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THE REFRIGERATION OF DRESSED POULTRY IN TRANSIT.

By M. E. Pennington, *Chief, Food Research Laboratory*, and A. D. Greenlee, *Assistant Chemist;* H. C. Pierce, E. Witmer, H. A. McAleer, and M. K. Jenkins, *in the field;* J. S. Hepburn, M. O. Stafford, H. C. Robertson, and E. L. Connolly, *in the laboratory*.

HISTORICAL SKETCH.

Considering the great commercial importance of the transportation of perishable products under refrigeration, very little systematic work has been done on the subject. The Transactions of the First International Congress of Refrigeration, held in Paris in 1908, have brought together a mass of diverse information which has been supplemented by the reports presented at the Second Congress of Refrigeration, at Vienna, in 1910. Yet the underlying principles of successful transportation under refrigeration, namely, the temperatures obtainable and their exact effect on the condition of the produce when it reaches the market, is but scantily treated. The very excellent report of J. M. Culp before the International Railway Congress, at Berne, Switzerland, in 1910, gives the history of refrigerated carriers in the United States, and much of technical and general interest as well. Horr [1] has presented some general facts regarding the transportation of poultry, butter, and eggs from the viewpoint of the dairy freight agent, but he gives nothing specific concerning car construction, temperatures maintained, or the effect of the haul on the condition of the goods.

The most definite information on this subject is given in the report by Powell and his associates [2] on the transportation of citrus fruits. This investigation shows that it requires several days for the iced refrigerator car to remove the heat from the load of wrapped, boxed oranges, and that precooled fruit maintains a more constant temperature during the haul than can be obtained when the fruit is loaded unchilled. Very decided differences in temperature were noted in the various parts of the car, especially between the top and bottom of the load, and in the air of the car as compared with the

[1] First International Congress of Refrigeration. Transactions, Paris, 1908.
[2] U. S. Dept. Agr., Bureau of Plant Industry Bul. 123.

fruit in the boxes. The temperature of the car followed the atmospheric fluctuations to a slight degree, while the fruit was frequently unaffected by a car temperature that rose or fell 5 degrees, provided the increased or decreased temperature was not continuous. The present investigation, which includes corresponding data for products requiring lower temperatures than do citrus fruits, confirms and amplifies this information. Powell fixed the fundamentals of the transportation of refrigerated citrus fruits, which do not require a temperature of less than 40° F., and if well handled survive at higher temperatures. He also demonstrated that while the use of low temperatures during transit might enable mechanically injured fruit to reach the market in a salable condition, such fruit would not stand the vicissitudes of marketing and would ultimately redound to the disadvantage of the industries involved, as do all poor products that reach the consumer. In this conclusion, also, the writers of the present bulletin concur, and would lay even more emphasis than does Powell on the bad results seen during the marketing of poultry transported at fluctuating or excessively high temperatures.

Decay in oranges, as well as in almost all other fruits, is definite, and can be gauged with accuracy by inspection; not so with meats, fish, dressed poultry, or eggs. Deterioration, the gradations of which in these products are almost infinite, is so obscure that a description of the appearance alone does not afford an accurate method of fixing the point to which it has progressed. If an exact statement of condition is desired, the laboratory must be depended upon for the composition, since it is the variation between the composition at the time of killing and at the time of observation that measures the changes occurring in the interim. In the course of certain investigations conducted in the Food Research Laboratory it has been found necessary to determine by chemical analysis the effect of temperature upon the speed of decomposition of dressed poultry. A summary of a large number of analyses of chicken flesh from dressed birds kept at varying temperatures[1] showed in a striking fashion the relative rate of decomposition when all the factors except the temperature were constant. The analyses include a study of the distribution of protein and nonprotein nitrogen, the latter increasing at the expense of the former as decomposition proceeds.

Since the amount of nonprotein nitrogenous material is especially indicative of deteriorative changes, an estimation of its quantity in a flesh of known normal composition gives a ready means of measuring the change that has occurred. A method[2] sufficiently rapid and accu-

[1] Hearings before the Committee on Manufactures, United States Senate, Sixty-second Congress, May, 1911.

