit. Siebel's formula is

$$S=0.008a+0.20$$

in which S is the specific heat of a substance containing a percent of water; 0.2 is the value which has been uniformly assumed to represent the specific heat of the solid constituents of food products.

The moisture content of oranges (no variety specified) as determined by Chatfield and McLaughlin (*2*) and generally accepted is 87.2 percent. Using this in the formula we have

$$S=0.008\times 87.2+0.2=0.8976, \text{ or practically } 0.9.$$

The specific heat of spruce wood, according to Dunlap (*3*), is 0.332, which was used as the specific heat of the wood in orange boxes.

Hodgman and Lange (*7*) give 0.37 as the specific heat of dry cellulose. This was used as the specific heat of the orange wraps, as they were considered to be composed largely of cellulose.

VITAL HEAT

As pointed out by Hawkins (*6*), in cooling nonliving commodities such as meats and fish, the amount of heat in the commodity can be calculated from the specific heat of that commodity; but in cooling living plants or parts of plants, such as a fruit, there is another factor to be reckoned with in addition to specific heat. Fruit stored or transported evolves heat which under adiabatic conditions raises its temperature. Gore (*4*) discusses the causes of this self-heating and concludes that the physiological processes involved in respiration are in general the cause of self-heating. This process of respiration in California oranges, according to Haller et al. (*5*), is due to the oxidation of sugar into CO_2 and water when held at a temperature of 50° to 70° F., and to oxidation of acid when held at 32°. The heat derived from the respiration of the fruit is termed "vital heat" (Hawkins (*6*)). The rate of its release varies with the temperature, and in this study particularly it must be taken into consideration.

Figures presented in this bulletin for vital heat liberated from oranges by respiration were calculated from CO_2 determinations made on both the Washington Navel (*5*) and Valencia [11] varieties by Haller during 1931 and 1932. These calculations for vital heat are approximate. They are based on the best information available and will serve to give an indication of the heat evolved by oranges under refrigeration in transit until better figures are available.

HEAT LEAKAGE PLUS INTERNAL HEAT OF CAR

Heat leakage refers to an infiltration of heat from the outside into the refrigerated space, and internal heat of car refers to the sensible heat contained in the insulation, inside lining, and inside

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[11] HALLER, M. H. RESPIRATION OF CALIFORNIA VALENCIA ORANGES. Unpublished data. 1932.

air of car before refrigeration begins. Sufficient data were not secured on the cars in this investigation to measure these two sources of heat separately, but the total for both is determined by subtracting the sum of field and vital heat from the total heat absorbed by the refrigerant. It is probable that the internal heat of the car is dissipated by ice meltage during the first day, making "heat leakage plus internal heat of car" relatively high that day. For the remainder of the transit period the figure given for the combination of the two is largely heat leakage.

THERMAL RELATIONS

The results of the test 1932-4, conducted in May 1932, are used to show approximately the relative amounts of the above-named sources of heat under different methods of refrigeration. Four standard Santa Fe refrigerator cars that had been in active service for 1 year were used. Insulation in each consisted of 2 inches of Insulite in the sides and ends; 2½ inches of Insulite in the roof, and 1 inch of Insulite plus 2 inches of cork in the floors. The four cars were adjacent to each other in the train. The mean atmospheric temperature during this test was 63° F.

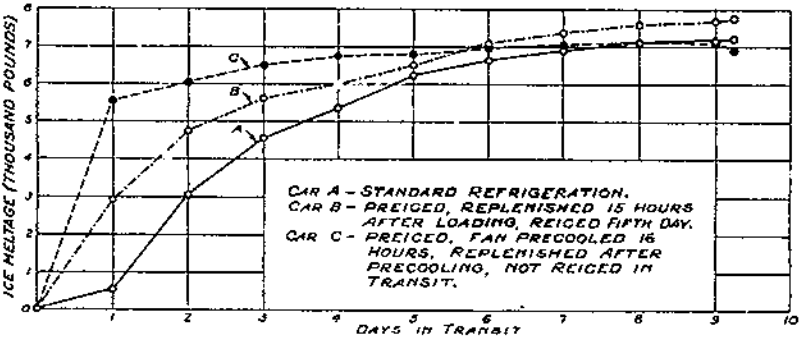

FIGURE 10.—Field heat removed from load (expressed by ice meltage) during transit, May 10–20, 1932.

The loading temperature of the fruit and methods of refrigeration were as follows:

Car A.—72° F., fruit loaded in dry car and moved under standard refrigeration.

Car B.—75° F., fruit loaded in preiced car, replenished by shipper on second day, reiced once in transit by carrier at Clovis, N. Mex., on fifth day.

Car C.—74° F., fruit loaded in preiced car, precooled 16 hours with portable fans in car immediately after loading, replenished by shipper after precooling, and not reiced in transit.

Car E.—Fruit precooled to 37.5° F. in warehouse before loading, loaded in preiced car (block ice), and not reiced in transit.

The field heat, expressed in pounds ice meltage, absorbed from the loads of cars A, B, and C during 9¼ days in transit are shown in table 5 and figure 10. The field heat down to 37.5° was removed from car E before loading and none was removed while in transit.

An examination of the data reveals that while the total amount of field heat removed from each of cars A, B, and C was about the same, there was a significant difference in the time required for its removal. In car A, under ventilation for the first 23 hours en route to the first icing station, only 9 percent of the total field heat was removed during the first day, whereas in car B, due to preicing, 40 percent was removed during the first day, and in car C, preiced and fan precooled, 80 percent was removed. This early heat removal in cars B and C shows that those methods of refrigeration were superior to that in car A because, as pointed out by Powell (*13*), decay in oranges develops most rapidly during the first few days in transit when the fruit is warm, and it is during this period that refrigeration is most necessary.

TABLE 5.—*Temperature drop and ice-meltage equivalent of field heat absorbed during 9¼-day transit period, test 1932–4, May 10–20*

Days in transit	Car A[1]		Car B[2]		Car C[3]	
	Total temperature drop	Field heat absorbed	Total temperature drop	Field heat absorbed	Total temperature drop	Field heat absorbed
	° F.	*Pounds ice meltage*	° F.	*Pounds ice meltage*	° F.	*Pounds ice meltage*
1	2.3	510	13.5	2,996	24.9	5,525
2	13.9	3,084	21.3	4,720	27.2	6,036
3	20.4	4,527	25.3	5,614	29.3	6,502
4	24.2	5,370	27.0	5,991	30.4	6,746
5	28.0	6,213	29.3	6,502	30.7	6,812
6	29.9	6,635	32.0	7,101	31.4	6,967
7	31.1	6,901	33.3	7,389	31.8	7,056
8	32.1	7,123	34.2	7,589	31.6	7,125
9	32.4	7,189	34.7	7,700	31.6	7,125
9¼	32.5	7,212	35.0	7,766	31.3	6,945

[1] Standard refrigeration.
[2] Preiced, replenished 15 hours after loading, reiced on fifth day.
[3] Preiced, fan precooled 16 hours, replenished after precooling and not reiced in transit.

During the next few days field heat absorption was more rapid in car A than in cars B and C, but during the remainder of the trip heat absorption was very slow in all three cars.

The daily mean fruit temperature and the vital heat liberated expressed in pounds of ice meltage in each of the four cars are presented in table 6. These figures for vital heat were calculated from CO_2 determinations made on California Valencia oranges in 1932 by Haller[12]. A study of these results reveals that respiration of oranges when loaded at high temperatures may be considered a significant factor in refrigeration. Vital heat liberated in car A during the first day, as calculated from Haller's figures, was sufficient to melt 467 pounds of ice. The temperature of the fruit at loading was 72.5° F., whereas during summer months fruit temperature at loading often varies between 80° and 90°, which would, of course, increase considerably the vital heat to be contended with.

Precooling the fruit before loading greatly reduces the rate of respiration. In car E, fruit temperature 37.8° F. at time of loading, the vital heat during the first day represented a meltage of 115 pounds of ice. Thus during the first day the increased vital heat in car A over car E was equivalent to 352 pounds of ice meltage.

[12] HALLER, M. H. See footnote 11.

TABLE 6.—*Daily mean fruit temperature and rate of liberation of vital heat as expressed in ice meltage, test 1032–4, May 10–20*

Time in transit	Car A[1]		Car B[2]		Car C[3]		Car E[4]	
	Mean fruit temperature	Vital heat	Mean fruit temperature	Vital heat	Mean fruit temperature	Vital heat	Mean fruit temperature	Vital heat
	°F.	*Pounds ice meltage*	°F.	*Pounds ice meltage*	°F.	*Pounds ice meltage*	°F.	*Pounds ice meltage*
First day	72.1	467	66.3	397	55.1	312	38.2	115
Second day	63.2	397	56.5	312	47.8	297	39.1	115
Third day	55.1	312	50.8	297	45.7	206	39.4	115
Fourth day	50.0	207	48.3	297	44.4	206	39.7	115
Fifth day	46.3	206	46.5	206	43.5	206	39.9	115
Sixth day	43.5	206	43.8	206	43.0	206	39.7	115
Seventh day	42.0	115	41.9	115	42.5	206	39.7	115
Eighth day	40.9	115	40.8	115	42.5	115	39.9	115
Ninth day	40.4	115	40.1	115	42.6	206	40.1	115
Additional ¼ day	40.2	29	40.0	29	42.7	51	40.5	29
Total or average 9¼ days	50.1	2,259	48.1	2,089	45.2	2,011	39.5	1,064

[1] Standard refrigeration.
[2] Preiced, replenished 15 hours after loading, reiced on fifth day.
[3] Preiced, fan precooled 10 hours, replenished after precooling, and not reiced in transit.
[4] Warehouse precooled fruit, preiced only.

The vital heat liberated in car A for 9¼ days in transit was sufficient to melt 2,259 pounds of ice, equivalent to a temperature change in the load of about 10° F. Vital heat was sufficient to melt 2,089 pounds of ice in car B; 2,011 pounds in car C; and 1,064 pounds in car E.

These results show that precooling saves considerable refrigeration that would ordinarily be required to counteract the heat of respiration if the fruit were loaded at a higher temperature.

After field heat and vital heat are accounted for, the remaining heat absorbed by the refrigerant is heat leakage plus internal heat of car. In the case of cars A, B, and C, the refrigerant is ice in the bunkers. However, in the case of car E, the precooled load as well as the ice in the bunkers acts as the refrigerant. Heat absorbed by the load is calculated from the specific heat of the fruit, wood, and paper. The ice in the bunkers absorbs a small amount of heat before melting if supplied to the cars at a temperature below melting point (32° F.), but the greater part of refrigeration derived from the ice is by meltage.[13] Although slight, the refrigeration secured from low-temperature ice should be taken into consideration. The amount of ice supplied each of the four cars, the amount of chilling of the ice, and the heat absorbed by the ice before melting are given in table 7.

A summary of calculations for field heat, vital heat, and heat leakage plus internal heat of car during the 9¼-day period in transit is given in table 8.

[13] According to Moyer and Fitts (*10*) the melting of 1 pound of ice absorbs 143.5 B. t. u.

TABLE 7.—*Heat absorbed by low-temperature ice, test 1932–4, May 10–20*

Icing station	Car A[1]			Car B[1]			Car C[1]			Car E[1]		
	Ice supplied	Amount of chilling below melting point	Heat absorbed by ice before melting	Ice supplied	Amount of chilling below melting point	Heat absorbed by ice before melting	Ice supplied	Amount of chilling below melting point	Heat absorbed by ice before melting	Ice supplied	Amount of chilling below melting point	Heat absorbed by ice before melting
	Pounds	° *F.*	*B. t. u.*	*Pounds*	° *F.*	*B. t. u.*	*Pounds*	° *F.*	*B. t. u.*	*Pounds*	° *F.*	*B. t. u.*
Orange, Calif.										15,300	4.0	30,600
San Bernardino, Calif.	12,133	7	42,466	11,883	7	41,590	11,917	7	41,709			
Placentia, Calif.							2,100	0	0			
Do.				3,600	4	7,200	6,000	4	12,000			
Needles, Calif.	1,356	5	3,390									
Winslow, Ariz.	1,786	7	6,250									
Belen, N. Mex.	1,495	3.5	2,617									
Clovis, N. Mex.	487	1.5	365	7,510	1.5	5,633						
Waynoka, Okla.	899	1	449									
Argentine, Kans.	1,538	.5	384									
Corwith, Ill.	1,798	1	899									
Marion, Ohio.	1,004	2.5	1,255									
Hornell, N. Y.	687	1.5	515									
Total heat absorbed by ice before melting			58,590			54,423			53,709			30,600
Ice-meltage equivalent (pounds)			408			379			374			213

[1] See footnotes to table 8.

TABLE 8.—*Thermal relations under different methods of refrigeration during 9¼-day period in transit, test 1932–4, May 10–20*

Item	Car A [1]	Car B [2]	Car C [3]	Car E [4]
Mean outside temperature during 9¼ days in transit ° F	63.0	63.0	63.0	63.0
Average fruit temperature at loading ° F	72.5	75.0	74.0	37.5
Average fruit temperature at end of 9¼ days ° F	40.0	40.0	42.7	40.5
Change in fruit temperature during 9¼ days ° F	−32.5	−35.0	−31.3	+3.0
Heat absorbed by load (fruit, wood, and paper) B. t. u.	----------	----------	----------	95,526
Field heat removed from load (fruit, wood, and paper) B. t. u.	1,034,865	1,114,470	996,655	----------
Vital heat liberated by fruit B. t. u.	323,867	299,557	288,443	152,218
Total field and vital heat removed from load B. t. u.	1,358,732	1,414,027	1,285,098	----------
Ice meltage during 9¼ days pounds	13,180	16,390	17,000	8,800
Heat absorbed by ice before starting to melt (table 7) B. t. u.	70,308	65,307	64,451	38,720
Heat absorbed by ice meltage B. t. u.	1,891,330	2,351,965	2,439,500	1,262,800
Total heat absorbed by ice plus ice meltage B. t. u.	1,961,638	2,417,272	2,503,951	1,299,520
Heat leakage plus internal heat removed from car B. t. u.	[5] 602,906	[5] 1,003,245	[5] 1,218,853	[6] 1,242,828
Ice meltage equivalent of heat leakage plus internal heat removed from car pounds	4,201	6,991	8,493	8,661

[1] Standard refrigeration.
[2] Preiced, replenished 15 hours after loading, and reiced on fifth day.
[3] Preiced, fan precooled 16 hours, replenished after precooling, not reiced in transit.
[4] Warehouse precooled fruit, preiced only.
[5] Derived by subtracting total field and vital heat from total heat absorbed by ice and ice meltage.
[6] Derived by subtracting vital heat from sum of heat absorbed by load, ice, and ice meltage.

It is noted from this table that instead of a lowering in temperature of the load of car E, there was a slight rise. This increase was caused by a combination of heat leakage and the vital heat liberated by the fruit; however, it is impossible to determine from the data at hand which source of heat had the greater effect. As shown in table 8, the heat absorbed by the load was small in comparison with that absorbed by ice meltage. There is no doubt but that most of the heat leakage and a good portion of the vital heat was absorbed by ice meltage.

Heat leakage plus internal heat of car was greatest in cars C and E, next in car B, and least in car A. Since the four cars moved east in the same train and were subject to the same atmospheric temperatures, the difference is explained by the various methods of refrigeration used and in the fruit temperatures maintained.

The 9¼-day period the cars were in transit began at time of loading. Car A was not iced until arrival at San Bernardino, 23 hours after loading; car E was initially iced 6 hours prior to loading, car C 16½ hours prior to loading, and car B, 22 hours prior to loading. This means that car E was under refrigeration and subject to heat leakage from outside air 29 hours longer than car A, car C, 39½ hours longer than car A, and car B, 45 hours longer.

With preiced cars heat leakage is further increased by the necessity of opening the doors for loading. The doors were open 4 hours during loading of cars B and C, and the atmospheric temperature during this period ranged from 62° to 75° F. In loading car E an effort was made to prevent a loss of refrigeration through open doors by installing a canvas tunnel from the car door to the corridor of the precooling plant through which fruit was transferred from the precooling rooms. (Fig. 29.)

Another factor which affects heat leakage is the difference between temperatures inside and outside of the cars. In this test the mean outside temperature was 63° F., whereas the mean inside temperature of car A was 50°, car B, 48°, car C, 45°, and car E, 40°. Heat leakage was less in car A, which had the least difference between inside and outside air temperatures, and was the greatest in car E which had the greatest difference between inside and outside temperatures. All the above-mentioned factors contributed to heat leakage occurring in those cars.

A comparison of the refrigeration in pounds of ice meltage required to absorb the field heat, vital heat, and heat leakage plus internal heat of car of the four cars is presented in figure 11.

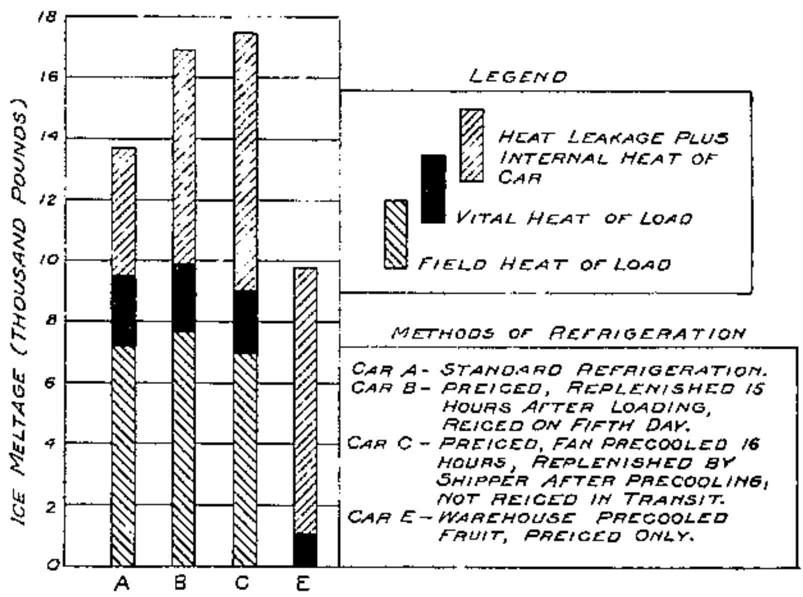

FIGURE 11.—Refrigeration required for absorption of field heat, vital heat, and heat leakage plus internal heat of car during 9¼ days in transit.

Removal of field heat from the load was the greatest item to be taken care of in the refrigeration of car A. In car B field heat and the combination of heat leakage and internal heat of the car were nearly equal, while in car C field heat was much less than heat leakage plus internal heat of the car. In car E, since field heat had already been removed from the fruit before loading, heat leakage was the greater. In all instances vital heat required much less refrigeration than did the other sources of heat.

While the above figures for field heat, vital heat, and heat leakage plus internal heat of car represent the condition studied in these specific cars, in this test it is believed that they are typical. However, there are many variable factors which influence the refrigeration of oranges. A discussion of the effect of outside temperatures, fruit temperatures at loading, and method of stacking fruit in car on the refrigeration of oranges follows.

EFFECT OF OUTSIDE TEMPERATURES ON REFRIGERATION OF ORANGES IN TRANSIT

In studying this problem comparable shipments of oranges under the same method of refrigeration in cars of similar construction and insulation were forwarded to New York at different seasons of the year. Fruit temperatures inside the cars and outside air temperatures were taken at frequent intervals en route in order to determine the effect of the temperature of the surrounding atmosphere on the refrigeration secured in the load. This phase of the work was conducted with nonprecooled fruit under standard refrigeration, precooled fruit initially iced only, and precooled fruit loaded in a dry car with vents closed during transit.

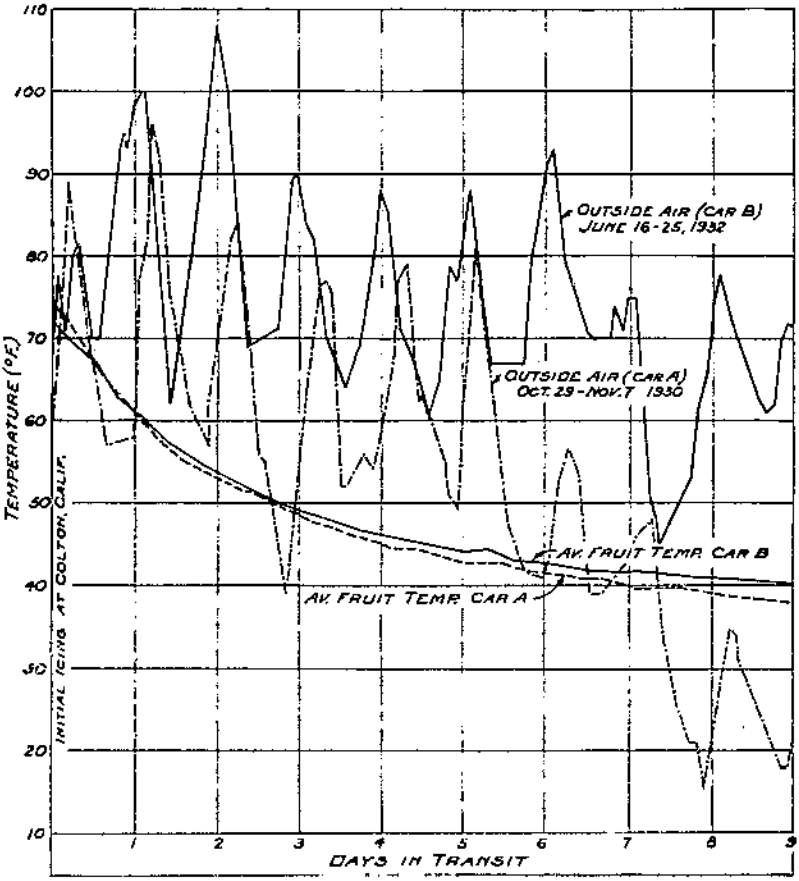

FIGURE 12.—Effect of atmospheric temperatures on those of fruit shipped nonprecooled under standard refrigeration.