[2] An Application of the Folin Method to the Determination of Ammoniacal Nitrogen in Meat. J. Amer Chem. Soc., 1910, *32:* 561.

rate for practical purposes has been devised and used to determine the amount of ammoniacal nitrogen in chicken flesh prepared for market in different ways.[1] Therefore, when the changes occurring in flesh during transportation were to be determined, the investigators had a very satisfactory laboratory method at hand by which to obtain the information sought. At the end of the railroad haul, and again at each change of environment during marketing, samples of the product were subjected to an analysis to determine the quantity of ammoniacal nitrogen present. It is upon these laboratory findings, supplemented by the usual visual market inspection, that the statements of condition given in this report are based. It has been found, also, that the development of acidity in the fat is an index of the rate of decay, being especially valuable as an indicator of the promptness and efficiency of the removal of the animal heat.[2] Accordingly, the amount of acid in the gizzard fat was determined for all shipments before they left the packing house.

From the previous work in the laboratory the methods for determining the state of preservation of dressed poultry are fairly well defined. These methods furnish a uniform means of determining the effect of changes in temperature on the keeping of the poultry. They, therefore, may be made the basis of a study of the relation of the temperatures in different parts of a refrigerator car to the changes that occur in dressed poultry while in transit and after arrival at the market. The results obtained furnish a definite means of testing the efficiency of refrigerator cars.

PURPOSE OF THE INVESTIGATION.

The purpose of this investigation has been to determine the temperatures prevailing in refrigerator cars hauling dressed poultry throughout the entire transportation period, and to observe the effect of such temperatures on the condition of the poultry when it arrives at the market. Records were kept of its condition during the whole period of marketing. The responsibility to be assigned to the packer, the carrier, the wholesaler, and the retailer has been apportioned in accordance with the history of the environment and the findings of the chemical laboratory, to which all samples have been submitted for analysis. The details of the effect of the preparation for market and of the treatment during marketing on the product which finally reaches the consumer are reserved for another publication, except in so far as they are needed to elucidate the part played by the carrier.

While gathering the data necessary to answer the primary question of the investigation, namely, the temperatures maintained by cars

[1] U. S. Dept. Agr., Bureau of Chemistry Cir. 70.

[2] Pennington and Hepburn. J. Amer. Chem. Soc., 1910, *32:* 568.

transporting perishable foodstuffs requiring more refrigeration than is needed for fruit, much that is of interest to the packer, the carrier, the middleman, and the consumer has been unearthed. It was observed, for example, that different lots of poultry having identical treatment before shipment, and approximately the same atmospheric conditions during the haul, and requiring the same amount of time to reach the market, arrived in widely varying states of preservation. The differences were attributable, apparently, to the type of car in which the journey was made. A study of the construction of the cars in use on different lines revealed a marked variation both in materials and in construction. Accordingly, those factors in car construction on which efficiency of refrigeration depends were studied, and the temperatures observed in the cars correlated, not only with the preservation of the produce but with the construction of the car as well. As was to be expected from previous work, the temperature of the air in the different parts of the car was found to vary within sufficiently wide limits to affect the stability of the flesh of the poultry. For example, that next to the side walls was quite unlike that in the middle of the car. It was deemed advisable to obtain accurate data on such variations, as well as on the fluctuations in the temperature of the air in the car, compared with the temperature changes undergone by the poultry inside the packages.

SCOPE OF THE INVESTIGATION.

The experiments herein reported, covering the period between August, 1909, and October, 1912, include 120 car-lot shipments of dressed poultry and aggregate 140,000 miles of haul. The hauls averaged between 1,000 and 1,500 miles, terminating almost invariably in New York City. No car was used twice, and six different car lines are represented. The weather conditions varied, because the work continued from season to season, and the territory involved extended from western Iowa to central Tennessee.

The treatment which the produce received before shipment was commercial, but represented the best methods in use. The cars were those ordinarily received by the packer and in no case was a special car used, nor was any difference made in the handling of the car en route because it was under observation. Indeed, the railroads in most instances did not know that the work was being done until after it was finished. The information obtained at the market center covered the usual routine of the unloading of the car, the holding of the goods by the wholesaler for a short period, and its further detention by the retailer. In all of this part of the work commercial surroundings and commercial routine prevailed; hence the facts which follow may be accepted as indicative of the results of the practices of that portion of the trade equipped to handle dressed poultry in car lots or in smaller quantities.