NONPRECOOLED FRUIT UNDER STANDARD REFRIGERATION

The results of two standard Pacific Fruit Express refrigerator cars insulated with 1½-inch Hairinsul plus ¾-inch Celotex in the sides and ends, 2 inches Hairinsul plus ⅜-inch Celotex in the roof, and 2 inches Hairinsul plus ½-inch Celotex in the floor may be cited as typical. Both cars were loaded with 462 boxes of nonprecooled fruit that varied not more than 2° in temperature. Car A moved under standard refrigeration in November (test 1930–5), and car B was forwarded under standard refrigeration in June (test 1932–5).

A comparison of fruit temperatures maintained in the two cars during transit and of the surrounding atmospheric temperatures is shown graphically in figure 12.

The data show that with warmer outside air there was an average of only 0.5° F. per day slower rate of cooling, resulting in slightly higher fruit temperatures at the end of the trip. However, this situation was not always consistent for each day, as in the cases of the third and sixth days of transit when car B showed more cooling than car A. Such discrepancies are to be expected in tests of this kind, since the refrigerator car is a rather large and rough instrument to use for exact experimental work. Even though two cars may be of similar construction, differences are bound to occur, as the cars are built for commercial purposes and not for laboratory tests. The best that can be said of the evidence presented is that. considering the entire period of the test, higher atmospheric temperatures seemed to retard cooling to a slight extent, but the significance of this reduced cooling in the transportation of oranges is doubtful.

Accompanying the lesser lowering of fruit temperature of car B during the 9 days there were 2.960 pounds, or 23 percent greater, ice meltage (table 9). Thus it appears that with an average of 20.6° higher outside temperature there was excessive ice meltage in car B, but less heat was absorbed from the load than in car A. The heat leakage plus internal heat of car as calculated in table 9 was 538,785 B. t. u., or 143 percent greater in car B than in car A. Since the variable factor for comparison was the difference in the temperature of the surrounding atmosphere, this 143 percent increase in heat leakage apparently was caused by the higher outside temperature. This increase in heat leakage in addition to causing more ice meltage was also the cause of the reduced cooling of the load in car B. The ice in the bunkers could not melt fast enough to absorb the additional heat leakage and still absorb the same amount of field heat and vital heat from the load as when the outside temperatures were lower with consequently less heat leakage.

TABLE 9.—*Effect of outside temperature on thermal relations, nonprecooled load, standard refrigeration, 9-day transit period*

Item	Car A, test 1930–5 (Oct. 29–Nov. 7)	Car B, test 1932–5 (June 16–25)	Difference (car A minus car B)
Mean outside temperature during 9 days in transit ° F.	53.5	74.1	−20.6
Average fruit temperature at time of initial icing at Colton ° F.	74.5	72.3	+2.2
Average fruit temperature 9 days later ° F.	38.0	40.2	−2.2
Drop in fruit temperature during 9 days ° F.	36.5	32.1	+4.4
Field heat removed from load (fruit, wood, paper) B. t. u.	1,162,233	1,022,128	+140,105
Vital heat liberated by fruit B. t. u.	269,263	295,443	−26,180
Total field and vital heat removed from load B. t. u.	1,431,496	1,317,571	+113,925
Ice meltage during the 9 days pounds	12,600	15,560	−2,960
Heat absorbed by ice meltage B. t. u.	1,808,100	2,232,860	−424,760
Heat leakage plus internal heat removed from car B. t. u.	376,504	915,289	−538,785
Ice meltage equivalent of heat leakage plus internal heat removed from car pounds	2,624	6,378	−3,754

PRECOOLED FRUIT

Four cars of oranges precooled to 35° F. were forwarded to New York City, two cars (C and D) in test 1929–7 (August-September), and two cars (H and K) in test 1931–2 (March). One car in each test, D in 1929–7 and H in 1931–2, was preiced only in California with block ice, while the other car of each test, C in 1929–7 and K in 1931–2, was forwarded without ice and with vents closed.

The four cars were of standard Santa Fe refrigerator-car construction and had the same thickness of insulation. However, the type of insulation varied as follows:

Car C, 2 inches Insulite in sides and ends, 2½ inches Hairinsul in roof; and 2 inches cork in floor.

Car D, same as car C.

Car H, 2 inches Flaxlinum in sides and ends, 2½ inches hair felt in roof, and 2 inches cork in floor.

Car K, 2 inches Flaxlinum in sides and ends, 2½ inches Hairinsul in roof, and 2 inches cork in floor.

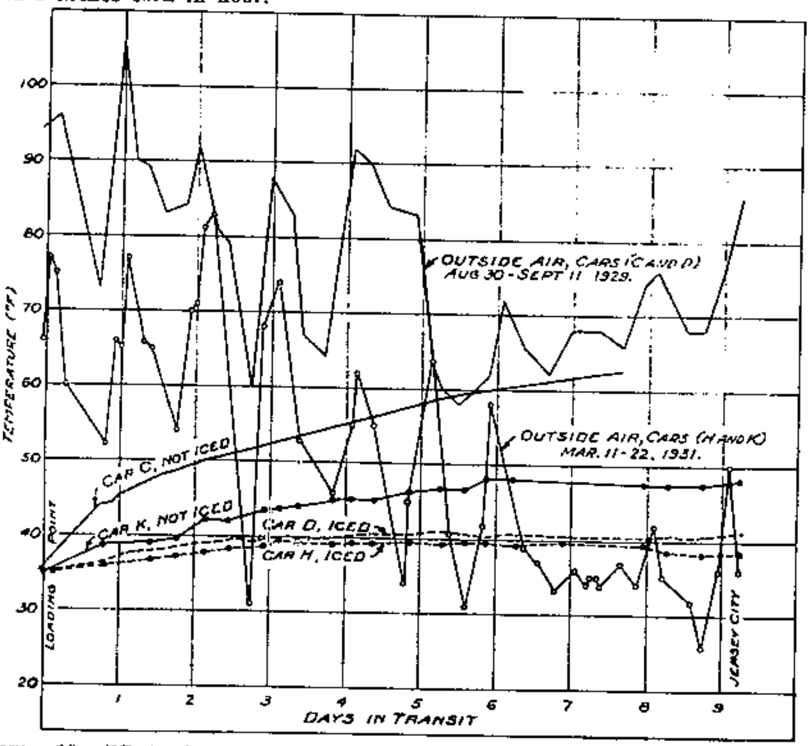

FIGURE 13.—Effect of atmospheric temperatures on those of precooled fruit shipped with ice (preiced only) and without ice (vents closed).

While all of the cars were not strictly comparable as to type of insulation, the differences are not considered significant enough to preclude the use of the results.

A graph showing average fruit temperatures in each of the four cars and the outside temperatures during each test is presented in figure 13. The effects of outside temperatures under each method of refrigeration will be discussed before comparing refrigeration secured by the two methods.

PRECOOLED FRUIT, PREICED ONLY

An examination of the results presented in figure 13 for cars D and H, both precooled and preiced but subjected to different outside temperatures, reveals that in the warmer weather the rise in fruit temperature was approximately one-third greater than in the cooler weather; however, this situation was not consistent for each day in transit. Heat leakage into the car may be so slow that the heat of 1 day does not affect the load till sometime later, which tends to reduce the significance of the daily comparisons, yet it can hardly be doubted that the more rapid rise in fruit temperature of car D during the second day was due to the extremely warm surrounding atmosphere of that day (fig. 13). It may also be pointed out that the drop in fruit temperature in car H during the eighth and ninth days was in all probability due to the low outside temperature during that period.

The effect of outside temperatures on the refrigeration of oranges in transit is most strikingly brought out by comparing the amounts of ice melted in the two cars. Referring to the results presented in table 10 it will be noted that during the 9¼-day transit period 7,500 pounds of ice were melted in car D and only 4,500 pounds in car H. At the same time car D showed 2.8° greater rise in average temperature of the load. The greater ice meltage and greater rise in average temperature of the load reflect the influence of higher outside temperatures. These results are similar to those secured with standard refrigeration except that under the latter ice meltage was greater.

TABLE 10.—*Effect of outside temperature on thermal relations, precooled load, preiced only, 9¼-day transit period*

Item	Car D, test 1929-7 (Aug. 30-Sept. 11)	Car H, test 1931-2 (Mar. 11-22)	Difference
Mean outside temperature during 9¼ days ° F	75.9	49.4	26.5
Average fruit temperature at loading ° F	35.0	35.0	.0
Average fruit temperature after 9¼ days ° F	41.3	38.5	2.8
Rise in fruit temperature during 9¼ days ° F	6.3	3.5	2.8
Heat absorbed by load (fruit, wood, and paper) B. t. u.	300,605	111,447	189,158
Vital heat liberated by fruit B. t. u.	[1] 146,387	[2] 209,100	62,713
Ice meltage during 9¼ days pounds	7,500	4,500	3,000
Heat absorbed by ice meltage B. t. u.	1,076,250	645,750	430,500
Heat leakage plus internal heat removed from car B. t. u.[3]	1,230,468	548,097	682,371
Ice meltage equivalent of heat leakage plus internal heat removed from car pounds	8,574	3,819	4,755

[1] Based on Haller's (unpublished data) CO_2 determinations for California Valencia oranges, as car D was loaded with Valencias.
[2] Based on Haller et al. (5) CO_2 determinations for California Washington Navel oranges, as car H was loaded with Washington Navels.
[3] Calculated by subtracting vital heat from the sum of heat absorbed by load and by ice meltage.

Calculations of internal heat of car plus heat leakage removed from cars D and H during the 9¼ days in transit are found in table 10. These calculations show that this amount of heat was 682,371 B. t. u., or 124 percent greater in car D than in car H. Assuming that the two cars were identical in all respects, this greater amount of heat leakage in car D was caused by the considerably higher outside temperature.

Precooled Fruit Shipped in a Dry Car with Vents Closed

An analysis of the temperature data of cars C and K, and calculations of heat absorbed by the load, vital heat, and heat leakage are found in table 11. It is possible in this instance to calculate the daily rate of increase in heat leakage plus removal of internal heat of car, since no ice meltage was involved. All heat leakage and internal heat of the car was absorbed by the load. In test 1929-7 car C was diverted to Cincinnati, Ohio. The thermometer equipment was removed from that car at Marion, Ohio, at the end of the eighth day, since the remainder of the cars of that test continued to New York City. Therefore, it is necessary to limit the discussion of this method of transportation to an 8-day period.

Table 11.—*Effect of outside temperature on thermal relations, precooled load, dry car with vents closed, 8-day transit period*

[Car C, fruit precooled to 35° F., test 1929-7, Aug. 30-Sept. 11; car K, fruit precooled to 35° F., test 1931-2, Mar. 11-22]

Time in transit (days)	Mean outside temperature			Mean fruit temperature			Difference between fruit and outside temperature		Rise in fruit temperature [1]		
	Car C 1929-7	Car K 1931-2	Difference	Car C 1929-7	Car K 1931-2	Difference	Car C	Car K	Car C 1929-7	Car K 1931-2	Difference
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1	88.7	60.6	28.1	41.6	37.3	4.3	47.1	23.3	11.4	4.0	7.4
2	87.9	65.5	22.4	47.8	39.5	8.3	40.1	26.0	3.3	2.3	1.0
3	76.3	59.9	16.4	51.1	42.5	8.6	25.2	17.4	2.6	2.3	.3
4	74.6	55.2	19.4	53.9	44.4	9.5	20.7	10.8	2.7	1.5	1.2
5	85.6	50.1	35.5	56.6	45.5	11.1	29.0	4.6	3.1	1.3	1.8
6	61.2	46.7	14.5	59.3	47.0	12.3	1.9	.3	2.0	1.6	.4
7	66.0	39.3	26.7	61.0	48.0	13.0	5.0	8.7	1.6	-.2	1.8
8	69.0	35.5	33.5	62.5	47.0	14.9	6.5	12.1	1.4	-.4	1.8
Total									28.1	12.4	15.7
Average	76.2	51.6	24.6	54.2	44.0	10.2	22.0	7.6	3.5	1.6	1.9

Time in transit (days)	Heat absorbed by load		Vital heat liberated by fruit		Heat leakage plus internal heat removed from car		
	Car C 1929-7	Car K 1931-2	Car C [2] 1929-7	Car K [3] 1931-2	Car C 1929-7	Car K 1931-2	Difference
	B.t.u.	B.t.u.	B.t.u.	B.t.u.	B.t.u.	B.t.u.	B.t.u.
1	362,099	127,368	16,456	18,768	346,543	108,600	237,943
2	108,079	73,237	42,636	23,664	65,443	49,573	15,870
3	82,789	73,237	42,636	37,128	40,153	36,109	4,044
4	85,973	47,763	44,795	37,128	41,178	10,635	30,543
5	98,710	41,395	44,795	37,128	53,915	4,267	49,648
6	63,684	50,947	47,124	37,128	16,560	13,819	2,741
7	50,947	-6,368	47,124	50,592	3,823	-56,960	60,783
8	44,579	-12,737	47,124	50,592	-2,545	-63,329	60,784
Total	897,760	394,842	332,690	292,128	565,070	102,714	462,356
Average	112,220	49,355	41,586	36,516	70,634	12,839	57,795

[1] Difference between temperatures at beginning and end of each day (fig. 13).
[2] Valencia oranges: Calculations based on Haller's (unpublished data) CO_2 determinations for California Valencias.
[3] Navel oranges: Calculations based on Haller et al. (5) CO_2 determinations for California Washington Navels.

In general, the data presented show that the outside temperature during transit has a direct bearing on the fruit temperatures maintained in the car. The warmer outside air during test 1929–7 caused 28.1° rise in average fruit temperature in car C during the 8 days, as compared with only 12.4° rise in car K in test 1931–2. These results show very definitely that the successful use of this method of shipping precooled oranges depends to a considerable extent on favorable outside temperatures en route. Although reasonably safe fruit temperatures were maintained in the March test (1931–2) the fruit temperature became entirely too high in the early fall test (1929–7) when outside temperatures were relatively high. Aside from the influence of these high temperatures in increasing loss from decay, the loss of sugars due to increased respiration doubtless impaired the flavor of the oranges.

An examination of the results in table 11 indicates that several factors may influence the rise in fruit temperatures. In these tests there was a lowering of outside temperature after the first 2 days. This condition, together with the rise of inside temperatures, created a much smaller difference between inside and outside temperatures at the end of the test than occurred during the first half of the trip. This necessarily caused less heat leakage and correspondingly a decreased rise in temperature of the load.

Another factor affecting the results was the vital heat liberated from the load by respiration. As the temperature of the fruit rose, respiration was increased and more vital heat was liberated (table 11), thus directly increasing the rate at which the temperature of the load was raised.

The removal of internal heat of car plus heat leakage in these two cars may be computed by subtracting vital heat from total amount of heat absorbed by the load. The combination of these two sources of heat during the first day was considerably greater than was observed during any of the other 7 days, and in all probability was caused partly by absorption of the internal heat of the car. This points to the advantage of preicing a car to remove this heat before the fruit is loaded.

Data given for heat leakage plus internal heat of car during the remaining 7 days appear to have been essentially heat leakage. This decreased as the trip progressed, depending on the difference between inside and outside temperatures, as has been previously mentioned. The heat leakage which occurred during the sixth day when inside and outside temperatures were practically the same probably means that the heat of the previous day was just finding its way into the load, as previously suggested (p. 34).

The rise in temperature of the load in car C during the last 2 days may be considered for the most part to be due to vital heat, since the difference between inside and outside temperatures during this period was not great enough to cause much heat leakage.

A point to consider in a discussion of the results with car K is the cooling of the load which occurred during the seventh and eighth days. This was undoubtedly caused by a reversal of the heat flow due to the outside temperature being lower during those days than the fruit temperatures inside the car.

As long as the fruit temperatures are above 45° F., as in car K, the heat flow outward is advantageous and desirable. One way of accomplishing this is to open the ventilators when the outside temperatures fall below inside fruit temperatures. In the case of car K considerable heat could have been removed from the load if the ventilators had been open during the last 4 days in transit. This suggests, as pointed out by Mann and Cooper (*9*), that in the shipping of precooled oranges in dry cars during cool weather, as in February and March, better results can be secured by closing the vents during the first part of the trip when outside temperatures are likely to be considerably higher than the fruit temperatures, and opening them during the latter part of the trip when outside temperatures are likely to be considerably lower than the fruit temperatures.

An examination of figure 13 leaves little doubt that much lower temperatures can be maintained in the shipping of precooled oranges if the car is iced than if a dry car is used; however, the cost of the icing and the expense for hauling it must be considered. The results with car K indicate that under conditions similar to those encountered in test 1931–2 reasonably safe temperatures for oranges of good keeping quality can be secured in transit without the use of ice by utilizing suitable ventilation methods.

EFFECT OF FRUIT TEMPERATURE AT LOADING ON REFRIGERATION OF ORANGES IN TRANSIT

In order to obtain information on this subject carloads of oranges varying only in temperature of the fruit at time of loading were forwarded to New York City at the same time, under the same methods of refrigeration, and in cars of similar construction and insulation. Results of two tests, one with nonprecooled fruit under standard refrigeration and another with precooled fruit preiced only, may be cited as typical.

NONPRECOOLED FRUIT UNDER STANDARD REFRIGERATION

Cars A and B of test 1929–4, under standard refrigeration, were forwarded to New York City in July. The maximum outside temperature during transit was 112° F., minimum, 51°, and the mean 80°. The average temperature of the fruit when loaded in car A was 81.5° and of that in car B, 72.0°. The record of fruit and air temperatures maintained during the 11 days in transit (table 12) shows higher temperatures and a more rapid rate of cooling in car A during the first 5 days, or until the fruit in that car cooled to practically the same temperature as that in car B. No significant difference in either fruit temperatures or rate of cooling occurred during the remainder of the trip.

TABLE 12.—*Effect of the temperature of fruit at time of loading on its temperature in transit under standard refrigeration, test 1929–4, July 6–16*

[Loading temperatures: Car A, 81.5° F.; car B, 72°]

Time in transit (days)	Bottom bunker air temperatures		Mean fruit temperatures		Difference between mean fruit and bottom bunker air temperatures		Degrees of cooling of fruit per day	
	Car A	Car B	Car A	Car B	Car A	Car B	Car A	Car B
	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
1 [1]	55.0	55.0	78.4	70.8	23.4	15.8	9.0	5.0
2	35.0	35.0	64.4	60.7	20.4	25.7	13.3	10.0
3	33.0	34.5	55.1	53.8	22.1	19.3	6.8	6.7
4	33.0	34.0	50.5	48.9	17.5	14.9	3.7	3.1
5	33.0	35.0	47.0	46.3	14.0	11.3	2.4	1.7
6	33.0	34.0	45.6	45.0	12.6	11.0	1.3	1.0
7	33.0	34.0	44.5	43.8	11.5	9.8	1.0	1.2
8	33.0	34.0	43.4	42.7	10.4	8.7	1.2	1.1
9	33.0	34.0	42.7	41.9	9.7	7.9	.4	.7
10	33.0	33.5	41.8	41.1	8.8	7.0	.9	.5
11	33.0	33.5	41.2	40.8	8.2	7.3	.7	.3
Total							40.7	31.3
Average			50.4	48.7			3.7	2.9

[1] Under ventilation 14 hours of first day en route to first icing station, Colton, Calif.

These results indicate that the rate of cooling in transit varies directly with the fruit temperature. Actually, however, rate of cooling depends also upon the difference in temperature between the fruit and the air issuing from the bottom bunker opening. Since, as shown in table 12, the bottom bunker air after the first day remained at a nearly constant temperature (33° to 34° F.), the difference in temperature between fruit and air was changed only by variations in the fruit temperature. The greater temperature difference during the first few days in car A caused the more rapid rate of cooling, but as the temperatures approached those in car B less difference in cooling was observed.

As shown in table 13, the greater drop of 9.4° in average fruit temperature of car A during the 11 days necessitated the removal of 299,314 more B. t. u. field heat and 40,103 more B. t. u. vital heat than was removed from car B. This combination of greater field and vital heat absorption would theoretically require the melting of 2,365 more pounds of ice in car A. Actually car A melted only 2,020 more pounds of ice than car B. The greater heat leakage of 49.547 B. t. u. noted in car B, equivalent to 345 pounds of ice meltage, doubtless occurred early in the trip when the difference in temperature between the outside air and the fruit was from 3° to 8° greater in car B than in car A.

This lesser ice meltage resulting from the low fruit temperature at loading is of considerable importance in the transportation of nonprecooled fruit under limited icing in transit. A low fruit temperature at time of loading is an added insurance that the car will go half way or all of the way across the country, depending on the outside temperatures, without running out of ice. At present some of the orange shippers, in order to secure this lower fruit temperature at loading, pick the fruit very early in the morning when the outside air is cool rather than later in the day when the outside air is considerably warmer. However, if it has been necessary to pick the fruit during the warmer part of the day considerable field heat can be removed before loading by holding the fruit in lug boxes overnight in a cool part of the packing house.

TABLE 13.—*Effect of the temperature of the fruit at time of loading on thermal relations, nonprecooled load, standard refrigeration, 11-day transit period, test 1929–4, July 6–16*

[Loading temperatures: Car A, 81.5° F.; car B, 72°]

Item	Car A	Car B	Difference
Average fruit temperature end of 11 days ° F.	40.8	40.7	0.1
Drop in fruit temperature during 11 days ° F.	40.7	31.3	9.4
Mean outside temperature during 11 days ° F.	80	80	0
Total field heat removed from load (fruit, wood, paper) B. t. u.	1,295,969	996,655	299,314
Vital heat liberated by fruit B. t. u.	409,088	368,985	40,103
Total field and vital heat removed B. t. u.	1,705,057	1,365,640	339,417
Ice meltage during 11 days pounds.	21,970	19,950	2,020
Heat absorbed by ice meltage B. t. u.	3,152,695	2,862,825	289,870
Heat leakage plus internal heat removed from car B. t. u.[1]	1,447,638	1,497,185	49,547
Ice meltage equivalent of heat leakage plus internal heat removed from car pounds.	10,088	10,433	345

[1] Calculated by subtracting the sum of field and vital heat from heat absorbed by ice meltage.

PRECOOLED FRUIT, PREICED ONLY

The results with cars H and I, loaded with precooled fruit, in test 1929–2, are used to illustrate the effects of fruit temperature at loading on refrigeration in transit. Both cars were newly built and insulated with 1½ inches of hair felt plus ½ inch of Celotex in the

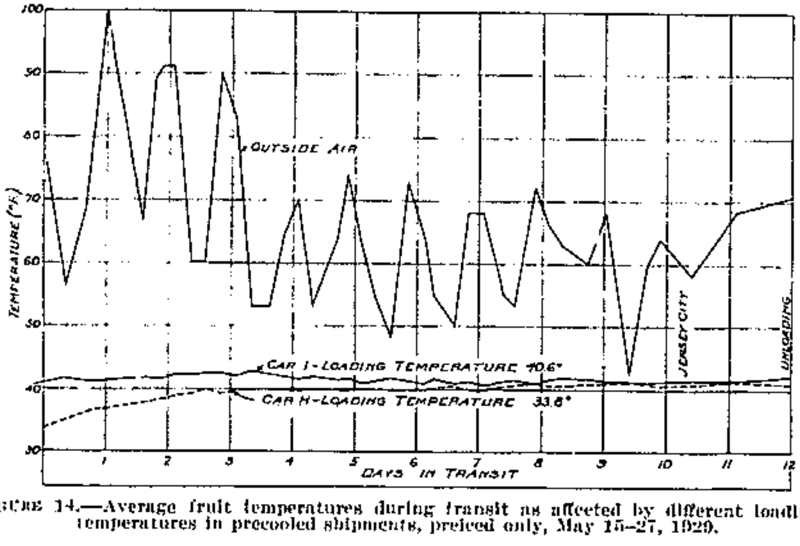

FIGURE 14.—Average fruit temperatures during transit as affected by different loading temperatures in precooled shipments, preiced only, May 15–27, 1929.

sides and ends, and 2 inches of hair felt plus ½ inch of Celotex in the roof and floor. They were preiced with 13,800 pounds of block ice 5 hours prior to loading and forwarded to New York in May.

Car H was loaded with fruit precooled to 33.8° F. and car I with fruit precooled to 40.6°. They were not reiced in transit. The average fruit temperatures maintained during transit and atmospheric temperatures encountered are shown in figure 14.

In car H the temperature rose rapidly to 39.5° F. during the first 3 days, and to 41° (the same as in car I) by the end of the eighth day. There was no significant change in average fruit temperature during transit in car I, and upon unloading in New York the average fruit temperature was 42°, or only 1.4° warmer than at time of loading.

Heat leakage plus internal heat of car, as shown in table 14, was equivalent to 1,726 pounds greater ice meltage in car H than in car I. The greater heat flow from the outside was probably caused by the greater temperature difference between the fruit and outside air (fig. 14). When the block ice in car H failed to melt fast enough to absorb the additional heat leakage the load took up the additional heat, thus causing a rise in temperature. Ice meltage in car I just about kept pace with the heat leakage. The heat absorbed by the load during the first 2 days was later partly absorbed by the ice.

TABLE 14.—*Effect of the temperature of the fruit at time of loading on thermal relations, precooled load, preiced only, 12-day transit period; test 1929-2, May 15–27*

[Loading temperatures: Car H, 33.8° F.; car I, 40.6°]

Item	Car H	Car I	Difference
Average fruit temperature at loading ° F.	33.8	40.6	6.8
Average fruit temperature at end of 12 days ° F.	40.8	41.8	1.0
Rise in fruit temperature during 12 days ° F.	7.0	1.2	5.8
Mean outside temperature during 12 days ° F.	66	66	-------
Heat absorbed by entire load (fruit, wood, paper) B. t. u.	222,894	38,210	184,684
Vital heat liberated by fruit B. t. u.	185,810	197,472	11,662
Ice meltage during 12 days pounds	9,011	8,653	358
Heat absorbed by ice meltage B. t. u.	1,293,079	1,241,706	51,373
Heat leakage plus internal heat removed from car B. t. u.[1]	1,330,163	1,082,444	247,719
Heat leakage plus internal heat removed from car expressed in ice meltage pounds	9,269	7,543	1,726

[1] Calculated by subtracting vital heat from sum of heat absorbed by load and by ice meltage.

These results indicate that refrigerator cars, constructed and insulated as were cars H and I, cannot maintain an average fruit temperature below 40° F. when preiced only with block ice and when encountering atmospheric temperatures similar to those shown in figure 14. Results of other tests show that in warmer weather even temperatures of 42° cannot be maintained during the entire trip in cars with 2½ inches of insulation and which are preiced only. It is doubtful, therefore, whether there is any practical benefit from precooling to a temperature much below 40°. The results of this test indicate that the expense of the added refrigeration secured during the first part of the trip by precooling the fruit to 33.8° was not justified.

EFFECT OF PLACING BULGE AND FLAT SIDE OF BOX AGAINST CAR WALLS

The usual or accepted way of loading oranges is to place the bulge or lid side of one row of boxes against one side wall and the flat side of another row against the other side wall. With the flat side of the box against the side wall there is no space for air circulation; with the bulge side next to the wall only a portion of the surface at the middle touches, and space is therefore left for circulation of air between the box and car wall. In tests 1931–6 and 1931–7 it was found that the temperature of the row of fruit with the bulge side next to the wall was the same as that of the center-line row, but that the temperature of the row with flat side of boxes against the wall was from 5° to 10° warmer than that of the center row or the row on the other side with bulge against the wall.

Since these results indicated that higher temperatures were maintained where boxes were loaded with flat sides against the wall, it was thought that possibly more even temperatures could be held by placing the bulges against the walls on both sides of the car; consequently in test 1932–4 this method was tried. A standard Santa Fe refrigerator car was used. One end (A) was loaded in the usual manner; in the other end (B) the row of fruit usually loaded

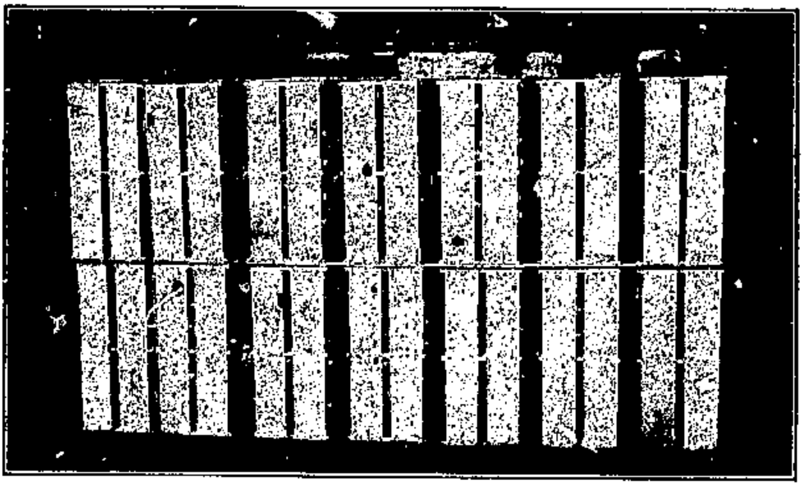

FIGURE 15.—Cross section of orange load showing the improved method of placing boxes in the car; i. e., with bulge side of boxes against either side wall.

with the flat side against the wall was turned around, bringing the bulge side of boxes next to the wall and the flat side against the flat side of the second row from the wall. This method of loading is illustrated in figure 15. Fruit temperatures were secured at quarter-length position in each end of the car and are shown graphically in figure 16. As other tests have shown that quarter-length-position temperature represents that of the major portion of the fruit in that end of the car, temperatures presented in figure 16 can be considered as representative of the performance of the respective methods of loading used in the opposite ends.

Figure 16 reveals that the refrigeration of the B end of the car was far superior to that of the A end. The row of fruit with flat side against the south wall in the A end showed temperatures from 3° to 7° warmer than the center row, while in the B end there was no significant difference in fruit temperatures of the outside and center rows. This occurred in both top and bottom layers. Temperatures taken in the bunker position in the B end showed results similar to those secured at the quarter-length position. Placing the two flat sides of rows 6 and 7 together did not retard refrigeration in those rows, as fruit temperatures taken in these rows were about the same as in the other rows. This indicates that a good circulation of air between the outside row and the wall is of more importance than between the rows of fruit in the center of the load, because in the latter position there is usually only field and vital heat to be removed, but in the outside row there is the heat leakage from the outside in

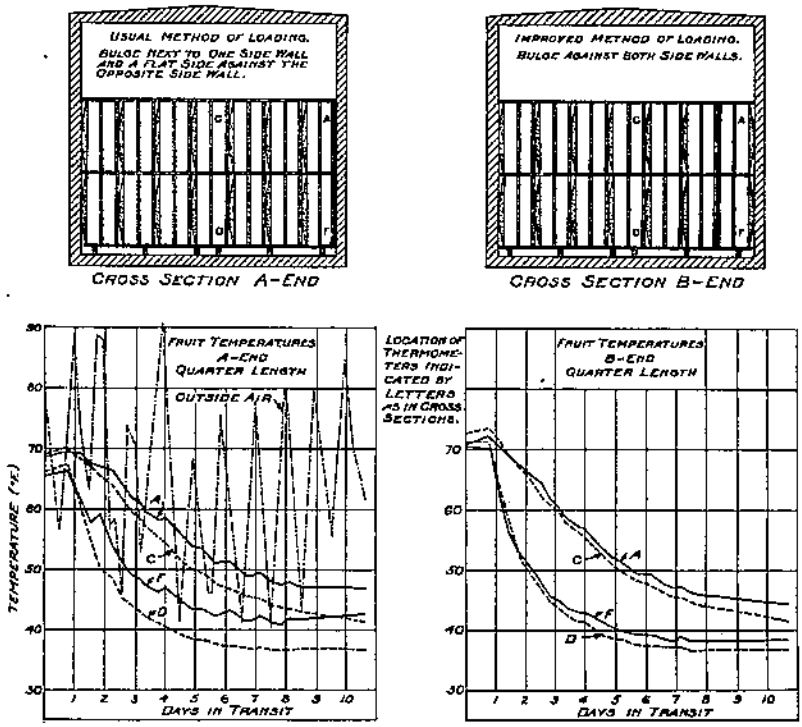

FIGURE 16.—Effect on fruit temperatures of two different methods of stowing boxes of oranges.

addition. If the circulation of air is not sufficient to transfer this heat leakage to the ice in the bunkers it will be absorbed by the outside row of fruit.

The method of loading the bulge side of the boxes against the wall, employed in the B end of this car, was used again in a car under standard refrigeration in test 1932–5 conducted in June 1932. The results obtained were similar to those described in the previous test.

In all cars included in tests conducted in 1931, fruit temperatures were secured at the quarter-length and doorway positions in the center row and in the row next to the south wall. In most instances when the bulge side of the box was against the wall, temperatures in that row were similar to those in the center row, but in all instances when the flat side was next to the wall, fruit temperatures were considerably warmer than the center-row temperatures.

Frequently with boxes of exceptionally high bulge the outside boxes fit so tightly against the wall that the bulge side is so flattened as to leave little space for air circulation. In such cases it was found that higher temperatures were maintained in that row of boxes.

The above results indicate that space for air circulation should be provided between the outside row and car walls and that this can be done by slightly modifying the usual method of loading so that on both sides of the car the bulge of the boxes is placed next to the wall. With other factors equal, this is more important in summer than at other seasons, as heat leakage into the car is greatest then.

REFRIGERATION OF NONPRECOOLED ORANGES IN TRANSIT

TEMPERATURE DIFFERENCES AND ISOTHERMIC LAYERS

Tests 1931–6 and 7 and 1932–4 and 5 were largely concerned with the determination of differences in temperature between side and center, top and bottom, and bunker and doorway, in nonprecooled loads under standard refrigeration and under various methods of limited icing in transit. The difference in temperature from side to center has already been discussed. It was pointed out that if the bulge side is placed against both side walls there will be no very significant temperature difference between the outside and center rows at the bunker, quarter-length, and doorway positions. Therefore, the temperature of the center-line row at any particular position is approximately the correct temperature for all the rows of fruit at that position. With this fact established, the study of difference in temperature between top and bottom and between bunker and doorway was limited to the center-line temperatures.

The results of car B (preiced, replenished on day after loading, and reiced once in transit at Clovis, N. Mex.) in test 1932–4 are cited as rather typical of temperature variations occurring between top and bottom and between bunker and doorway under all methods of limited icing in transit and under standard refrigeration. The slight differences which do occur in temperature variations under the various methods will be discussed after presenting the results of car B.

The standard orange load of two layers of boxes standing on end actually consists of four layers of fruit, since the orange box is divided in the middle by a solid wood partition. A series of graphs showing fruit temperatures during transit for each of the four layers in the first, second, eighth, thirteenth, and seventeenth stacks along the center line of car B is presented in figure 17. It is noted from this figure that rather wide differences in temperature developed in the four layers of fruit at all positions during the first 5 days. The fourth or top layer invariably maintained the highest temperature, the third layer next, the second next, and the first or bottom layer the lowest temperature. These differences between the top and bottom layer temperatures were caused by the fact that as the cold air, issuing from the bottom bunker opening, moved past the bottom layer it absorbed heat from the fruit and became warmer as it rose to the upper layers. Thus the difference in temperature between fruit and air was less in the second layer than in the first; less in the third than in the second, and so on. Since the rate of heat absorption by the cold air varies directly with the temperature difference

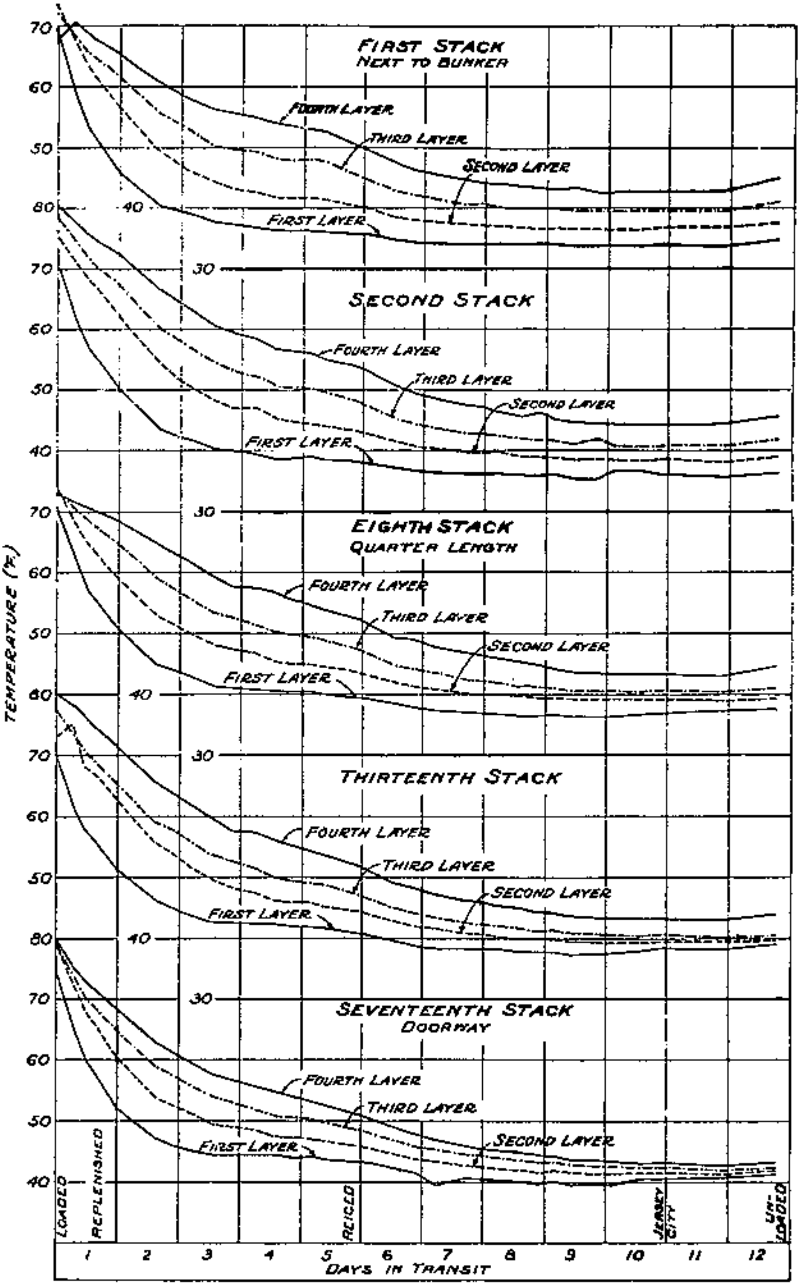

FIGURE 17.—Difference in fruit temperatures from top to bottom, May 10–22, 1932, car B, preiced, replenished, reiced.

between the fruit and air, the rate of cooling was greatest in the bottom layer and least in the top layer. This difference in rate of cooling tended to accentuate the differences in temperature in the four layers of fruit.

As shown in figure 17, after the first 2 days in transit the rate of cooling in the bottom layer slowed down rapidly at all positions, because the temperature difference between the fruit and the air issuing from the bunker became less as the bottom fruit cooled. This in turn retarded the rate of heat absorption. Thus the air reached the upper layers at a lower temperature, thereby increased the rate of heat absorption in those layers over that of the bottom layer and decreased the difference in temperature between the top and bottom layers. This occurred at all positions after about 4 or 5 days, but was first evident and most marked at the doorway position.

The mean temperature of each curve in figure 17 was derived by use of the planimeter and is illustrated in figure 18 for the location in the load where the temperature was secured. In this manner it is possible to obtain a general view of the temperature throughout the load. Figure 18 reveals that with the exception of the bunker

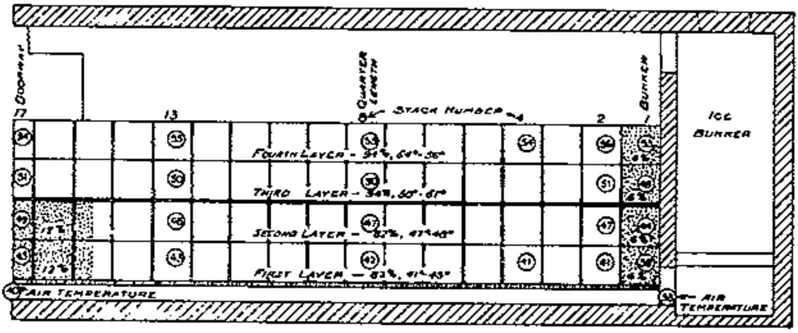

FIGURE 18.—Average fruit temperatures car B during transit, preiced, replenished 15 hours after loading, reiced the fifth day, May 10–22, 1932. Temperatures are shown in the circles which indicate the location of the thermometers along center line of the car.

position there was a marked uniformity in all top-layer temperatures and in all third-layer temperatures. The bunker temperature was found to represent only one stack of fruit, or 6 percent of each layer, since the second stack from the bunker in these two layers had practically the same temperature as the other stacks in those layers.

Fruit in the first and second layers showed a distinct rise in temperature from the bunker to the doorway position; therefore, the differences between top- and bottom-layer temperatures at the various positions were not uniform but were greatest at the bunker and least at the doorway. This lack of uniformity was caused mainly by uneven refrigeration through the bottom layers rather than through the top layers. These results are similar to those reported by Newell and Lloyd (*11*) for carloads of apples and peaches from Illinois under refrigeration.

A further examination of bottom-layer temperatures in figure 18 shows, however, that the bunker temperature of the two bottom layers represented the temperature of only 6 percent of each layer and the doorway temperature only 12 percent. The remaining 82 percent had practically the same temperature as that at the quarter-length position. From these results it may be concluded that the major portion of the orange load in car B was composed of four approximately isothermic layers corresponding to the four layers of fruit. As illustrated in figure 18, the isothermic layers included 94 percent of the fourth layer; 94 percent of the third layer; 82 percent of the second layer; and 82 percent of the first layer.

Temperature differences under standard refrigeration and under the various methods of limited icing in transit showed no marked variation from those observed in car B except in degree of difference between top and bottom. Because of this difference both top- and bottom-layer fruit temperatures are presented when comparing results of the various methods of refrigeration. The temperature at the center-line quarter-length position is used in each instance to represent the temperature of the respective layers because under all methods, as in car B, the average temperature of each layer was found to be near that obtained at the quarter-length position.

STANDARD REFRIGERATION

Since prior to these investigations standard refrigeration service was used by practically all orange shippers for nonprecooled fruit, it seems desirable to present temperature and ice-meltage data for this type of refrigeration before considering the more strictly experimental methods.

One or more cars under standard refrigeration were included in each of the 29 test trips to be used as checks. Table 15 presents a summary of the temperature and icing records of all standard refrigerator cars in the 20 test trips from California to New York City. In most instances the period in transit was 9¼ days from time of loading at the packing house in California to arrival at Jersey City. In one case a car was held as long as 9 days before unloading; in a few cases they were unloaded within 24 hours, but generally they were held from 2 to 4 days. In view of the different lengths of holding period, temperature and icing records up to arrival in Jersey City were considered the best index for comparing the results of the different tests. In the 1929 tests no records were made of the ice remaining in the bunkers until the time of unloading; therefore, for these tests it is necessary to compare results on the basis of total ice meltage and the temperature drop from time of loading to time of unloading. In such comparisons any differences in the length of time the cars had been held in Jersey City must be kept in mind.