SHIPMENT OF POULTRY.

PREPARATION.

The dressed poultry used in this investigation was prepared for shipment in modern poultry packing houses equipped with mechanical refrigeration. The birds varied in size, some being broilers, some roasters, and some fowls or stewing chickens. Killing was done by cutting the jugular vein in order to drain the carcass of blood, then puncturing the brain to paralyze the feather muscles and destroy life.

The poultry was dry picked according to the usual commercial methods, special care being taken to select only those birds with sound skins to obviate the nonuniformity which might be introduced by torn and rubbed skins. Immediately after dressing, the birds were placed in chill rooms cooled by means of mechanical refrigeration to 32° F. (0° C.), where they were held for 24 hours to remove all of the animal heat. A thermograph registered the temperature changes during chilling. The birds, chilled to 32° F. (0° C.) or less throughout, were then packed in boxes, one dozen to the box. The packing was done in a chilled room, where the boxes remained until they were loaded into the refrigerator car with the usual commercial carload shipment of dressed poultry.

LOADING.

The cars were iced 24 hours before loading, the percentage of salt added varying from 5 to 15 per cent, depending upon the weather. The temperature of the car midway between the door and the end was recorded at that time and again when the loading was finished and the car closed. Records were also kept of prevailing atmospheric conditions. Thermographs, or self-registering thermometers, which made a complete record of the temperature during the entire transit period, were placed in the car, one near the floor next to the bunker to record the air temperature in the coldest part of the car, and another at the top of the load near the center of the car to furnish a similar record for the warmest part of the car, that is, warmest in warm weather, but, on account of loose doors and poor insulation, perhaps not as warm as some other parts of the car in extremely cold weather. The boxes of poultry to be examined chemically were in juxtaposition to one of these thermographs. The period of transit varied from 5 to 10 days and in almost every case was concluded in New York City.

CHEMICAL ANALYSIS.

When the car was opened for unloading, a sample from three fowls was selected from the experimental packages and subjected to the laboratory examination. This consisted in estimating the amount of ammoniacal nitrogen [1] in the muscle tissue, which is an index of

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[1] Pennington and Greenlee. An application of the Folin method to the determination of ammoniacal nitrogen in meat. J. Amer. Chem. Soc., 1910, *32* (4): 561.

the progress of flesh changes, and also the amount of free acid [1] in the fat, since the rise in acidity is an indication of the aging of the whole carcass. The results of the chemical analyses and the condition on arrival at destination of 78 such experiments which are comparable in their methods of procedure are shown in Table 1.

TABLE 1.—*The transportation of dry-packed dressed poultry in refrigerator cars.*