High fruit temperatures at loading and high outside temperatures en route caused heavy ice meltage; opposite conditions caused light ice meltage. The maximum ice meltage occurred in car A of test 1931–5, and the minimum in car G of test 1931–2. The former was loaded with fruit at a temperature of 84° F., moved eastward in early August, encountering an average atmospheric temperature of 80°, and melted 22.184 pounds of ice in 12¼ days. Car G, loaded with fruit at a temperature of 66°, moved eastward in March through an average outside temperature of 49° and melted 9,579 pounds of ice in 11¼ days.

Table 15.—*Summary of temperature and icing record of all experimental cars moving under standard refrigeration from California to New York City over a period of years*

Test no.	Mean outside temperature	Car	Age of car	Average thickness of insulation	Loading date	Fruit temperature at loading	Number of times reiced	Total ice supplied in transit	Date of arrival at Jersey City	Fruit temperature on arrival at Jersey City	Fruit temperature drop during transit period	Ice melted in transit [1]	Date of unloading	Fruit temperature at unloading	Drop in temperature during entire test period	Total ice melted during test	Duration of holding period [2]	Surplus ice
	°F.		*Years*	*Inches*		*°F.*		*Pounds*		*°F.*	*°F.*	*Pounds*		*°F.*	*°F.*	*Pounds*	*Days*	*Pounds*
1929-1	60	A	5	2⅛	May 1	86	9	26,111	May 11	39	47	----------	May 13	40	46	17,399	2	8,713
1929-2	66	A	New	2¼	May 15	76	9	23,634	May 25	41	35	----------	May 27	42	34	16,224	2	7,410
	66	B	New	2¼	do	81	9	25,464	do	40	41	----------	do	40	41	18,474	2	6,990
1929-3	60	A	5	2	May 29	67	10	22,229	June 8	40	27	----------	June 8	40	27	12,989	0	9,240
	60	B	5	2	do	65	10	20,218	do	42	23	----------	June 9	44	21	12,098	1	8,120
1929-4	80	A	3	2½	July 6	81	10	29,610	July 16	41	40	----------	July 17	41	40	21,975	1	7,635
	80	B	3	2½	do	73	10	27,729	do	41	32	----------	do	41	32	19,953	1	7,776
1929-5	80	A	3	2½	July 20	83	10	26,984	July 29	43	40	----------	Aug. 1	41	42	21,317	3	5,667
1929-6	76	A	3	2⅛	Aug. 9	83	9	26,924	Aug. 17	41	42	----------	Aug. 19	40	43	19,884	2	7,040
	76	B	3	2⅛	do	81	9	25,342	do	40	41	----------	do	40	41	18,302	2	7,040
1929-7	76	B	3	2⅛	Aug. 30	90	9	27,012	Sept. 8	44	46	----------	Sept. 10	43	47	19,820	2	7,192
1929-8	76	A	3	2¼	Sept. 20	76	9	24,551	Sept. 29	42	34	----------	Oct. 8	40	36	20,911	9	3,640
	76	B	3	2¼	do	73	9	24,160	do	42	31	----------	Oct. 1	40	33	17,015	2	7,145
1929-9	58	A	3	2¼	Oct. 15	75	10	21,530	Oct. 24	38	37	----------	Oct. 28	38	37	13,580	4	7,950
1930-1	73	A	New	2¼	June 4	85	9	25,359	June 13	41	44	15,661	June 16	41	41	20,189	3	5,170
1930-2	78	A	½	2¼	July 9	77	9	24,552	July 18	40	37	14,552	July 20	40	37	17,678	2	6,874
1930-3	73	A	New	2⅜	Aug. 13	78	9	26,096	Aug. 23	41	37	16,627	Aug. 24	41	37	17,709	1	8,387
1931-2	49	A	New	2⅜	Mar. 11	69	10	20,457	Mar. 20	39	30	9,889	Mar. 22	38	30	10,096	2	10,361
	49	G	½	2⅜	do	66	10	19,972	do	39	27	9,089	do	38	29	9,579	2	10,393
1931-3	66	A	New	2⅜	May 13	79	9	23,336	May 22	41	38	13,202	May 24	40	39	14,386	2	8,950
1931-4	80	A	1	2⅜	July 8	85	10	27,517	July 17	43	42	17,558	July 19	42	43	21,119	2	6,398
	80	B	New	2⅜	do	85	10	26,047	do	43	42	17,648	do	41	44	20,339	2	5,708
1931-5	80	A	New	2⅜	July 30	84	9	27,014	Aug. 8	40	44	17,235	Aug. 11	39	45	22,184	3	4,830
1931-6	68	A	7	2⅛	Sept. 16	76	9	25,841	Sept. 25	41	35	16,057	Sept. 27	40	36	20,041	2	5,800
1931-7	61	A	1	2¼	Oct. 14	66	9	21,911	Oct. 23	39	27	11,411	Oct. 26	38	28	15,051	3	6,860
	61	F	New	2⅜	do.	72	9	22,155	do	39	33	12,055	do	38	34	14,565	3	7,590
1932-4	64	A	1	2⅜	May 11	72	9	23,181	May 20	40	32	13,181	May 22	39	33	15,781	2	7,400
1932-5	74	A	New	2⅜	June 15	75	9	24,464	June 24	41	34	14,464	June 29	40	35	21,014	5	3,450
Average	70	-----	2	2¼	----------	77	--------	24,621	----------	41	36	[3] 14,188	----------	40	37	17,489	2½	7,132

[1] Records on ice meltage in transit not taken in 1929. [2] No ice was supplied cars during the holding period at Jersey City. [3] 14 cars in this average; all other averages include 28 cars.

A general idea of the rate of ice meltage in transit may be obtained from a study of the amount of ice supplied at the various reicing stations en route. The location of these stations on each route with reference to the daily schedule of the trains is shown in figure 3 (p. 10). The average interval between reicings and average amounts of ice supplied at each for different seasons of the year are presented in table 16. In general, at all seasons of the year 2 or 3 times as much ice was melted during the early part of the trip as during the latter part. Ice meltage during the summer averaged about 25 percent greater than in May and October and nearly twice as great as in March.

Tables 15 and 16 show that in every instance heavy surpluses of ice were found in standard refrigeration cars at the time of unloading in New York, all of which the shipper pays for at the standard refrigeration rate. This surplus averaged 7,132 pounds in 28 cars which moved east at different seasons of the year and which were held in Jersey City without reicing for an average of 2½ days (table 15).

Fruit temperatures at the top- and bottom-layer quarter-length positions, during different seasons of the year in the same cars for which ice meltage data were presented, are shown in table 17. Outside temperatures encountered during these tests appear in table 18. These data show that higher fruit temperatures were maintained in the summer tests than in the May and October tests and warmer fruit temperatures in the May and October tests than in the March test. These differences were caused both by differences in the temperature of the fruit at loading and atmospheric temperatures through which the cars moved. However, the temperature of the fruit at loading time in the summer tests was so much higher than in the March test that the rate of cooling was greater despite the much higher outside temperatures encountered. Thus, the difference between the fruit temperatures in the two seasons tended to become less during each succeeding day in transit. This is more apparent when the summer tests are compared with the March test than when they are compared with the May and October tests. The greater cooling and the higher outside temperatures during the summer tests account for the increased ice meltage.

TABLE 16.—*Icing record of test shipments under standard refrigeration at different seasons of the year*

Icings	Early spring (March)[1]		Late spring (May) and early fall (October)[2]		Summer (June to September)[3]	
	Time since last icing	Ice supplied	Time since last icing	Ice supplied	Time since last icing	Ice supplied
	Hours	*Pounds*	*Hours*	*Pounds*	*Hours*	*Pounds*
Initial		10,883		11,086		11,080
First	15	1,368	19	2,462	19	2,686
Second	17	1,078	16	1,728	18	1,888
Third	19	1,056	19	1,397	16	1,660
Fourth	23	1,884	21	1,898	23	1,883
Fifth	12	940	22	1,128	21	1,643
Sixth	20	532	23	1,158	23	1,440
Seventh	28	611	23	1,145	25	1,377
Eighth	15	524	27	841	22	1,025
Ninth	19	206	22	965	22	1,091
Tenth	18	884				
Total ice supplied		19,972		23,808		25,673
Ice in bunker on arrival at Jersey City		10,883		[4] 10,184		[5] 9,840
Ice melted in transit		9,089		[5] 12,462		[4] 15,766
Surplus ice at unloading		[6] 10,393		[7] 7,702		[8] 6,060
Total ice melted		9,579		15,983		19,613

[1] Test 1931-2, car O, average thickness of insulation, 2⅜ inches; mean outside temperature en route, 40° F.; average fruit temperature at loading, 66°.

[2] Average of 7 tests; 1929-1, car A; 1929-2, cars A and B; 1931-3, car A; 1931-7, cars A and F; 1932-4, car A. Average thickness of insulation, 2¼ inches; mean outside temperature en route, 63° F. Average fruit temperature at loading, 76°.

[3] Average of 11 tests: 1929-6, cars A and B; 1929-7, car B; 1929-8, cars A and B; 1930-1, car A; 1930-2, car A; 1930-3, car A; 1931-5, car A; 1931-6, car A, and 1932-5, car A. Average thickness of insulation, 2¼ inches. Mean outside temperature en route, 75° F. Average fruit temperature at loading, 80°.

[4] Only 4 tests included in this average. Data not secured in 1929 tests.

[5] Only 6 tests included in this average. Data not secured in 1929 tests.

[6] Interval held before unloading, 2 days.

[7] Interval held before unloading, 2½ days.

[8] Interval held before unloading, 3 days.

TABLE 17.—*Comparison of fruit temperatures maintained in test shipments in transit under standard refrigeration at different seasons of the year*[1]

Time after initial icing (days)	Fruit temperature at quarter-length position					
	Early spring (March)[2]		Late spring and early fall (May and October)[2]		Summer (June to September)[3]	
	Top layer	Bottom layer	Top layer	Bottom layer	Top layer	Bottom layer
	° F.	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*
At initial icing	66.5	60	77	72	80	76
1	62	46	68	52	73	55
2	57	41	61	44	65	46
3	52	39	56	41	60	42
4	49	37.5	52	39	55	40
5	46	37	48	38	52	39
6	44	36	46	37	49	38
7	42.5	36	45	37	47	38
8	41	36	43	37	46	38
9	41	36	43	37	44	38

[1] Data from same tests as presented in table 16.

[2] Average interval between loading and initial icing, 20 hours.

[3] Average interval between loading and initial icing, 18 hours.

TABLE 18.—*Average atmospheric temperatures encountered en route at different seasons of the year*

Time after initial icing (days)	Early spring (March)[1]	Late spring (May) and early fall (October)[2]	Summer (June to September)[3]	Time after initial icing (days)	Early spring (March)[1]	Late spring (May) and early fall (October)[2]	Summer (June to September)[3]
	° F.	° F.	° F.		° F.	° F.	° F.
Between loading and initial icing	61	69	74	5	47	64	72
1	66	76	86	6	39	60	71
2	60	68	80	7	36	59	71
3	55	68	75	8	34	57	66
4	50	65	78	9	43	60	74

[1] See table 16, footnote 1. [2] See table 16, footnote 2. [3] See table 16, footnote 3.

During the interval between loading of the fruit at the packing house and arrival at the first icing station (Colton, Calif., on the Southern Pacific and Union Pacific, and San Bernardino, Calif., on the Santa Fe) the vents were opened on cars to be moved under standard refrigeration. Top-layer temperatures during this period showed very little change, while bottom-layer temperatures usually showed a drop of about 5°. This delay in cooling reduces the effectiveness of standard-refrigeration service as used for oranges, because, according to Powell (*13*), decay develops most rapidly early in the transit period while the fruit is warm.

During 1929 several tests were made with half-tank standard refrigeration which consisted of icing only the lower half of the bunkers at the initial icing and at each reicing instead of icing the bunkers to capacity, as under ordinary standard refrigeration. In none of these tests did lower half-tank standard refrigeration cool the load as much as did ordinary standard refrigeration. Field heat removal and heat leakage into the car during the early part of the transit period were sufficiently great so that the larger part of the half bunker of ice was melted before arrival at the first reicing station en route, and the level of ice in the bunkers dropped so low that refrigeration of the load was not as effective as when the bunkers contained more ice.

INITIALLY ICED AT FIRST ICING STATION AND NOT REICED IN TRANSIT

[Tests during comparatively cool weather in spring and fall]

The first experimental trip (1928–1) was made with late Valencias in transit to Chicago during November 1928. In this test the results obtained in two cars (A and B) under standard refrigeration were compared with those in two cars (C and D) initially iced at San Bernardino, Calif., but not reiced en route. The maximum outside temperature encountered was 67°, minimum 32°, and the mean 49°.

Some data pertaining to the cars and a record of the temperatures obtained are given in table 19. These data show that in this test there was no significant difference in the fruit temperatures maintained in cars initially iced only as compared with those moving under standard refrigeration. Ice meltage records were not obtained on these cars.

Initial icing only was tested again in October, test 1929–9, in which five cars, initially iced at Colton and not reiced in transit to New York, were compared with a car under standard refrigeration. The average fruit temperature of all cars in this test at loading time was 76° F., and the mean outside temperature en route was 56°. Under these conditions initial icing only maintained top-layer temperatures equal to those of standard refrigeration only as far as Ogden, Utah. East of Ogden top-layer temperatures were from 2° to 8° higher than under standard refrigeration. Fruit temperatures of the bottom layers were about the same under both methods to Jersey City.

Temperature and icing records of a third test comparing initial icing only (car B) with standard refrigeration (car A) are pre-

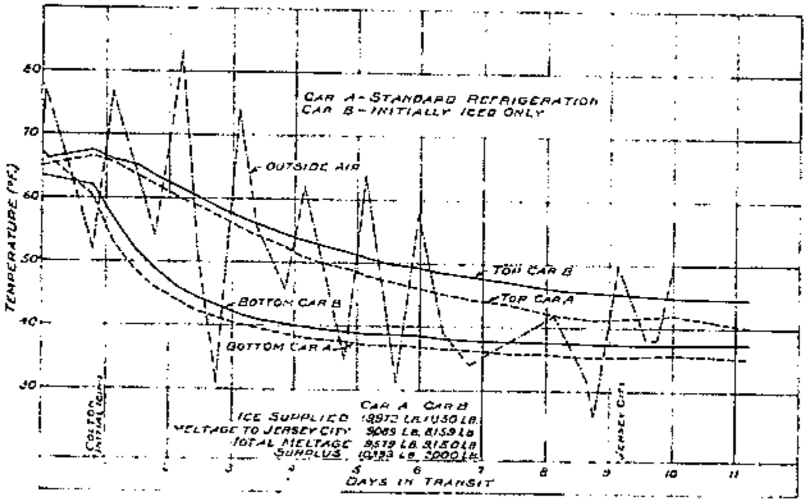

FIGURE 19.—Fruit temperatures at quarter length (center) in car under standard refrigeration and car initially iced only; March 11–22, 1931.

sented in figure 19. This test was made in March 1931, the average outside temperature en route being 49° F. The low outside temperatures, together with the rather cool fruit loaded in the cars, enabled car B to maintain fruit temperatures nearly as low as those in car A during the entire test.

These results indicate that the success of initial icing only as a method of refrigeration depends on the fruit temperature at loading and on the outside temperatures en route. Low fruit temperatures at loading means less field heat to be absorbed by ice meltage, and low outside temperatures mean less heat leakage to be absorbed.

This method of refrigeration, initial icing only, appears to be satisfactory for the transportation of nonprecooled oranges during the early spring months, provided fruit temperatures are low at loading, i. e. below 70° F.

TABLE 19.—*Comparison of fruit temperatures maintained under standard refrigeration and initially iced only, test 1928–1, October 31 to November 7*

Car	Age of car	Average thickness of insulation	Average fruit temperature at loading	Top quarter-length fruit temperature in transit			Bottom quarter-length fruit temperature in transit		
				After 3 days	After 5 days	After 8 days	After 3 days	After 5 days	After 8 days
	Years	*Inches*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
A [1]	1	1½	64	54	47	42	43	39	39
B [1]	1	2⅜	73	57	48	42	45	39	37
C [2]	½	2⅜	67	53	47	44	42		
D [2]	1	2⅜	62	52	46	42	44	40	38

[1] Standard refrigeration. [2] Initially iced only.

INITIALLY ICED AT FIRST ICING STATION AND REICED ONCE IN TRANSIT

[Tests during hot summer weather]

A study of the results produced by initial icing only suggested that possibly initial icing (at the first icing station en route) with one reicing in transit would give temperatures approximately as low as those obtained under standard refrigeration, even during the

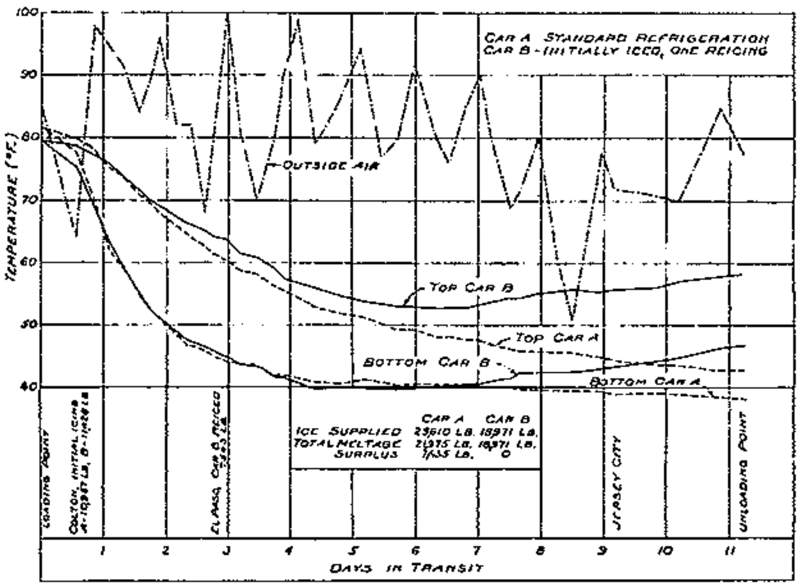

FIGURE 20.—Fruit temperatures at quarter length (center) in car under standard refrigeration and car initially iced with one reicing after 3 days in transit, July 6–17, 1929.

warmer months of the year. Six different tests of this method were made during the summer of 1929; 4 in 1930; and 1 in 1931. However, in none of these tests, when very warm fruit was loaded in the car and when high outside temperatures were encountered, did the method referred to above give refrigeration equal to that secured by standard refrigeration. Not much space will be given to presentation and discussion of the results of these tests, because at this time initial icing and one reicing in transit is not believed to be as satisfactory for the transportation of nonprecooled oranges as are other methods which afford more refrigeration at no greater cost.

Typical results secured from initially icing at the first icing station and reicing early in transit at some point corresponding to El Paso, Tex., or Ogden, Utah, are shown in the records of cars A and B of test 1929–4 (fig. 20). Car B, initially iced at Colton and reiced at El Paso, afforded nearly the same refrigeration as car A, standard refrigeration, as far east as St. Louis, Mo., but beyond that point furnished very little refrigeration. The bunkers of this car were dry at unloading in New York and the top-layer fruit was 15° warmer than that of car A.

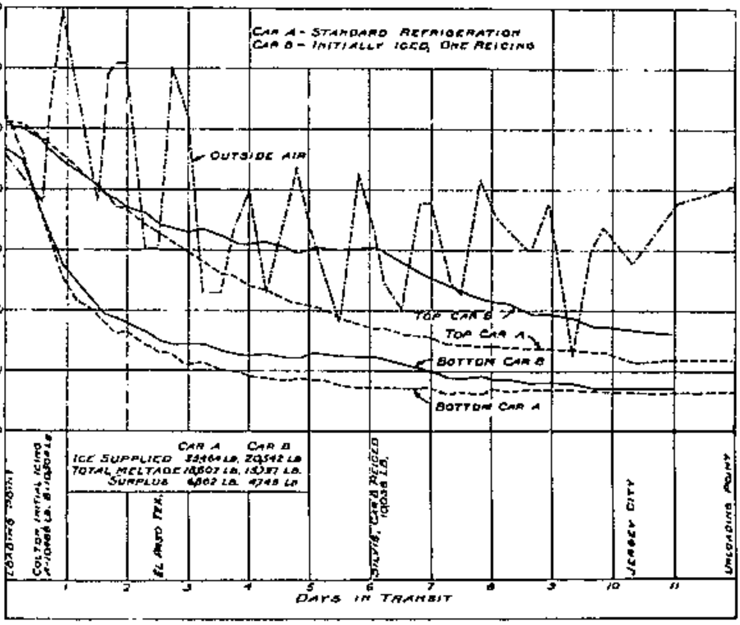

Figure 21.—Fruit temperatures at quarter length (center) in car under standard refrigeration and car initially iced with one reicing after 6 days in transit, May 15–27, 1929.

The results of test 1929–2 are typical for cars initially iced at the first icing station en route and reiced at some point late in transit, and are presented in figure 21. Car B was initially iced at Colton, and reiced at Silvis, Ill., nearly 6 days out of Colton, while car A moved under standard refrigeration. The test was made in May, but as shown in figure 21 the atmospheric and fruit temperatures at loading were exceptionally high for that season of the year and are representative of those occurring in summer.

Cooling was practically the same in both cars as far east as El Paso, but between El Paso and Silvis it was much less in car B than in car A. This lack of refrigeration in car B was most noticeable in the top layer where maximum temperatures occur under all forms of ice refrigeration in transit. When the car was reiced at Silvis the bunkers were practically empty and the temperature of the top layer fruit was 60.5° F. as compared with 47° in car A. The reicing at Silvis increased the rate of cooling of car B over that of car A, so that upon arrival at Jersey City the top-layer temperature was 47° as compared with 43° in car A.