Experiment No.	Shipment made from—	Date of killing.	Record of chilling.			Record of transportation.					At the market.				
			Time (days).	Maximum and minimum temperature of chill room.	Temperature of body cavity when packed.	Temperature of car. Before loading.	Temperature of car. After loading.	Time (days).	Thermometer record.	Temperature of body cavity at end of journey.	Date of arrival at New York City.	Time since killing (days).	Ammoniacal nitrogen. Fresh basis.	Ammoniacal nitrogen. Dry basis.	Acid value of crude gizzard fat.
		1910.		°*F.*	°*F.*	°*F.* Center.	°*F.*		°*F.*	°*F.*	1910.		*P. ct.*	*P. ct.*	
2001	Iowa ..	Sept. 6	1	26 to 33	30	57	73	6	32 to 37	....	Sept. 13	7	0.0147	......	2.13
2003	...do...	Sept. 13	1	28 to 36	34	32	50	6	34 to 36	....	Sept. 20	7	.0132	......	2.13
2004	...do...	Sept. 20	1	27 to 33	34	40	65	7	30 to 37	37	Sept. 28	8	.0118	......	2.21
2006	...do...	Sept. 27	1	23 to 32	33	35	55	7	30 to 33	37	Oct. 5	8	......	......	3.95
						Top.									
2008	...do...	Oct. 4	1	28 to 34	36	40	50	7	31 to 33	36	Oct. 12	8	.0115	......	1.76
2010	...do...	Oct. 10	1	29 to 37	35	50	58	7	31 to 34	36	Oct. 18	8	......	......	2.88
2012	...do...	Oct. 11	1	30 to 43	34	36	60	6	34 to 36	36	Oct. 18	7	.0129	......	1.63
2015	...do...	Oct. 17	1	27 to 32	41	50	58	8	26 to 30	34	Oct. 26	9	.0140	......	3.03
2017	...do...	Oct. 18	1	24 to 32	30	39	40	7	27 to 29	34	Oct. 26	8	.0127	......	1.94
2018	...do...	Oct. 24	1	31 to 35	36	48	50	8	29 to 35	41	Nov. 2	9	.0123	......	2.43
2019	...do...	Oct. 25	2	28 to 30	34	32	34	6	....	32	Nov. 2	8	.0122	......	1.90
2020	...do...	Nov. 1	1	30 to 36	34	39	43	8	26 to 31	34	Nov. 10	9	.0122	......	2.10
2022	...do...	Nov. 8	1	27 to 37	32	32	36	7	25 to 32	37	Nov. 16	8	.0140	......	3.31
2024	...do...	Nov. 16	1	27 to 33	30	36	36	7	19 to 25	36	Nov. 24	8	.0129	0.0512	2.31
2025	...do...	Nov. 22	1	29 to 40	34	34	37	6	24 to 32	36	Nov. 29	7	.0137	.0545	1.41
2026	...do...	Nov. 26	1	17 to 28	39	30	30	8	10 to 22	34	Dec. 5	9	.0123	.0492	2.89
2027	...do...	Nov. 29	1	20 to 31	32	30	30	7	23 to 25	30	Dec. 7	8	.0137	.0538	1.87
2028	...do...	Dec. 6	1	24 to 32	30	32	30	7	22 to 24	34	Dec. 14	8	.0120	.0474	2.06
2029	...do...	Dec. 9	3	28 to 41	32	32	30	10	19 to 28	30	Dec. 22	13	......	.0572	2.30
2030	...do...	Dec. 10	1	29 to 35	32	30	25	8	22 to 37	30	Dec. 19	9	......	.0564	3.08
											1911.				
2031	...do...	Dec. 23	1	30 to 35	32	30	28	10	25 to 38	30	Jan. 3	11	.0139	.0541	2.17
2032	...do...	Dec. 30	1	32 to 35	28	32	32	11	20 to 37	30	Jan. 11	12	.0158	.0616	2.88
		1911.													
2033	...do...	Jan. 3	1	26 to 37	32	27	28	8	24 to 26	35	Jan. 12	9	......	.0594	1.81
2034	...do...	Jan. 20	1	35 to 39	34	30	30	7	24 to 26	40	Jan. 28	8	.0132	.0496	1.28
2035	...do...	Jan. 24	1	31 to 34	41	38	40	7	25 to 30	34	Feb. 1	8	.0134	.0482	1.12
2036	...do...	Jan. 30	1	30 to 36	36	36	38	7	28 to 34	31	Feb. 7	8	.0129	.0506	1.87
2037	...do...	Feb. 1	2	33 to 37	30	30	26	7	31 to 37	34	Feb. 10	9	.0140	.0519	1.54
2038	Tennessee.	Mar. 9	1	28 to 35	30	39	59	5	28 to 34	36	Mar. 15	6	.0106	.0396	.95
2039	...do...	Mar. 13	2	26 to 39	26	28	36	6	27 to 29	36	Mar. 21	8	.0125	.0449	1.25
2040	...do...	Mar. 15	2	28 to 45	28	21	26	5	28 to 30	34	Mar. 22	7	.0102	.0387	.91
2041	...do...	Mar. 21	2	24 to 36	30	29	35	6	28 to 31	32	Mar. 29	8	.0120	.0451	1.06
2042	...do...	Mar. 28	2	30 to 34	30	31	35	6	28 to 35	34	Apr. 5	8	.0129	.0513	1.45
2044	...do...	Apr. 12	2	26 to 38	32	41	48	6	26 to 37	....	Apr. 20	8	.0126	.0498	1.08
2046	...do...	Apr. 19	2	27 to 42	32	33	47	6	28 to 35	35	Apr. 27	8	.0126	.0488	1.44
2048	...do...	Apr. 26	2	28 to 50	37	34	44	6	32 to 41	37	May 4	8	.0132	......	1.80
2050	...do...	May 3	2	27 to 38	28	36	46	6	35 to 47	42	May 11	8	.0149	.0568	1.36
2053	...do...	May 16	2	36 to 50	33	37	52	6	....	46	May 24	8	.0188	.0760	3.76
2054	...do...	May 23	1	31 to 40	32	34	44	7	32 to 42	42	May 31	8	.0146	.0564	1.59
2055	...do...	May 30	1	37 to 40	26	35	52	6	25 to 34	(2)	June 6	7	.0127	.0497	1.06
2056	...do...	June 15	1	31 to 42	31	37	52	6	34 to 42	35	June 22	7	.0146	.0564	1.27
2057	...do...	June 27	4	24 to 36	33	36	56	5	20 to 28	35	July 6	9	.0110	.0437	2.03
2059	...do...	July 6	1	30 to 42	30	43	50	5	27 to 44	40	July 12	6	.0154	.0610	1.38
2060	...do...	July 13	1	26 to 41	31	37	52	6	36 to 44	41	July 20	7	.0140	.0533	1.08