These results, along with similar ones secured in 10 other tests, show that during the summer months initial icing at the first icing station en route with only one reicing in transit, regardless of time of reicing, does not furnish warm fruit as much refrigeration as does standard refrigeration. Early reicing gives maximum protection against heat during the first two-thirds of the trip but very

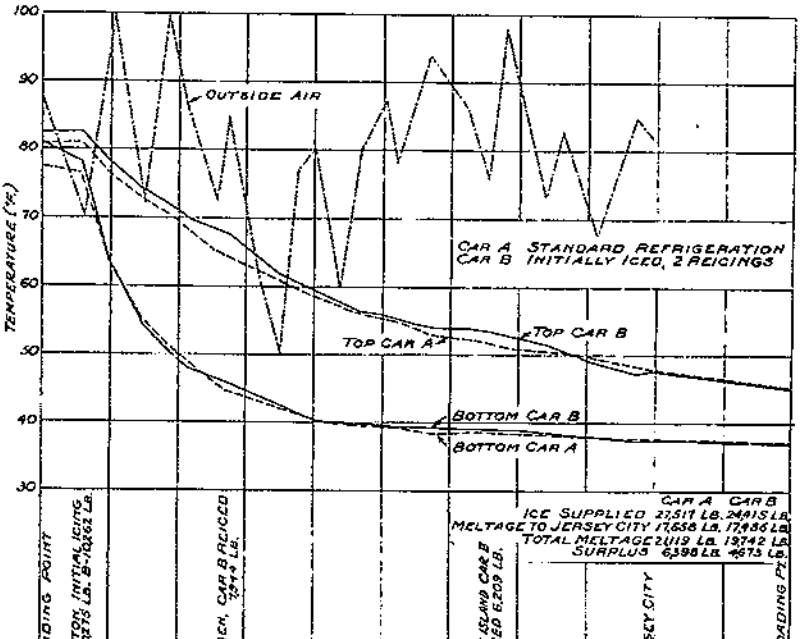

FIGURE 22.—Fruit temperatures at quarter length (center) in car A under standard refrigeration and car B initially iced plus two reicings in transit, July 8–19, 1931.

poor protection near the end, whereas late reicing gives early and late protection but very little during the middle of the transit period.

INITIALLY ICED AT FIRST ICING STATION EN ROUTE AND REICED TWICE IN TRANSIT

[Tests during hot summer weather]

Observing that during warm weather initially iced cars, reiced but once in transit, did not furnish as much refrigeration as did standard refrigeration, several tests of reicing to capacity twice in transit were made. Typical results of these tests are presented in figure 22. It is noted that there was no significant difference in fruit temperatures maintained and in the quantity of ice melted under these two methods of refrigeration. The reicing of experimental car B at Blue Island, Ill., prevented a rise in fruit temperature near the end of the trip.

Other tests were made, in which only 4,000 pounds of ice were supplied at each of the two reicings instead of the 6,000 or 7,000 pounds necessary for reicing to capacity. In these tests the fruit cooled less than under standard refrigeration. An application of more than 4,000 pounds of ice is necessary at the first reicing to furnish refrigeration equal to that of standard refrigeration. Perhaps at the second reicing an application of only 4,000 pounds would be sufficient, as beyond Blue Island the greatest source of heat is heat leakage, the greater portion of the field heat having been absorbed prior to arrival at Blue Island.

These results indicate that reicing 9 or 10 times in transit, as under standard refrigeration, is not necessary because nearly the same refrigeration is afforded the fruit with only two reicings. Keeping the bunkers filled to capacity at all points is not necessary. Under the conditions of these tests, as long as the ice in the bunkers did not drop much below half full, nearly as much refrigeration was afforded the fruit as when the bunkers were kept full.

EFFECTIVENESS OF PREICING

In none of the experimental methods discussed heretofore was an attempt made to correct a certain weakness in standard-refrigeration service as used for citrus fruit; namely, the lack of refrigeration from time of loading to arrival at the initial icing station, an interval of approximately 18 hours when fruit temperatures are highest. In test 1930-2, during July, preicing was first tried experimentally by the United States Department of Agriculture as a means of furnishing refrigeration to nonprecooled oranges immediately upon loading into the car. Refrigeration secured in the interval between loading and arrival at the first icing station by preicing in this and 11 other tests made during 1930, 1931, and 1932, as compared with the cooling obtained under ventilation in cars scheduled for standard refrigeration, is presented in table 20. While practically no change was observed during this ventilation interval in top-layer temperatures of cars scheduled for standard refrigeration, they dropped from 2° to 9° in preiced cars, the greatest drop occurring in cars containing the warmest fruit. Bottom-layer temperatures under ventilation dropped from 3° to 7°, and those of preiced cars from 14° to 33°. The large amount of ice melted during this period is further evidence of the great amount of refrigeration secured by preicing. These results clearly indicate that preicing should be used for the transportation of oranges, particularly during the summer when fruit temperatures are high and refrigeration for the control of decay is most needed.

TABLE 20.—*Cooling secured between time of loading and time of arrival of cars at first icing station by preicing as compared with cooling obtained under standard refrigeration*

Test	Car	Method of refrigeration	Time of initial icing	Average fruit temperature at loading	Interval from loading to arrival at first icing station: Hours	Interval from loading to arrival at first icing station: Mean outside temperature	Change in fruit temperature: Top layer	Change in fruit temperature: Bottom layer	Ice supplied preiced cars at first icing station
				° F.	Number	° F.	° F.	° F.	Pounds
1930-2 (July)	A	Standard	14 hours after loading	77	14	73	0.0	−6.0	
	B	Preiced	20 hours before loading	76	20	80	−7.0	−25.0	5,279
	E	do	do	82	16	80	−4.0	−33.0	6,114
1930-3 (August)	A	Standard	17 hours after loading	79	17	71	.0	−3.0	
	F	Preiced	19 hours before loading	80	17	73	−6.0	−24.0	5,673
1930-4 (September)	C	do	do	70	20	67	−4.0	−17.0	4,921
1931-2 (March)	G	Standard	20 hours after loading	66	20	59	.0	−6.0	
	B	Preiced	42 hours before loading	67	19	65	−4.0	−23.0	[1]
	C	do	26 hours before loading	60	18	64	−3.0	−15.0	[1]
	D	do	29 hours before loading	68	16	57	−2.0	−20.0	[1]
1931-3 (May)	A	Standard	20 hours after loading	79	20	71	−1.0	−7.0	
	G	Preiced	31 hours before loading	75	16	71	−3.0	−21.0	[1]
	H	do	24 hours before loading	77	18	71	−3.0	−18.0	[1]
1931-4 (July)	A	Standard	20 hours after loading	81	20	80	.0	−4.0	
	B	Preiced	22 hours before loading	87	20	79	−7.0	−24.0	6,636
	D	do	21 hours before loading	78	20	79	−7.0	−24.0	6,163
	H	do	20 hours before loading	77	23	79	−7.0	−27.0	4,821
1931-5 (July)	A	Standard	20 hours after loading	84	20	78	.0	−5.0	
	D	Preiced	15 hours before loading	84	20	78	−9.0	−32.0	[1]
	E	do	19 hours before loading	80	21	81	−9.0	−31.0	[1]
	L	do	do	89	15	77	−9.0	−31.0	[1]
1931-6 (September)	A	Standard	13 hours after loading	76	13	64	+1.0	−4.0	
	B	Preiced	10 hours before loading	76	18	65	−5.0	−22.0	[1]
	D	do	15 hours before loading	82	14	70	−6.0	−25.0	[1]
	F	do	9 hours before loading	68	20	70	−5.0	−19.0	[1]
1931-7 (October)	A	Standard	20 hours after loading	67	20	69	.0	−5.0	
	B	Preiced	21 hours before loading	69	24	65	−5.0	−22.0	[1]
	C	do	19 hours before loading	75	25	65	−7.0	−26.0	[1]
	D	do	21 hours before loading	76	24	65	−7.0	−23.0	[1]
1932-1 (March)	A	do	16 hours before loading	60	20	59	−3.0	−14.0	[1]
1932-2 (March)	A	do	do	65	20	59	−5.0	−20.0	[1]
1932-6 (August)	A	Standard	24 hours after loading	78	24	85	−1.0	−6.0	
	B	Preiced	20 hours before loading	79	19	85	−6.0	−23.0	[1]
	C	do	15 hours before loading	69	25	85	−6.0	−22.0	[1]
	D	do	20 hours before loading	80	20	85	−6.0	−22.0	5,700

[1] No ice supplied at first icing station.

PREICED, REPLENISHED BY CARRIER AT FIRST ICING STATION, AND REICED ONCE IN TRANSIT

[Tests during hot summer weather]

The lower temperatures in preiced cars on arrival at the first icing station as compared with those under standard refrigeration suggested that possibly preicing combined with limited icing in transit would afford better and cheaper refrigeration than standard refrigeration. Accordingly, in July 1930 (test 1930–2) a test was made in which a preiced car (B) was replenished at the first icing station and was reiced once (Kansas City) in transit to New York. The temperature and icing record of this car as compared with that of car A, under standard refrigeration, in the same test is presented in figure 23.

The average fruit temperature in car A at loading was 77° F. and in car B 76°. By the time the cars arrived at Colton, the first icing station, the fruit in car B was 8° lower in the top layer and 20° lower in the bottom layer than in car A. By reason of this early cooling, car B maintained top-layer temperatures 1° to 8°, mostly about 7° or 8°, lower than those in car A during the next 3½ days and bottom-layer temperatures from 1° to 20° lower for the next 3 days. For the remainder of the transit period fruit

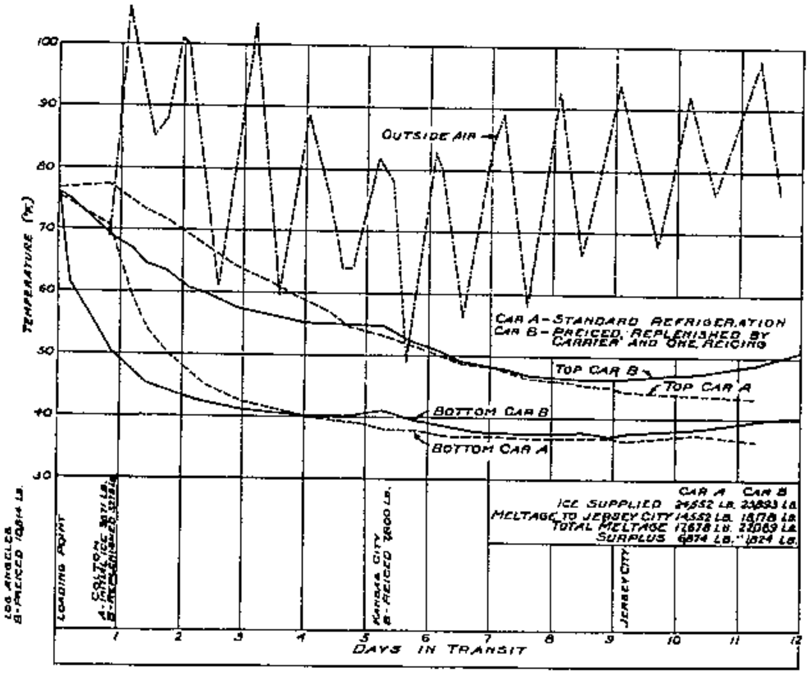

Figure 23.—Fruit temperatures at quarter length (center) in car A under standard refrigeration and car B preiced, replenished, and one reicing in transit, July 9–21, 1930.

temperatures in both top and bottom layers were practically the same for both cars, but during a 2-day holding period in Jersey City temperatures in car B rose 5° above those of car A. At the end of the second day in Jersey City, car A was unloaded but car B was held for a third day, during which it showed an additional rise of 2.5° in the top layer and 0.7° in the bottom layer. The bunkers of car B contained only 1,824 pounds of ice at the time of unloading, as compared with 6,874 pounds in car A.

The advantage gained in refrigeration by car B during the early part of the trip more than compensated for the somewhat higher fruit temperatures at the end of the trip because the average fruit temperature at the top quarter-length position for the 11-day period during which the 2 cars were compared was nearly 2° lower in car B than in car A. In addition to furnishing better average refrigeration, car B furnished more refrigeration at the period in transit when fruit temperatures were highest and cooling for control of decay was most needed. Results similar to these were secured again in July 1931 (test 1931–4), so that on the basis of these results the method of preicing, replenishing bunkers at the first icing station, and reicing once in transit is clearly demonstrated as being superior to standard refrigeration for the transportation of oranges in direct shipments for eastern markets, even when warm fruit is loaded in the car and when high outside temperatures prevail.

PREICED AND REICED ONCE IN TRANSIT

[Not replenished at first icing station]

During the 1931–32 season carriers permitted one reicing in transit for citrus fruits at a rate lower than that for standard refrigeration; however, at that time they ruled that replenishing at the first icing station constituted a reicing, thus a car replenished at Colton and reiced at Kansas City would be charged the standard-

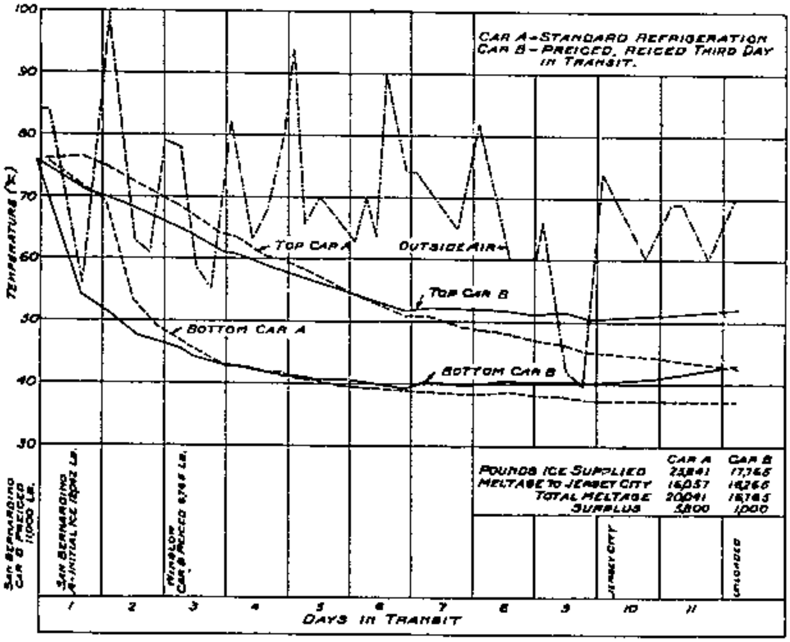

FIGURE 24.—Fruit temperatures at quarter length (center) in car A under standard refrigeration and in preiced car B, reiced once in transit, September 16–27, 1931.

refrigeration rate. In September 1931 a test (1931–6) was made, in which a preiced car (B) was not replenished at the first icing station but was carried to the third icing station and reiced (Winslow, Ariz.) and received no further icing in transit. Top and bottom quarter-length fruit temperatures in this car as compared with those of car A under standard refrigeration in the same test are presented in figure 24.

The advantage gained by prompt cooling from preicing enabled car B with only one reicing in transit at Winslow (2¼ days from loading) to record top-layer temperatures 5° to 0° below that of car A for the first 5 days en route. However, for the remainder of the trip top-layer temperatures were warmer in car B than in car A (fig. 24), making the average temperature for the 9¼-day transit period the same (58.6° F.) in both cars, but 1.2° higher in car B if the entire 11¼ days during which temperatures were secured is considered. In the bottom layer, fruit temperatures in car B were below those of car A for the first 3 days, but for the remainder of the trip they were either the same or slightly higher than those of car A.

These results show that in this test the average refrigeration afforded the fruit by preicing and reicing once in transit was nearly equal to that of standard refrigeration. Similar results were again obtained in test 1931–7 made in October. However, outside temperatures encountered in these tests were considerably lower than those

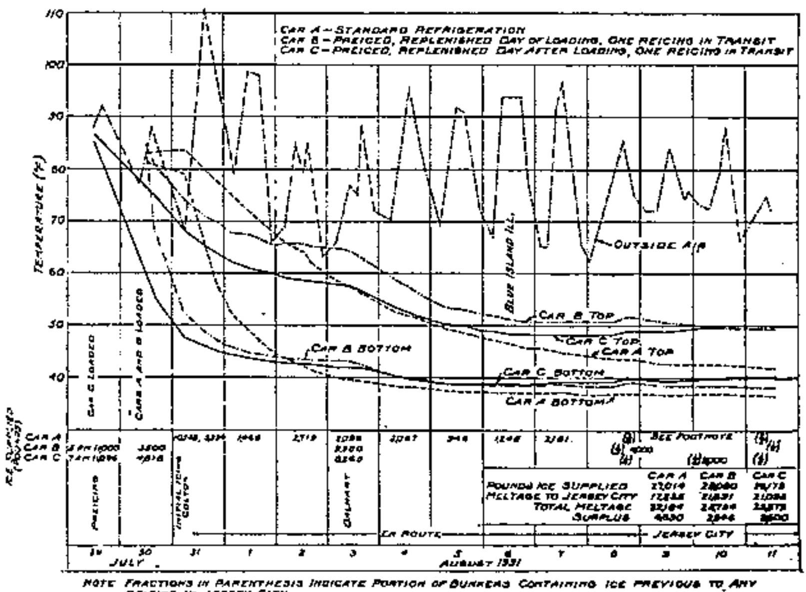

FIGURE 25.—Fruit temperatures at quarter length (center) in car A under standard refrigeration and two preiced cars; one (car B) replenished the day of loading and the other (car C) the day after loading. Each car was reiced once in transit, July 29–Aug. 11, 1931.

occurring in normal summer weather. In all probability had car B (fig. 24) encountered warmer weather, as in test 1930–2, it would have made a poorer showing. For these reasons this method of refrigeration is not recommended except in the comparatively cool spring and fall months.

PREICED, REPLENISHED BY SHIPPER, AND REICED ONCE IN TRANSIT BY CARRIER

[Tests during hot summer weather]

An effort was made in test 1931–5 to determine whether the shipper could secure refrigeration equal to that of standard refrigeration, even during the warm summer months, by replenishing the bunkers of preiced cars just before they leave the packing house, and ordering one reicing in transit by the carrier. Car B of this test was preiced by the shipper at the packing house at 4 p. m. on July 29, loaded during the morning of July 30, and replenished by the shipper at 5 p. m. on the same day. Car C was preiced by the shipper at the packing house at 7 a. m., July 29, loaded during the morning of the same day, held for a day at the packing house, and replenished by the shipper at the same time as car B. Both cars were reiced only once in transit, at Dalhart, Tex. The temperature and icing records of these two cars are compared in figure 25 with those of a car (A) under standard refrigeration loaded the same day as car B. It will be noted that after the 18-hour interval between loading and arrival at the first icing station (Colton) car B showed a temperature 10° lower in the top layer and 27° lower in the bottom layer than car A. By reason of this early cooling from preicing, car B held both top- and bottom-layer temperatures below those of standard refrigeration for 2¾ days, but for the remainder of the trip bottom-layer temperatures in this car were 1° to 4° higher; and top-layer temperatures were 4° to 8° higher than those of car A. The average top-layer temperature for the 9¼-day period in transit from loading to arrival in Jersey City was 60.4° F. in car B, as compared with 58.7° in car A.

In this test the record made by car B was not so good as that by car B in test 1930–2. The chief difference between the two was that car B in test 1930–2 was replenished by the carrier at the first icing station, 18 hours after loading, requiring 5,279 pounds to fill the bunkers, while car B in this test was replenished by the shipper 5 hours after loading, requiring only 3,500 pounds of ice. Thus, due to the bunkers being replenished at a later time, the car replenished by the carrier was able to travel farther before the ice melted below the amount necessary for effective refrigeration than did the car replenished by the shipper.

In studying the performance of car C (fig. 25) it is noted that by being loaded a day earlier than cars A and B and being held at the packing house for a day, it was possible to lengthen the interval between loading and replenishing; therefore at the time of replenishing, car C showed top-layer temperatures 6.5° lower and bottom-layer temperatures 5° lower than those in car B, and required 1,300 pounds more ice to fill the bunkers. On account of this greater heat removal from the load while in the hands of the shipper, car C was able to maintain top-layer temperatures 3° to 7° lower than car B for the entire trip. When comparing cars C and A it is noted that car C held top-layer temperatures an average of about 10° lower than car A for the first 4 days, or until arrival at Dalhart. By reicing at that point it was possible to maintain practically the same temperature in car C as in car A for the fifth, sixth, and seventh days, or until arrival at Blue Island, Ill. During the last 2 days in transit the top fruit in car C remained at the same temperature, whereas that in car A continued to cool and on arrival at Jersey City was 5.5° lower than that in car C. Bottom-layer temperatures in car C were an average of about 20° cooler than in car A for the first 4 days but were slightly higher during the remainder of the trip. These results show that by preicing, holding the car an extra day at the packing house, replenishing by shipper just before the pick-up engine arrives, and reicing once in transit, a lower average temperature is maintained during transit than under standard refrigeration.

In car C the modified method of refrigeration was used whereby the railroads permit one reicing in transit at a cheaper rate than standard-refrigeration service; however, holding the car at the packing house an extra day is inconvenient to the shipper, as it complicates the loading of other cars and also delays the arrival of the car at destination. Furthermore, most packing houses are not equipped to ice cars.

Preicing, replenishing by carrier at the first icing station, and reicing once in transit, as in test 1930–2, is superior in many respects to either of the above-described methods involving replenishing of bunkers by the shipper, but it was not until the beginning of the 1933 refrigeration season that the rail carriers granted a special rate for the former type of service.[14]

REICING AT DESTINATION

[Tests during hot summer weather]

One objectionable feature that develops when cars are given only limited icing in transit during summer months is the rise in fruit temperature observed when the amount of ice in the bunkers becomes less than one-fourth their capacity while the cars are held at the terminal prior to unloading. It would appear that if refrigeration is desirable in transit some refrigeration should be afforded the fruit while it is being held in the cars at destination. In test 1931–5 a rise in fruit temperature in cars B and C during a 3-day holding period in Jersey City was prevented by an application of 2 and 1 tons of ice, respectively, as shown in figure 25. The bunkers in each case were about one-fifth full when they were reiced, and this ice melted at the rate of 1,500 pounds per day. Outside temperatures during the 3-day holding period varied from 66° to 88° F. These results indicate that approximately 1,500 pounds of ice per day during the holding period is about the proper amount to prevent a rise in fruit temperature under conditions such as occurred in this test; i. e., bunkers less than one-fourth full and outside temperatures moderately high. In cooler weather if any ice is left in the bunkers the rise in temperature will be negligible, and in such instances reicing at destination may not be necessary.

PREICED, REPLENISHED BY SHIPPER, AND NOT REICED IN TRANSIT

[Tests during cool weather in spring]

It was thought that this method would give about the same results as standard refrigeration during early spring months when fruit temperatures at loading and outside temperatures en route are low. Accordingly, in test 1931–2, made in March 1931, car C handled under this method was compared with car A under standard refrigeration. Figure 26 shows that car C held top-layer temperatures 5° to 1° lower and bottom-layer temperatures 16° to 1° lower than did car A

[14] NATIONAL PERISHABLE FREIGHT COMMITTEE. Perishable Protective Tariff no. 6. 1933. Issued by R. C. Dearborn, Agent, 516 West Jackson Boulevard, Chicago, Ill.

for the first 4 days; i. e., as far east as Fort Worth, Tex. For the rest of the trip bottom-layer temperatures were the same in both

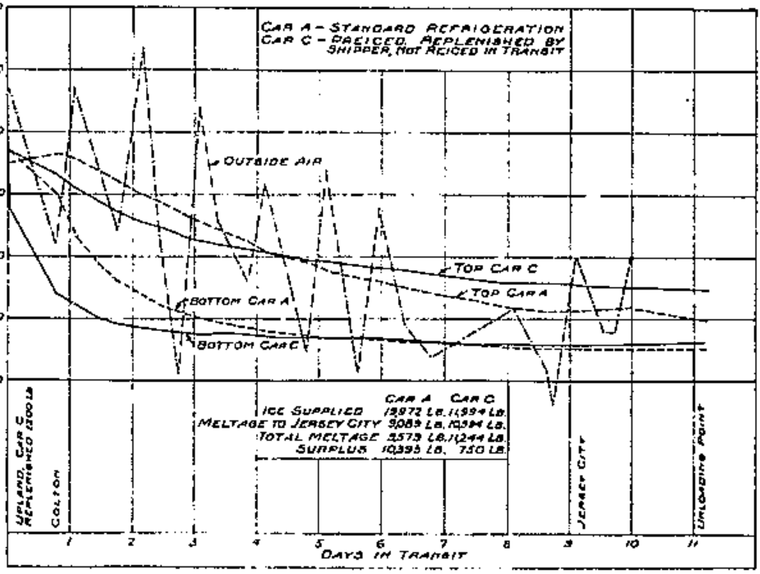

FIGURE 26.—Fruit temperatures at quarter length (center) in car under standard refrigeration and car preiced, replenished, and not reiced in transit, March 11–22, 1931.

FIGURE 27.—A typical warehouse precooling plant located at the rear of a packing house. Note block-and-tackle arrangement at each end of the first car at left used to lower whole 300-pound cakes of ice into the bunkers.

cars, but top-layer temperatures were 5° to 1° higher in car C than in car A. The average top-layer temperatures for the 9¼-day transit period were 51.7° F. in car A and 51.8° in car C.

Upon arrival at Jersey City the top-layer temperature of car C was 45.5° as compared with 41.5° in car A. The bunkers of car C contained only about 1,000 pounds of ice as compared with 10,883 pounds in car A, but during the 2-day holding period with outside temperatures varying from 36° to 50° car C cooled the top fruit one-half degree as compared with 1¼° cooling in car A. Under such conditions as were encountered in this test reicing at destination would have been a waste of ice. The rail carriers on May 1, 1933, by permitting the replenishing of preiced cars at the first icing station,[15] established a service which is superior to the method described above because the bunkers are replenished at a later time

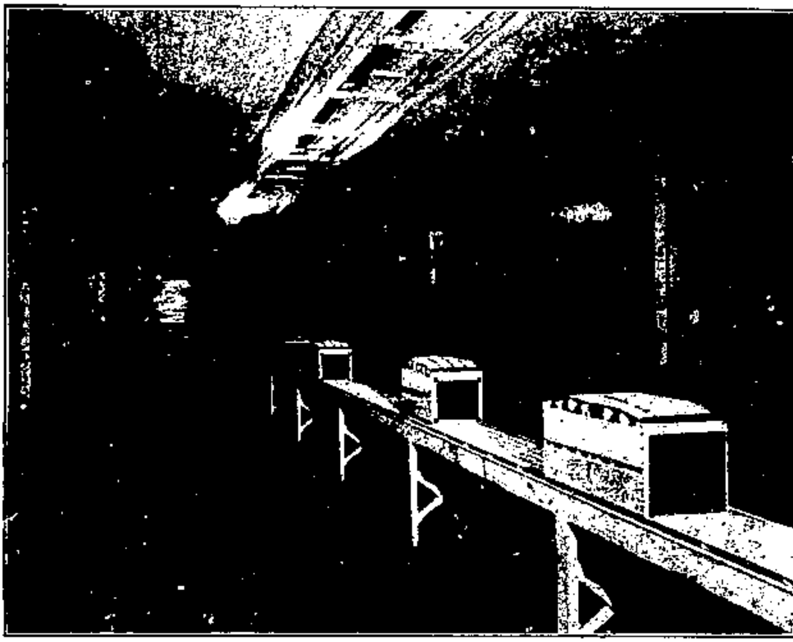

FIGURE 28.—An interior view of a nearly emptied precooling room. The air enters the room through the duct in the center of the ceiling and leaves through similar ducts on each side, the direction of the circulation being governed by canvas baffles which are lowered from the ceiling and insure the air being forced through the stacks of fruit.

after loading. Either method furnishes approximately the same refrigeration as standard refrigeration during the early spring months.

PRECOOLING AND REFRIGERATION OF PRECOOLED FRUIT IN TRANSIT

Aside from the benefit secured by retarding development of decay (*13*), precooling lessens refrigeration cost in transit by removing field heat from the fruit before the start of the transcontinental trip, thus obviating the necessity of all, or all but one, reicing in transit, as the ice has only heat leakage and a small amount of vital heat to absorb (fig. 11).

[15] NATIONAL PERISHABLE FREIGHT COMMITTEE. See footnote 14.

METHODS OF PRECOOLING

The three general methods of precooling now in use for California oranges are: Warehouse precooling, portable fan precooling, and carrier precooling.

WAREHOUSE PRECOOLING

By the warehouse method fruit is cooled in permanent precooling plants that are owned by the packing houses using this method and are located adjacent to the packing house (fig. 27). These precool-

FIGURE 29.—A canvas tunnel through which precooled fruit is conveyed from the precooling plant to the refrigerator car.

ing plants consist of a series of specially insulated cooling rooms (fig. 28), each of which holds three or more carloads of fruit. As the fruit is packed it is conveyed to the precooling rooms and stacked. Air maintained by mechanical refrigerating equipment at a temperature varying from 31° to 36° F. is kept blowing over this fruit from 48 to 72 hours, or until the desired temperature is reached. After the fruit is cooled it is usually conveyed to the car through a canvas tunnel (fig. 29) to maintain its low temperature. The cars are usually iced several hours before loading in order to remove some of the heat contained in the roof, floor, and walls, so that it will not be absorbed by the precooled fruit. In most instances ice is manufactured at the precooling plant and the icing is done by the shipper. Blocks of ice weighing 300 pounds each are lowered into the bunkers with a block and tackle (fig. 27) and stowed so that the entire bunker space is filled. By this method it is possible to get 14,000 to 15,000 pounds of ice into the bunkers as compared with only 10,500 to 11,000 pounds when it is broken into chunks.

PORTABLE FAN PRECOOLING

By the portable fan method of precooling, the warm fruit is loaded into an iced car and 1 or 2 fans of propeller type are in-

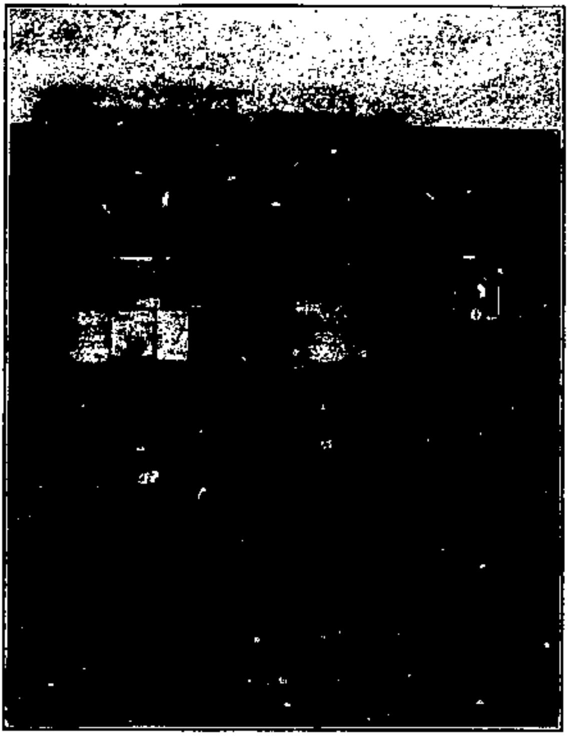

FIGURE 30.—Precooling fan in position in end of refrigerator car.

stalled at the top opening of the bunker at each end of the car. These fans are held in place by special fittings which direct the air coming from the ice bunkers entirely through the fans (fig. 30), and are operated by small electric motors, the wiring of which is carried out of the car at the top of the doorway and is attached to the power line of the packing house. The fans pull the car air into the ice bunkers through the bottom opening and force it out over the top of the load, thus reversing the normal circulation of air in the car. Some shippers apply salt to the ice during precooling in order to speed up the rate of cooling. After precooling, the bunkers are replenished by the shipper before the car is moved.

This system of fan precooling is an outgrowth of the original portable car precooler described by Galloway [16], where small motor-driven blowers were installed in the bunkers directly under the hatch plugs, which pulled air up through the ice and discharged it into the body of the car through the top bunker opening.

CARRIER PRECOOLING

Carrier precooling consists of forcing low-temperature air (10° to 30° F.), from a refrigerated room through a duct into the car loaded with warm fruit. Warm air within the car is returned through a duct to low-temperature brine coils to be recooled. Very

FIGURE 31.—Precooling plant and icing station of the Pacific Fruit Express Co. at Colton, Calif.

large plants are required for this method of precooling. The Pacific Fruit Express Co. maintains one at Colton (fig. 31) for fruit loaded on the Southern Pacific, Union Pacific, and Pacific Electric, and the refrigerator department of the Santa Fe Railway maintains a plant at San Bernardino for Santa Fe shipments. By the method in use at the Colton plant the cold air is blown into the car through the doorway and is exhausted through one hatch of each bunker. Canvas baffles are hung over the top bulkhead opening of the bunkers, thus forcing the air to leave the load at the bottom bunker openings. At the San Bernardino plant cold air is blown into the car through a hatch in one ice bunker and drawn out through a hatch in the bunker at the other end of the car (fig. 32) thence being returned to the brine coils for recooling. Every half-hour the direction of air movement in the car is reversed. A canvas baffle is in-

[16] GALLOWAY, A. G. See footnote 6.

stalled across the car at the doorway extending from the top of the load to the ceiling for the purpose of forcing the air to penetrate the load instead of allowing it to pass over the top of the boxes and out the top bunker opening at the other end of the car without coming in contact with the fruit. Either of these methods can be used on a dry or an iced car. After precooling the bunkers are iced to capacity.

In test 1932–4 a study was made of the differences in temperature throughout the orange load in cars precooled by each of the three

FIGURE 32.—Air ducts of Santa Fe precooling system at San Bernardino in place over hatch at each end of car. Air is blown into the car at one end and is drawn out at the other end.

general methods and forwarded to New York with no reicing in transit. Two cars of nonprecooled fruit, one moving under standard refrigeration and the other preiced, replenished the day after loading and reiced once in transit, were included in the same test for purposes of comparison. Temperature variations in the two cars of nonprecooled fruit have already been discussed on pages 25 to 30. Before comparing the results of the precooled and nonprecooled shipments, temperature differences in each of the precooled cars will be discussed. The test was made May 10–22, 1932.

TEMPERATURE DIFFERENCES IN THE ORANGE LOAD UNDER DIFFERENT METHODS OF PRECOOLING

WAREHOUSE PRECOOLING

Car E was preiced with 15,300 pounds of block ice at 7 a. m., May 11, and was loaded between 1 and 2 p. m., of the same day. The fruit was precooled to 38° F. by the Santiago Orange Growers. Temperatures obtained during the precooling period in the plant are not discussed here, as this report is concerned only with refrigeration in refrigerator cars.

There was very little variation in fruit temperatures in car E during transit, all three of the upper layers and the doorway position of the bottom layer having practically the same temperature during the entire transit period. A rise in temperature of only 3° (38° to 41° F.) was recorded in this portion of the load during the

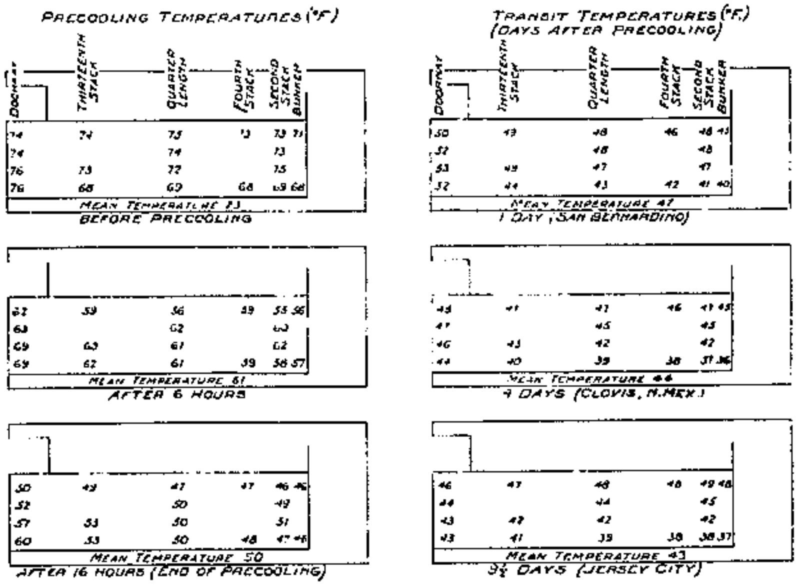

FIGURE 33.—Fruit temperatures during precooling and transit at center row of car C preiced, fan precooled, replenished after precooling, but not reiced in transit, May 10–20, 1932.

9¼-day period in transit. The remainder of the load, or that represented by the bottom bunker and bottom quarter-length positions, held temperatures from 3° to 7° lower than the above.

PORTABLE FAN PRECOOLING

Car C was preiced at 3 p. m., May 9. Loading began at 7:30 a. m., May 10, and was completed at noon the same day. Four fans of propeller type, two installed at each bunker as described above, were put into operation upon completion of loading and were run continuously till 4 a. m., May 11, making a total running time of 16 hours. The bunkers were seven-eighths full of ice at beginning of precooling and less than one-third full at 2 a. m., at which time they were supplied 2,100 pounds of ice. At 7 a. m., 3 hours after precooling was finished, the bunkers were replenished to capacity, taking approximately 6,000 pounds of ice. The car was not reiced in transit to New York City.

During the 16-hour precooling period fruit temperatures were fairly uniform from side to center of car at the bunker, quarter-length, and doorway positions, which indicates that the fans were spreading the air across the car and not concentrating on any particular row of fruit. Figure 33 presents temperatures from bunker to doorway in the center row in each of the four layers of fruit at different intervals during the precooling period and during transit after precooling. All four layers were precooled, but the top layer showed a greater drop in temperature than the lower layers at all positions, this more rapid cooling of the top layer occurring largely during the first 6 hours. Temperatures were lower at the bunker and quarter-length positions than at the doorway positions in all layers; however, these variations in temperature were of no significance with the exception of those in the two lower layers. The temperatures at the thirteenth stack and doorway position of these two layers ranged from 5° to 12° warmer than the rest of the load at the end of the precooling period. This area of poor cooling represents probably not more than 12 percent of the load.

After the fans were turned off circulation of air in the car became normal again. Top-layer temperatures remained practically stationary while those in the third layer at all positions dropped below those in the top layer, the second-layer temperatures below the third, and the first or bottom layer below the second (fig. 33). The differences in temperature from top to bottom ranged from 3° to 11°. Temperature differences from bunker to doorway were similar to those occurring under standard refrigeration, and no significant difference was observed between the temperature of the side and center rows at any position.

Upon arrival at Jersey City, 9½ days after precooling, the bunkers were about one-fourth full of ice and the top-layer temperatures were practically the same (48° F.) as at the end of precooling. All bottom-layer temperatures were much lower than at the end of precooling.

CARRIER PRECOOLING

Car D was a dry car which, after loading, moved to San Bernardino under ventilation, where it was precooled for 8 hours. The interval between loading and the beginning of precooling was 17 hours. Owing to lack of thermometers, fruit temperatures were obtained at only 10 positions in this car, these being in the center-line row of the top and bottom layers. These temperatures before precooling and at the end of 6 and 8 hours of precooling are presented in figure 34. Large differences in temperature between top and bottom and between bunker and doorway positions are noted at the end of both 6 and 8 hours of precooling, these differences being greater at the end of 8 hours than at the end of 6. The difference in temperature between layers was least at the fourth-stack position (3°) and greatest at the thirteenth-stack position (21°). Bottom temperatures were lower than top temperatures at all positions except at the baffle (doorway position) which was 7° lower on the top layer than on the bottom.

The top-layer fruit cooled the most at the bunker and doorway positions and least at the fourth-stack, quarter-length, and thirteenth-stack positions (fig. 34). These differences in cooling indicate that as the low-temperature air entered the top bunker opening it dropped to the fruit near the bunker, thereby cooling it. As a suction operated at the other end of the car this air probably passed over the load, penetrating only at the doorway position where the canvas baffle was located. It is likely that more uniform cooling could be accomplished in the top layer by placing a baffle at about the quarter-length position in each end of the car.

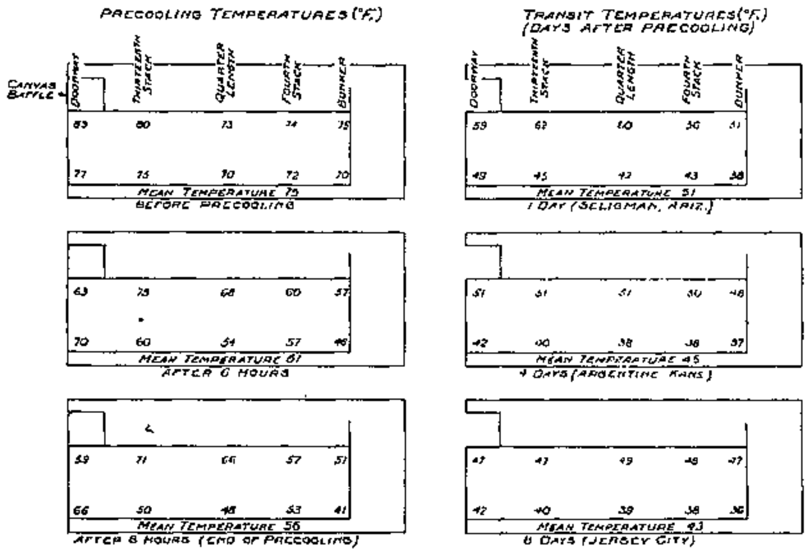

FIGURE 34.—Fruit temperatures during precooling and transit at center row of car D, carrier precooled, initially iced after precooling and not reiced in transit, May 10–20, 1932.

In a later test, 1933–2, fruit temperatures were taken in rows other than the center in a car precooled at San Bernardino. Results of this test showed that fruit in the rows next to the side cooled approximately 5° more than the center-row fruit on both top and bottom layers, indicating that in all probability a large portion of the air entering at the top bunker opening had got by the canvas baffle by moving down between the side walls and outside rows of fruit, thence passing to the other end of the car along the wall below the level of the baffle. Air circulating in such a manner would naturally cool the outside rows of fruit more than the center row. Since the temperatures in car D (fig. 34) were all taken in the center row, they are probably about 3° warmer than the true average of the load.

At the end of the 8-hour precooling, car D was initially iced by the Santa Fe Railway and was not reiced while in transit to New York City. All positions except those at the bunker showed a large drop in fruit temperatures during the first 4 days, while during the remaining 4 days only top-layer fruit temperatures dropped, and they only slightly (fig. 34). All top-layer fruit showed a uniform temperature at the end of the fourth day; bottom-layer temperatures varied as under standard refrigeration.