[1] Pennington and Hepburn. The determination of the acid value of crude fat and its application in the detection of aged foods. J. Amer. Chem. Soc., 1910, *32* (4): 568.

[2] Hard frozen.

TABLE 1.—*The transportation of dry-packed dressed poultry in refrigerator cars*—Contd.

Experiment No.	Shipment made from—	Date of killing.	Record of chilling.			Record of transportation.					At the market.				
			Time (days).	Maximum and minimum temperature of chill room.	Temperature of body cavity when packed.	Temperature of car. Before loading.	Temperature of car. After loading.	Time (days).	Thermometer record.	Temperature of body cavity at end of journey.	Date of arrival at New York City.	Time since killing (days).	Ammoniacal nitrogen. Fresh basis.	Ammoniacal nitrogen. Dry basis.	Acid value of crude gizzard fat.
		1911.		°F.	°F.	°F.	°F.		°F.	°F.	1911.		P.ct.	P.ct.	
2062	Tennessee.	Aug. 30	2	26 to 35	30	34	42	6	35 to 43	39	Sept. 7	8	......	......	1.45
2063	...do...	Sept. 6	2	34 to 38	....	42	47	6	34 to 43	35	Sept. 14	8	.0102	.0418	3.20
2064	...do...	Sept. 14	1	32 to 39	36	41	54	6	30 to 36	40	Sept. 21	7	.0110	.0465	2.84
2065	...do...	Sept. 21	2	35 to 40	30	37	41	5	33 to 40	39	Sept. 28	7	.0140	.0560	1.82
2066	...do...	Sept. 26	3	29 to 38	32	39	52	6	26 to 37	35	Oct. 5	9	.0126	.0519	2.61
2067	...do...	Oct. 4	2	34 to 38	32	35	46	6	....	32	Oct. 12	8	......	.0639	3.08
2068	...do...	Oct. 23	1	31 to 38	30	28	38	6	14 to 19	30	Oct. 30	7	.0112	.0460	2.48
2069	...do...	Nov. 2	1	27 to 34	32	36	40	5	19 to 30	30	Nov. 8	6	.0123	.0483	2.22
2070	...do...	Nov. 8	2	27 to 36	28	31	45	6	28 to 39	29	Nov. 16	8	.0129	.0516	2.10
2071	...do...	Nov. 20	1	27 to 34	32	38	38	8	35 to 47	44	Nov. 29	9	.0148	.0568	3.10
2072	...do...	Dec. 1	4	22 to 35	28	35	41	6	20 to 28	33	Dec. 11	10	......	......	4.46
2073	...do...	Dec. 7	5	22 to 35	....	44	44	6	25 to 38	28	Dec. 18	11	......	......	1.82
2074	...do...	Dec. 19	1	23 to 29	35	......	......	6	21 to 33	36	Dec. 26	7	.0125	.0502	1.66
		1912.									1912.				
2075	...do...	Mar. 26	2	30 to 34	29	38	38	6	25 to 32	33	Apr. 3	8	.0118	......	1.05
2076	...do...	Mar. 28	1	....	30	40	48	5	35 to 44	38	Apr. 3	6	.0087	......	.85
2077	...do...	Apr. 12	1	28 to 33	33	41	52	5	28 to 35	39	Apr. 18	6	.0141	......	1.24
2078	...do...	Apr. 16	1	24 to 32	31	34	48	6	24 to 29	30	Apr. 23	7	.0115	......	1.07
2079	...do...	Apr. 18	1	20 to 33	31.5	......	......	5	23 to 34	33	Apr. 24	6	.0112	......	.99
2080	...do...	Apr. 24	2	25 to 33	31	36	48	5	26 to 32	35	May 1	7	.0106	......	1.58
2081	...do...	Apr. 26	4	26 to 36	30.5	36	48	6	27 to 38	37	May 6	10	.0105	......	2.37