Comparison of Temperature in Precooled and Nonprecooled Shipments

The weighted average temperatures of the precooled cars, C, D, and E, and of the nonprecooled cars, A and B, in the same test, 1932–4, are illustrated in figure 35. Although all five cars moved

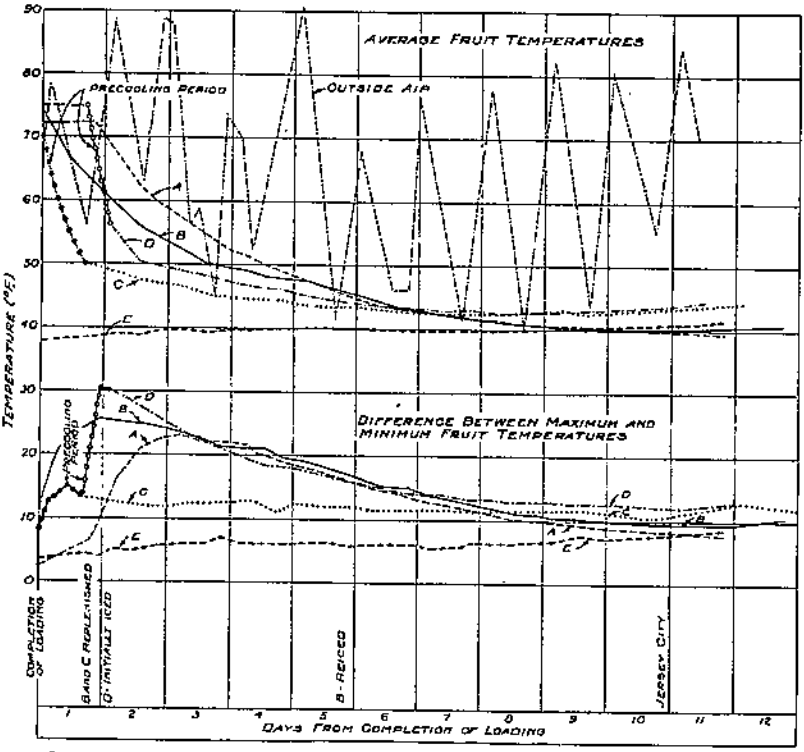

Figure 35.—Average fruit temperatures and the difference between maximum and minimum temperatures in precooled and nonprecooled loads, May 10–20, 1932.

eastward in the same train, car B to permit replenishing of the ice on the day after loading by the shipper, and car C to allow time for fan precooling were loaded a day previous to the other cars and were held for a day at the packing house. To show the rate of cooling in the five cars with the elapsed time, the temperature curves of cars B and C were moved forward 1 day on the graph in figure 35 so that the temperature record of all cars starts at the same time. The mean temperature of each curve for each day in transit is found in table 21. Car E containing warehouse-precooled fruit maintained the lowest temperatures in transit. This car had nearly arrived at Jersey City before standard refrigeration cooled to the same temperature (40.5° F.). The bunkers of car E were half full on arrival at Jersey City and only a rise of 2½° in average temperature of the load had occurred during transit.

Using the average temperature for the transit period as an index of refrigeration furnished, the second-best record was made by car C, the third by car B, and the fourth by car D. The poorest record was made by car A.

TABLE 21.—*Daily average fruit temperatures for all positions in five cars in test 1932-4, May 10-20*

Time in transit (days)	Car A [1]	Car B [2]	Car C [3]	Car D [4]	Car E [5]
	°F.	*°F.*	*°F.*	*°F.*	*°F.*
At completion of loading	72.0	74.5	72.5	75.0	38.0
First	72.1	66.3	55.1	72.0	38.2
Second	63.2	56.5	47.8	51.5	39.1
Third	55.1	50.8	45.7	48.0	39.4
Fourth	50.0	48.3	44.4	46.0	39.7
Fifth	46.3	46.5	43.5	44.5	39.9
Sixth	43.5	43.8	43.0	43.5	39.7
Seventh	42.0	41.9	42.5	43.0	39.7
Eighth	40.9	40.8	42.5	42.5	39.9
Ninth	40.4	40.1	42.6	43.0	40.1
Additional ¼ day	40.2	40.0	42.7	43.0	40.5
Average	50.1	48.1	45.2	49.0	39.5

[1] Standard refrigeration.
[2] Preiced, replenished 15 hours after loading, reiced fifth day.
[3] Preiced, fan precooled 16 hours, replenished after precooling, and not reiced in transit.
[4] Dry car, precooled for 8 hours by carrier, initially iced after precooling, and not reiced in transit.
[5] Preiced car loaded with warehouse precooled fruit.

However, perhaps the best index for the relative merits of the methods is the rapidity with which they cool the load to a temperature below 50° F., since temperatures above 50° are not considered conducive either to the control of decay or to the preserving of best eating quality of the fruit. The greatest value from refrigeration is in cooling to temperatures below 50° as quickly as possible. Beginning with a temperature of 72°, standard refrigeration took 3½ days to lower the average temperature to 50°, whereas preicing reduced it from 74.5° to 50° in 2½ days, carrier precooling from 75° to 50° in 1¾ days, and fan precooling from 72.5° to 50° in 16 hours. Thus, under the conditions of this test, preicing with limited icing in transit and all three methods of precooling with no reicing in transit were superior to standard refrigeration, whether the basis of comparison is the average temperature in transit or the rapidity in cooling to a temperature below 50°. Standard refrigeration did give temperatures of 1° to 4° lower than those of the other cars at destination, the benefit of which is doubtful.

Differences in the temperatures maintained in transit in the precooled cars were due to differences in the amount of precooling furnished by the different methods. The carrier method, although more rapid than fan precooling, cooled the load only to 56° F., as compared with 50° for the latter, because of a shorter precooling period. However, under neither method was field heat removal from the load completed during the precooling period. Car C cooled 7° and car D 13° after precooling was finished.

The bunkers of cars C and D were both less than one-third full upon arrival at Jersey City, and a slight rise in temperature had occurred in both cars. In all probability had the test been made during the summer with warmer outside temperatures heat leakage would have been sufficiently great to require one reicing in transit. The bunkers of car E contained enough ice (one-half full) upon arrival at Jersey City so that there was probably a sufficient reserve to take care of any additional heat leakage that might occur during summer weather.

Actually, however, the average fruit temperatures do not give a complete picture of what happened under each method. It has already been shown that in each car there was a lack of temperature uniformity at different positions. A comparison of the maximum temperature range in each car, that is, the difference in temperature between the warmest and coldest parts of the load, is presented graphically in the lower part of figure 35. The inequalities in temperatures were greatest in car D, carrier precooled, and least in car E, warehouse precooled. Of the cars loaded with warm fruit,

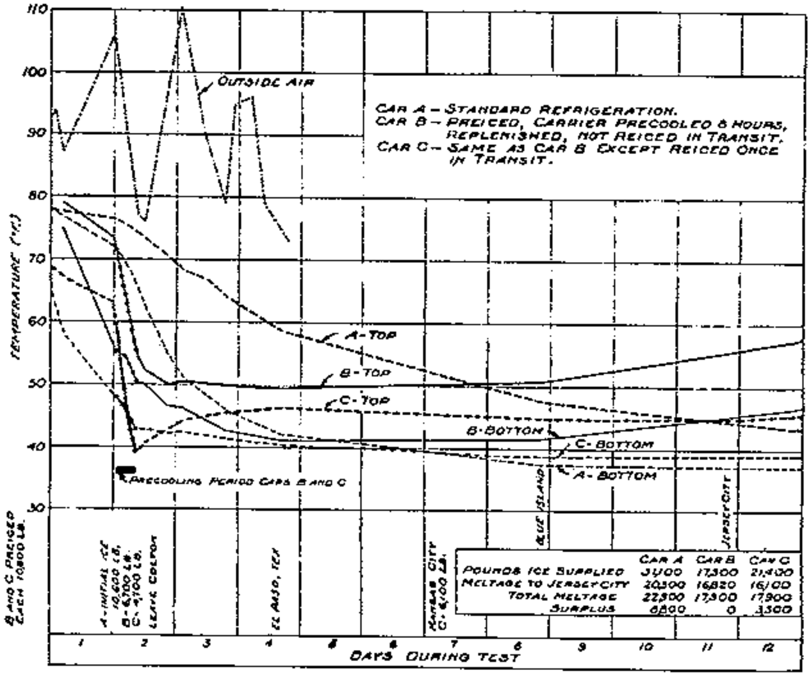

Figure 36.—Average top and bottom fruit temperatures in car A under standard refrigeration and in cars preiced, precooled, and replenished. Car B had one reicing in transit and car C none; August 17–29, 1932.

car C, fan precooled, showed the least variation in temperature. In cars A, B, and D, which had the least uniform temperatures, the differences were greater during the period of most rapid cooling at the beginning of the test.

Preiced, Carrier Precooled for 8 Hours, Replenished After Precooling, and Either Reiced or Not Reiced in Transit

[Tests during hot summer weather]

One of the difficulties to be overcome in carrier precooling as used in test 1932–4 was the delay between loading and the beginning of cooling. In test 1932–6 it was found that this delay in cooling could be avoided by precooling a preiced car. The results of this test are presented graphically in figure 36. Fruit temperatures were taken in transit as far as El Paso, again at Blue Island, Ill., and on arrival at Jersey City. Preicing cars B and C cooled the top layer 6° and the bottom layer 22° during transit to the precooling plant at Colton. At Colton air at 23° to 30° F. was blown through cars B and C for 8 hours, causing a drop of 19° in the top layer of car B and 24° in the top layer of car C. Both cars cooled the bottom layer 5½°. Although car C showed the greatest drop in top temperatures, the effective precooling accomplished was about the same in both cars, as evidenced by a sharp rise in car C following precooling while car B continued to cool.

This cooling, obtained in car B by preicing plus precooling, maintained top-layer temperatures in that car below those of standard refrigeration for 6 days without reicing in transit. Car C, reiced once in transit, maintained temperatures below standard refrigeration for 9 days; however, the fruit temperature at loading was lower in this car than in car A. The excessive rise in top-fruit temperature in car B near the end of the trip indicates that when this method was used during the summer months the cars should be reiced once in transit.

These data show that preicing plus carrier precooling followed by replenishing gives lower temperatures in transit than standard refrigeration. Also, by comparing results of this test with those of other tests, it is evident that the preiced, carrier-precooled method as used in these tests furnished more refrigeration than any other method except warehouse precooling and possibly fan precooling.

FRUIT INSPECTION AT DESTINATION

SPOILAGE

Fruit inspections in tests made during 1929 and 1930 consisted of an examination for decay at the time of unloading of six boxes of oranges of the same grade from each car. These boxes were selected from the following positions in the car: Top south-side doorway, bottom south-side doorway, top center doorway, bottom center doorway, top center bunker, and bottom center bunker. Considerable variation was expected in the keeping quality of fruit in the various test cars because no attempt was made to obtain fruit grown and handled under strictly comparable conditions. Nevertheless, the sample of fruit inspected was sufficiently large and the tests were repeated often enough so that the resulting data (table 22) should throw some light on the amount of decay to be expected under the different methods of refrigeration.

In the later tests, 1931 and 1932, comparable lots of fruit from the same grove, of the same size, picked the same day and given the same packing-house treatment were placed in different cars of the same test, thus making it possible to secure more reliable data on the relation of method of refrigeration and spoilage in transit. Examination was made of the fruit in one end of each box at the time of unloading in New York City, and 7 to 21 days later a similar examination was made of the fruit in the other end of the box. During the holding period in New York City the fruit was stored at room temperature either in the market disease laboratory of the United States Department of Agriculture or in a wholesale fruit store in New York (table 22).

TABLE 22.—*Summary of decay records made at time of unloading test carloads of oranges in New York City during 1929 and 1930*

Test no. and date	Variety	Experimental lot no.	Method of refrigeration	Origin of fruit	Cars	Average decay [1]
					Number	*Percent*
1929-1, May 1-13.	Washington Navel.	1	Standard refrigeration	Upland	2	1.7
		2	Initially iced, San Bernardino; not reiced.	do	2	1.7
		3	Warehouse precooled; preiced only.	La Verne	4	2.8
1929-2, May 15-27.	Valencia	4	Standard refrigeration	Upland	2	1.7
		5	Half-tank standard refrigeration	Ontario	2	1.0
		6	Initially iced, Colton; reiced, Silvis.	Upland	2	3.3
		7	Warehouse precooled; preiced only.	Pomona	2	.1
		8	do	Narod	2	.5
1929-3, May 29-June 6.	do	9	Standard refrigeration	Tustin	2	.0
		10	Initially iced, Colton; reiced, North Platte.	Hillgrove	2	.0
		11	Warehouse precooled; preiced only.		2	.0
		12	do		2	.0
1929-4, July 6-17.	do	13	Standard refrigeration	Tustin	2	.5
		14	Half-tank standard refrigeration	Anaheim	2	1.3
		15	Initially iced, Colton; reiced, El Paso.	Tustin	2	.5
		16	Warehouse precooled; preiced only.	Orange	2	.2
1929-5, July 20-31.	do	17	Standard refrigeration	Whittier	1	.0
		18	Half-tank standard refrigeration	do	1	.7
		19	Initially iced, Colton; reiced, North Platte.	Tustin and La Habra.	2	.4
		20	Warehouse precooled; preiced only.	San Dimas	2	.2
1929-6, Aug. 9-19 and 26.	do	21	Standard refrigeration (Aug. 19) [2]	Placentia	1	.0
		22	Standard refrigeration (Aug. 26) [2]	do	1	1.6
		23	Half-tank standard refrigeration (Aug. 19).[2]	do	1	.7
		24	Half-tank standard refrigeration (Aug. 26).[2]	do	1	1.6
		25	Initially iced, San Bernardino; reiced, Belen (Aug. 19).[2]	Orange County	7	.5
		26	Initially iced, San Bernardino; reiced, Belen (Aug. 26).[2]	do	1	.6
		27	Warehouse precooled; preiced only (Aug. 19).[2]	Orange	1	.5
		28	Warehouse precooled; preiced only (Aug. 26).[2]	do	1	1.5
1929-7, Aug. 30-Sept. 10 and 15.	do	29	Standard refrigeration (Sept. 10)[2]	Placentia	2	.3
		30	Standard refrigeration (Sept. 15)[2]	Frances	2	.2
		31	Initially iced; reiced, Clovis (Sept. 10)[2].	Tustin	2	.6
		32	Initially iced, reiced, Clovis (Sept. 15)[2].	do	1	.8
		33	Initially iced, reiced, Belen (Sept. 10)[2].	Orange County	3	.3
		34	Warehouse precooled; preiced only (Sept. 10)[2].	Orange	1	.3
		35	Warehouse precooled; preiced only (Sept. 15)[2].	do	1	.6
1929-8, Sept. 20-Oct. 1 and 8.	do	36	Standard refrigeration (Oct. 1)[2]	Orange County.	2	.7
		37	Standard refrigeration (Oct. 8)[2]	do	1	1.1
		38	Initially iced, Colton; reiced, Silvis—2 tons (Oct. 8)[2].	do	1	3.4
		39	Initially iced, Colton; reiced, Silvis—2 tons (Oct. 1)[2].	do	1	1.4
		40	Initially iced, Colton; reiced, Silvis—1 ton (Oct. 1)[2].	do	1	1.0
		41	Initially iced, Colton; not reiced (Oct. 1)[2].	do	1	1.1
		42	Warehouse precooled; preiced only (Oct. 1)[2].	do	3	.1

[1] Based on decay found in a box taken from the following positions in each car: Top center bunker; bottom center bunker; top center doorway; bottom center doorway; top south-side doorway; and bottom south-side doorway.

[2] Date in parentheses indicates time of unloading.

TABLE 22.—*Summary of decay records made at time of unloading test carloads of oranges in New York City during 1929 and 1930*—Continued

Test no. and date	Variety	Experimental lot no.	Method of refrigeration	Origin of fruit	Cars	Average decay[1]
					Number	*Percent*
1929-9, Oct. 15-28.	do	43	Standard refrigeration	La Habra and Fullerton.	2	1.0
		44	Initially iced, Colton; not reiced	Whittier, Anaheim, and La Habra.	9	1.5
		45	Warehouse precooled; preiced only.	San Dimas and Orange.	2	.1
1930-1, June 4-16.	do	46	Standard refrigeration	Fullerton and Olive.	2	.2
		47	Initially iced, San Bernardino; reiced, Kansas City.	Placentia and Anaheim.	2	1.0
		48	Initially iced, San Bernardino, reiced, Clovis and Clearing.	Placentia and Orange.	2	.4
		49	Warehouse precooled; preiced only.	Orange.	2	.2
		50	Fan precooled; preiced; replenished after precooling.	Placentia	1	.7
1930-2, July 9-20.	do	51	Standard refrigeration	La Habra	1	.5
		52	Preiced; standard refrigeration	Mission	2	.1
		53	Preiced; replenished, Colton; reiced, Kansas City.	Tustin	1	.0
		54	Preiced plus salt; replenished, Colton; reiced, Kansas City.	do	1	.0
		55	Preiced; replenished, Colton; reiced, El Paso and Blue Island.	Villa Park	1	.2
		56	Preiced plus salt; replenished, Colton; reiced, El Paso and Blue Island.	Tustin	1	.0
		57	Initially iced, Colton; reiced Kansas City.	Hillgrove	1	.5
		58	Initially iced, Colton; reiced, El Paso and Blue Island.	do	1	.5
		59	Warehouse precooled; preiced only.	Fullerton and San Dimas.	4	.2
1930-3, Aug. 13-24.	do	60	Standard refrigeration	Yorba Linda	1	.0
		61	Initially iced, Colton; reiced, Grand Junction.	Whittier	1	.0
		62	Initially iced, Colton; reiced, Chicago.	Anaheim and Covina.	2	.3
		63	Preiced; replenished, Colton; reiced, Chicago.	Hillgrove	1	.2
		64	Preiced plus salt; replenished, Colton; reiced Chicago.	Whittier	1	1.1
1930-4, Sept. 16-28.	do	65	Standard refrigeration	Hillgrove	1	.0
		66	Initially iced, Colton; reiced, Council Bluffs.	Anaheim	1	.7
		67	Preiced; replenished, Colton; not reiced.	Hillgrove	1	2.9
		68	Precooled by carrier; initially iced after precooling; not reiced.	Placentia	1	.4

[1] Based on decay found in a box taken from the following positions in each car: Top center bunker; bottom center bunker; top center doorway; bottom center doorway; top south-side doorway; and bottom south-side doorway.

TABLE 23.—*Summary of inspection records made on test carloads of oranges in New York City during 1931 and 1932*

[All lots of fruit in the same test were picked from the same grove, and treated the same while in the packing house. Fruit in all tests except 1932-5 was washed and treated with a borax solution but was not waxed. That in test 1932-5 was neither washed, treated, nor waxed. Fruit in tests 1931-2 and 1932-4 and 1932-5 was not sweated, while that in all other tests was sweated 60 to 72 hours prior to treatment with borax solution]

Test trip no.	Variety and size	Experimental lot no.	Source and date of packing and loading	Method of refrigeration	Boxes per lot	Location in car	Date of unloading
					Number		
[1] 1931-2	Washington Navel, 216	69	Upland, Mar. 11	Standard refrigeration	1	Top center doorway	Mar. 23
		70		do	1	Bottom bunker	
		71		Preiced; replenished; not reiced	1	Top center doorway	
		72		do	1	Bottom bunker	
		73		Initially iced, Colton; not reiced	1	Top center doorway	
		74		do	1	Bottom bunker	
1931-3	Valencia, 200	75	La Habra, May 13	Standard refrigeration	1	Top center doorway	May 25
		76		Preiced; replenished; reiced, Dalhart	1	do	
		77		Initially iced, Colton; reiced, El Paso and Blue Island	1	do	
		78		Initially iced, Colton; reiced, Kansas City	1	do	
1931-4	Valencia, 216	79	Anaheim, July 8	Standard refrigeration	1	do	July 19
		80		Initially iced, Colton; reiced, Ogden and Blue Island	1	do	
1931-5	Valencia, 252	81	Fullerton, July 30	Standard refrigeration	1	do	Aug. 12
		82		Preiced; replenished; reiced, Dalhart	1	do	
1931-6	Valencia, 216	83	Fullerton, Sept. 15	Standard refrigeration	5	do	Sept. 26
		84		Preiced; reiced, Winslow	5	do	
		85		Preiced; replenished; reiced, Waynoka	5	do	
		86		do	5	Bottom bunker	
1931-7	do	87	Anaheim, Oct. 14	Standard refrigeration	5	Top center doorway	Oct. 27
		88		Preiced; replenished; reiced, Clovis	5	do	
		89		Standard refrigeration	5	Bottom bunker	
[2] 1932-4	do	90	Tustin, May 10	do	1	Top center doorway	May 22
		91		Preiced; replenished; reiced, Clovis	1	do	
		92		Preiced; fan precooled; replenished; not reiced	1	do	
		93		Standard refrigeration	1	Bottom bunker	
1932-5	do	94	Anaheim, June 14	do	1	Top center doorway	June 27
		95		Warehouse precooled; preiced only	1	do	

[1] Test 1931-1 was a ventilation test. This bulletin deals only with refrigeration tests.
[2] No inspection was made of fruit in tests 1932-1, 1932-2, 1932-3.

TABLE 23.—*Summary of inspection records made on test carloads of oranges in New York City during 1931 and 1932*—Continued

Test trip no.	Time and condition of holding	Total decay[3]		Slight pitting[4]		Bad pitting[4]		Slight spotting[4]		Bad spotting[4]		Slight aging[4]		Bad aging[4]		Total bad pitting, spotting, aging[4]		Total slight and bad pitting, spotting, aging[4]	
		At unloading	After holding	At unloading	After holding	At unloading	After holding	At unloading	After holding	At unloading	After holding	At unloading	After holding	At unloading	After holding	At unloading	After holding	At unloading	After holding
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
[1] 1931-2	7 days in laboratory at room temperature	0.6	5.7	4.5	11.3	1.1	4.0	0	0	0	0	0	0	0	0	1.1	4.0	5.0	15.3
		0	4.0	4.5	18.7	0	1.7	0	0	0	0	0	0	0	0	0	1.7	4.5	20.4
		0	5.1	10.2	11.3	.6	1.1	0	0	0	0	0	0	0	0	.6	1.1	10.8	12.4
		0	4.5	14.7	13.0	.6	1.1	0	0	0	0	0	0	0	0	.6	1.1	15.3	14.1
		1.1	6.7	9.6	20.0	1.1	.6	0	0	0	0	0	0	0	0	1.1	.6	10.7	20.0
		0	2.8	2.8	11.9	0	0	0	0	0	0	0	0	0	0	0	0	2.8	11.0
1931-3	21 days in wholesale store at room temperature	4.0	9.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		3.0	4.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		2.0	6.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		6.0	8.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1931-4	do	0	2.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
		0	.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
1931-5	do	0	4.0	2.0	3.2	1.2	2.4	2.0	4.0	1.2	5.5	1.6	8.7	2.4	3.2	4.8	11.1	10.4	27.0
		0	5.5	7.1	7.1	2.0	3.2	0	0	1.2	3.2	0	4.8	2.4	0	5.6	6.4	12.7	18.3
1931-6	do	2.0	5.0	2.8	5.8	.6	3.5	2.3	5.5	1.3	2.4	.8	1.2	0	0	1.9	5.9	7.8	18.4
		.9	4.5	4.1	8.3	.4	3.5	1.7	9.6	.9	1.7	2.1	2.7	.5	0	1.8	5.2	9.7	25.8
		.9	5.2	5.3	6.0	.9	5.9	2.4	7.3	.4	3.5	.9	2.3	0	0	1.3	9.4	9.9	25.0
		0	6.1	1.3	6.9	.7	3.4	1.5	5.6	1.3	2.5	.2	1.4	.2	.7	2.2	6.6	5.2	20.5
1931-7	do	3.0	9.6	6.5	15.7	1.5	10.8	1.5	5.6	1.5	3.0	.2	.4	0	0	3.0	13.8	11.2	35.5
		3.7	11.1	2.3	12.8	1.6	9.4	.9	2.4	1.3	2.0	0	1.1	0	0	2.8	11.4	6.0	27.7
		2.4	10.9	1.9	9.4	1.3	10.4	1.3	3.5	.4	3.4	.2	.7	0	0	1.7	13.8	5.1	27.4
[2] 1932-4	14 days in laboratory at room temperature.	0	1.8	0	.9	0	.9	0	0	0	0	0	12.0	0	0	0	.9	0	13.8
		0	0	0	1.8	0	0	0	0	0	0	0	14.8	0	0	0	0	0	16.6
		0	1.8	0	0	0	0	0	0	0	.9	0	6.5	0	0	0	.9	0	7.4
		0	0	0	0	0	0	0	0	0	0	0	8.3	0	0	0	0	0	8.3
1932-5	do	0	.5	0	2.0	0	0	0	4.0	0	0	0	0	0	0	0	0	0	6.0
		0	0	0	1.0	0	0	0	4.0	0	3.0	0	0	0	0	0	3.0	0	8.0

[1] Test 1931-1 was a ventilation test. This bulletin deals only with refrigeration tests.
[2] No inspection was made of fruit in tests 1932-1, 1932-2, and 1932-3.
[3] Practically all decay was caused by *Penicillium italicum* and *P. digitatum*.
[4] No inspection in tests 1931-3 and 1931-4 for pitting, spotting, and aging.

Aging, as interpreted by those making the inspections, is described as a shriveling of the skin at the stem end and does not involve collapse of oil vesicles. Pitting is the collapse of individual oil vesicles, the pitted area not being uniformly sunken or discolored. Spotting is defined as an area involving five or more oil vesicles all of which are uniformly discolored. It was noted that the majority of the spots were associated with aging or pitting and seemed to be an advanced stage of either where possibly secondary organisms had entered. Thus, when studying the inspection data the above observation should be kept in mind.

The spoilage record of all tests is presented in tables 22 and 23. Typical temperature curves of these different methods were presented earlier in this bulletin. In the 1929–30 tests only the average decay of all six positions in the car is presented, as there was no significant difference in the decay found at the individual positions. In these tests (table 22) decay was only slight under all methods of refrigeration, there being no significant difference in that occurring under any of the methods even when the cars were held for 1 week in Jersey City without reicing as in certain lots of tests 1929-6, 1929-7, and 1929-8.

Similar results were also obtained at the unloading inspection in the 1931-32 tests (table 23) which contained comparable lots of fruit in each car of the individual tests. Particular attention should be given to the results of tests 1931-6 and 1931-7, which contained five boxes at each position. The average percentage for each of the diseases or disorders occurring in the five-box lots is used as an index of the behavior of that lot, as there was no extreme variation among the individual boxes of those lots. It will be noted on observing table 23 that only a few troubles were found in all lots of either test. Of the two tests spoilage was greatest in test 1931-7, the reason perhaps being inherently weaker fruit.

The inspection made 21 days after unloading showed a decided increase in all disorders in all lots, this increase being greatest in test 1931-7. Of the physiological disorders, pitting was the most severe. Some of the boxes at this inspection had over 50 percent of pitted fruit.

The results of these tests as a whole show no relation between spoilage and the method of refrigeration, or the temperature maintained in transit. The bottom bunker lots numbered 70, 72, and 74 in test 1931-2, 86 in test 1931-6, and 89 in test 1931-7, showed slightly less decay and pitting than the other lots at the end of the transit period; however, since these disorders occurred to only a slight extent in all lots the differences between lots in the individual tests were not considered significant. After the holding period in New York there was still no significant difference in spoilage among the lots of the individual tests, although it was heavy in all lots.

While temperatures in transit influence the keeping quality of the fruit, other factors, such as orchard treatment, time of picking, handling, sweating, washing, etc., likewise influence the keeping quality and may partly overshadow the effect of differences in transit conditions. The results presented above are of value in indicating that the modified forms of refrigeration can be used with safety, since spoilage is no greater under these methods than under standard refrigeration.

LOSS IN WEIGHT

Information on loss in weight during transit to New York City and during the 21-day [20] holding period in New York was obtained for all experimental lots in 5 of the tests and is presented in table 24. These data show that loss in weight of Valencia oranges in transit was slight under all methods of refrigeration, but where there were any great differences in temperatures maintained under the various methods the loss in weight varied directly with the temperature. Fruit placed at the bottom bunker position lost only three-fourths to one-half as much weight as that placed at the top center doorway position, the difference in temperature of the two positions ranging from 10° to 15° in the different tests.

[20] The fruit in test 1932-4 was held for only 14 days after unloading in New York.

No record was taken of humidity in the cars during transit, but it was realized that loss in weight was undoubtedly influenced thereby as well as by the temperature. In all probability the relative humidity was higher at the bottom bunker position than at the doorway because of proximity to the melting ice as well as the lower temperature.

Additional loss in weight during the 21-day holding period following unloading in New York was practically the same in all lots of the same test and amounted to considerably more in each lot than during the transit period. The average air temperature and average relative humidity in the wholesale store where the fruit was held is shown in table 24 in connection with the percentage loss in weight. It is probable that in these tests the higher temperatures, and possibly lower humidities as well as the longer time interval of the holding period as compared with the transit period, all contributed to the greater loss while the fruit was held in New York City than while it was in transit.

TABLE 24.—*Effect of method of refrigeration on loss in weight of Valencia oranges*[1] *while in transit from California to New York during 1931 and 1932*

Test trip number and date	Experimental lot number	Origin of fruit	Method of refrigeration	Boxes per lot	Location in car	During transit: Time	During transit: Average temperature	During transit: Loss in weight	During holding period[2] in New York City: Time	During holding period: Average temperature	During holding period: Average relative humidity	During holding period: Additional loss in weight	Total loss in weight
				Number		*Days*	*° F.*	*Percent*	*Days*	*° F.*	*Percent*	*Percent*	*Percent*
1931–4, July 7–Aug. 9.	79	Anaheim	Standard refrigeration	1	Top center doorway.	12	56	1.2	21	80	58	3.8	5.0
	80		Initially iced, Colton; reiced, Ogden and Blue Island.	1	do	12	56	1.3	21	80	58	4.6	5.9
1931–5, July 28–Sept. 3.	81	Fullerton	Standard refrigeration	1	do	14	54	1.3	21	75	59	2.8	4.1
	82		Preiced, replenished; reiced at Dalhart	1	do	14	58	1.4	21	75	59	3.1	4.5
1931–6, Sept. 14–Oct. 19.	83	do	Standard refrigeration	5	do	14	55	2.4	21	64	65	3.1	5.5
	84		Preiced; reiced at Winslow	5	do	14	57	2.9	21	64	65	2.5	5.4
	85		Preiced; replenished; reiced, Waynoka	5	do	14	55	2.3	21	64	65	3.0	5.3
	86		do	5	Bottom bunker	14	40	1.4	21	64	65	3.4	4.8
1931–7, Oct. 13–Nov. 17.	87	Anaheim	Standard refrigeration	5	Top center doorway.	13	50	2.6	21	54	60	3.7	6.3
	88		Preiced; replenished; reiced, Clovis	5	do	13	50	2.4	21	54	60	3.7	6.1
	89		Standard refrigeration	5	Bottom bunker	13	40	2.0	21	54	60	3.3	5.3
1932–4, May 9–June 6.	90	Tustin	do	1	Top center doorway.	13	56	3.1	14	74	54	4.2	7.3
	91		Preiced; replenished; reiced, Clovis	1	do	13	54	2.6	14	74	54	3.9	6.5
	92		Preiced; fan precooled; replenished; not reiced.	1	do	13	48	2.0	14	74	54	4.2	6.2
	93		Standard refrigeration	1	Bottom bunker	13	42	1.5	14	74	54	4.1	5.6

[1] No wax in any form was applied to any of the fruit.
[2] The fruit in all tests except 1932–4 was held in a wholesale store in Washington Market, New York City; that of test 1932–4 was held at room temperature in the Government laboratory in New York City.

APPLICATION OF RESULTS

The results of these investigations have received wide and general application in the transportation of citrus fruit from California. The methods of modified refrigeration tested with oranges have also been adopted and extensively used in the shipment of some of the less perishable deciduous fruits from the Pacific coast.

A study of the fruit temperatures in the various transit tests revealed that certain types of refrigeration could be employed safely and economically on orange shipments at different periods of the season; and that the method of refrigeration to be used with economy is largely governed by the temperature of the fruit at time of loading and the outside temperatures likely to be encountered en route. Thus, the maximum refrigeration is obviously required for shipments forwarded during the period from about June 15 to September 15, when outside temperatures en route are highest. Unnecessary icing of shipments in the past has given rise to excessive expense without benefit to the fruit. For example, it was shown in the investigation that nonprecooled oranges forwarded during the cooler part of the season under initial icing only, held practically as low temperatures as were obtained by frequent reicing of the cars in transit according to standard-refrigeration practice.

As previously stated, the method of preicing with replenishing of the ice after loading plus one reicing in transit provided as effective refrigeration for oranges as was obtained from standard refrigeration during the warmest period of the year. Various modifications of this preicing method were repeatedly tested on shipments in transit. The precooling of oranges with portable fans after loading in preiced cars and replenishment of the ice melted in cooling the fruit appears to offer a useful method for securing satisfactory refrigeration of oranges. Shipments handled in this manner may require one reicing en route in warm weather unless the fruit is precooled to a temperature as low as about 40° F.

The method by which fruit is precooled and then shipped in dry (uniced) cars provided satisfactory carrying temperatures in early spring or between the periods of shipment under ventilation and of shipment in iced cars, and at a relatively low cost. Shipments that were precooled at railroad precooling plants and forwarded in cars without ice but with the ventilators closed for the first 2 or 3 days and then moved under standard ventilation to destination were maintained at very satisfactory temperatures. Precooling without icing of the cars afforded temporary protection across the desert area of high temperature where conditions were unfavorable for ventilated shipment.

The types of refrigeration tested in the investigation, for which provision has since been made in the Perishable Protective Tariff,[21] are indicated in table 25. The refrigeration rates that apply on the various types of service are illustrated by the rates applying on shipments from California to Chicago and New York.

[21] NATIONAL PERISHABLE FREIGHT COMMITTEE. See footnote 14.

TABLE 25.—*Comparison of cost per car lot for shipments of citrus fruit under different methods of refrigeration*[1]

Method of refrigeration	Rate from California to—	
	Chicago	New York
Dry car loaded, standard refrigeration	$80.00	$95.00
Preiced car loaded, standard refrigeration	85.00	100.00
Dry car loaded, precooled and initially iced by carrier, not reiced	47.50	52.50
Preiced car loaded, precooled by carrier, ice replenished, not reiced	52.50	57.50
Dry car loaded, precooled and initially iced by carrier, reiced once in transit	60.00	65.00
Preiced car loaded, precooled by carrier, ice replenished, reiced once in transit	65.00	70.00
Dry car loaded, initially iced by carrier, not reiced	35.25	38.25
Preiced car loaded, ice replenished, not reiced	40.00	43.00
Initially iced by carrier, reiced once in transit	56.00	62.00
Preiced car loaded, ice replenished, reiced once in transit	58.00	62.00
Precooled and preiced by shipper, not reiced in transit	16.00	19.00
Precooled and preiced by shipper, reiced once in transit by carrier	28.00	33.00
Initially iced by shipper, not reiced in transit	16.00	19.00
Initially iced by shipper, reiced once in transit by carrier	32.00	38.00
Preiced car loaded, fan precooled in car by shipper, ice replenished [2]	40.00	43.00
Preiced car loaded, fan precooled in car by shipper, reiced once in transit [1]	56.00	62.00

[1] The refrigeration charge includes cost of transporting ice as well as actual cost of ice and the service of supplying the ice to the bunkers.

[2] On shipments cooled in car by shipper the charges given include not to exceed 4,000 pounds of ice in replenishing. Additional ice that may be required to fill the car bunkers is supplied at the rate of $3.50 per ton.

The granting of lower rates on the various modified types of refrigeration service as shown in table 25 resulted in a general adoption of these methods of refrigeration in place of the more costly standard refrigeration.

The extent to which the modified types of refrigeration have since been applied in the transportation of oranges from California is indicated in table 26, which is based on the shipments made by the California Fruit Growers Exchange in 1933, representing approximately 70 percent of the total orange shipments from California. It may be noted that, as shown in table 2 (p. 8), shipments of oranges under standard refrigeration in 1926, at the beginning of this investigation, exceeded 26,000 cars. In 1933 the modified forms of refrigeration were used on 23,920 cars while standard refrigeration was used on only 152 cars. This indicates that the modified refrigeration services have effected an annual saving to the citrus industry in excess of $1,000,000 when compared with the former cost of refrigeration. The results of the investigation indicate also that improvements in refrigerator cars to further reduce heat leakage should result directly in further economic saving by reducing wasteful meltage of ice in the refrigeration of oranges in transit.

TABLE 26.—*Car-lot shipments of oranges from California under ventilation and under various types of refrigeration, 1932–33* [1]

Type of service	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Total
Standard ventilation	2,710	2,516	2,396	2,494	2,535	1,755	1,150	1,034	540	333	231	317	18,011
Preiced by carrier, standard refrigeration	21	1							2	2			26
Dry car loaded, standard refrigeration	44						2	4	21	40	9	6	126
Precooled and preiced by shipper, reiced once in transit												2	2
Precooled and preiced by shipper, not reiced	540				193	793	1,006	877	977	1,015	1,203	1,777	9,080
Precooled and iced by carrier, reiced once in transit	247					44	33	444	491	499	473	318	2,540
Precooled and iced by carrier, not reiced	61			3	169	396	302	459	311	215	247	242	2,404
Preiced or iced after loading by carrier, reiced once in transit	4					7	24	103	27	5	3	12	185
Preiced or iced after loading by carrier, not reiced	7			1	21	18	168	112	35	25	28	65	480
Preiced or iced after loading by shipper, reiced once in transit	120					22	185	198	301	192	178	181	1,377
Preiced or iced after loading by shipper, not reiced	88		2	5	172	416	212	169	221	222	217	184	1,928
Preiced by carrier, replenished by carrier at first icing station, reiced once in transit								301	412	516	300	203	1,851
Preiced by carrier, replenished by carrier at first icing station, not reiced					58	70	159	360	93	167	279	351	1,533
Preiced by carrier, precooled and replenished by carrier, reiced once in transit								168	382	357	306	171	1,384
Preiced by carrier, precooled and replenished by carrier, not reiced						7	33	209	105	195	180	352	1,147
Total	3,851	2,517	2,398	2,503	3,148	3,527	3,874	4,464	3,978	3,772	3,810	4,241	42,083

[1] As reported by California Fruit Growers Exchange. The data includes about 70 percent of total shipments of oranges from California during the season 1932–33. Complete data on protective services used by all other shippers were not available.

SUMMARY

Twenty-nine refrigeration tests were made during the years 1928–33, during which temperature and icing records were obtained on 189 carloads of California oranges in transit to Chicago and New York. The fruit in these cars was inspected for decay, pitting, and spotting at the time of unloading and in some cases was inspected again after being held in a wholesale market 1 to 3 weeks.

A study of the sources of heat to be reckoned with in the refrigeration of oranges in transit showed that:

Field heat of load and heat leakage from outside the refrigerated space are the major sources of heat in the refrigeration of nonprecooled oranges in transit.

Vital heat is a significant factor in the refrigeration of oranges loaded at high temperatures.

Precooling removes field heat from lading before the start of the transcontinental trip, thus obviating the necessity of removing it in transit at the expense of the ice in the bunkers of the car.

Heat leakage was greater in precooled than in nonprecooled loads, as the lower temperatures of the precooled load produced a greater temperature difference between the outside air and fruit inside the car.

High outside temperatures increased heat leakage considerably over that occurring at lower outside temperatures, even in newly built cars protected against heat with 2¼ to 2½ inches of insulation.

ERRATUM

U. S. Department of Agriculture Technical Bulletin 505, "Refrigeration of Oranges in Transit from California."

Page 85. Sixth and seventh paragraph should read as follows:

Large differences in temperature from top to bottom of the load existed at all positions, these differences becoming smaller during the latter part of the transit period.

Relatively small differences in temperature existed from bunker to doorway position in the first and second layers, but practically no difference in temperature in the third and fourth (top) layers.

Results indicate that circulation of air in the car carries heat that leaks into the car from the outside, together with the field and vital heat of the load, to the bunkers where it is absorbed by ice meltage; when heat leakage is excessive the normal circulation of air in the car is not sufficient to carry this additional heat to the ice so it is absorbed by the load, thus retarding the rate of cooling, or causing an increase in temperature when low temperatures are maintained in the car.

When outside temperatures are lower than the fruit temperatures inside the car the heat flows from the inside to the outside thus causing a loss of heat from the lading.

Both rate of cooling and ice meltage decreased as the temperature of the lading dropped.

Lower temperatures were maintained in outside rows of fruit when the boxes were placed with the bulge side against the side walls of the car than when the boxes were placed with the flat side against the walls.

Nonprecooled loads moving under either standard refrigeration or preiced with limited icing in transit showed that:

Large differences in temperature from top to bottom of the load existed at all position in the first and second layers, but practically no difference in tempera- period.

Relatively small differences in temperature existed from bunker to doorway position in the first and second layers, and practically no difference in temperature in the third and fourth (top) layers.

Nonprecooled oranges moving under standard refrigeration took from 4 to 6 days to lower top-layer temperatures below 50° F., and on arrival in New York City had top-layer temperatures varying from 40° to 45°.

The method of initially icing at first icing station and not reicing in transit afforded refrigeration to nonprecooled fruit about equal to that afforded by standard refrigeration only in early spring when atmospheric and loading fruit temperatures were low.

With nonprecooled fruit during warm summer weather standard refrigeration gave more satisfactory transit temperatures than were secured by the method of initially icing at the first icing station plus one reicing in transit.

The method of initially icing at first icing station plus two reicings in transit gave refrigeration to nonprecooled fruit approximately equal to that of standard refrigeration during summer weather.

During the summer months the prompt cooling obtained in preiced cars replenished at the first icing station and reiced once in transit afforded nonprecooled fruit better temperatures than did standard refrigeration.

Preiced cars, not replenished at first icing station but reiced once in transit, gave refrigeration equal to standard refrigeration in the fall but not during the summer.

Preiced cars replenished by the shipper at the packing house and reiced once in transit gave better refrigeration than standard refrigeration during the summer, provided cars were held at the packing house for 12 to 24 hours after loading before replenishing the bunkers.

Preiced cars replenished after loading and not reiced in transit afforded nonprecooled fruit refrigeration equal to standard refrigeration during early spring and late fall.

Precooling fruit in the car with fans for 16 hours materially increased the rate of cooling, especially in the top layer, and decreased the temperature differences throughout the load below those occurring under any of the methods previously cited.

Carrier precooling for 8 hours was not found to be quite so effective as fan precooling for 16 hours.

Carrier precooling as a refrigeration service was materially improved by the use of a preiced car instead of a dry car for precooling. Preicing provided refrigeration for the fruit during transit to the carrier precooling plant, which is not afforded fruit loaded in a dry car.

The lowest and most uniform temperature in these tests occurred in carloads of warehouse-precooled fruit preiced only.

The value of precooling much below 40° F. is doubtful, as refrigerator cars now in use when preiced only cannot maintain an average fruit temperature below 40° to 45° F., depending on the outside temperatures encountered and the condition of the car.

The results of these tests showed no significant relation between method of refrigeration and spoilage, very little spoilage occurring in any of the experimental cars during transit.

Loss in weight of fruit in transit, which was slight in all cases, was determined largely by the temperature of the fruit.

The granting of lower rates on the various modified types of refrigeration service tested in this investigation has led to a general adoption of these modified methods in place of the more costly standard refrigeration. The results indicate that the use of the modified protective services represents an annual saving to the citrus industry in excess of $1,000,000 when compared with the former cost of refrigeration.

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