2082	...do...	Apr. 30	1	27 to 34	32	31	40	5	34 to 37	42	May 6	6	.0109	......	1.53
2083	...do...	May 3	1	30 to 34	32	36	46	6	27 to 36	30	May 10	7	.0132	......	1.76
2084	...do...	May 13	1	30 to 34	31	30	44	7	21 to 45	29	May 21	8	.0140	......	1.48
2085	...do...	May 24	1	33 to 36	32	38	50	6	24 to 34	38	May 31	7	.0123	......	2.23
2086	...do...	June 11	1	29 to 34	29	34	54	6	30 to 36	29	June 18	7	.0118	......	1.08
2087	...do...	June 13	6	25 to 37	32	39	50	6	31 to 36	45	June 25	12	.0137	......	2.12
2088	...do...	July 1	1	25 to 36	30	40	56	7	28 to 34	42	July 9	8	.0132	......	1.71
2089	...do...	July 8	3	26 to 39	35	35	50	5	26 to 30	36	July 16	8	.0126	......	3.34
2090	...do...	July 25	1	28 to 36	30	40	60	6	30 to 36	43	Aug. 1	7	.0132	......	1.92
2091	...do...	July 30	3	28 to 33	30	40	58	6	28 to 34	42	Aug. 8	9	.0130	......	2.35
2093	...do...	Aug. 29	1	28 to 33	33	36	46	5	24 to 33	39	Sept. 4	6	.0120	......	3.27
2094	...do...	Sept. 18	2	27 to 33	31	33	48	6	19 to 32	30	Sept. 26	8	.0119	......	3.23
2096	...do...	Sept. 26	1	28 to 33	31	31	47	5	20 to 27	29	Oct. 2	6	.0118	......	1.51
2097	...do...	Oct. 4	0	26 to 30	30	33	53	5	....	34	Oct. 9	5	.0127	......	1.69
2099	...do...	Oct. 17	1	28 to 30	31	31	48	6	22 to 31	34	Oct. 24	7	.0112	......	1.22

GRAPHIC REPRESENTATION OF FOUR TYPICAL SHIPMENTS.

Table 1 shows that there is a decided variation in the different factors which influence the keeping of dressed poultry during transportation, even when proper methods of commercial procedures are followed. It will be observed that the amount of change occurring during the haul varies, and that, generally speaking, the higher the temperature of the carrier the greater the decomposition. To convey clearly the effect of differences in temperature during the haul and while on the market, four typical shipments, taken from Table 1, are shown graphically in figure 1. The rectangular bars indicate the relative deterioration, the solid bars standing for comparatively high-temperature shipments and the frame bars for comparatively low-temperature shipments. The lines on the chart are the temperature records for the different periods indicated at the bottom of the chart. The figures at the side of the chart are degrees Fahrenheit. The periods of day and night are indicated at the bottom of the chart as solid or open rectangles.

Shipment No. 2003 is an example of a shipment made under conditions that would have been satisfactory for citrus fruit. This shipment left the packing house in western Iowa on September 13, 1910. The haul occupied 6 days, during which time the temperature in the car increased from 32° to 36° F. (0° to 2.2° C.), most of this rise

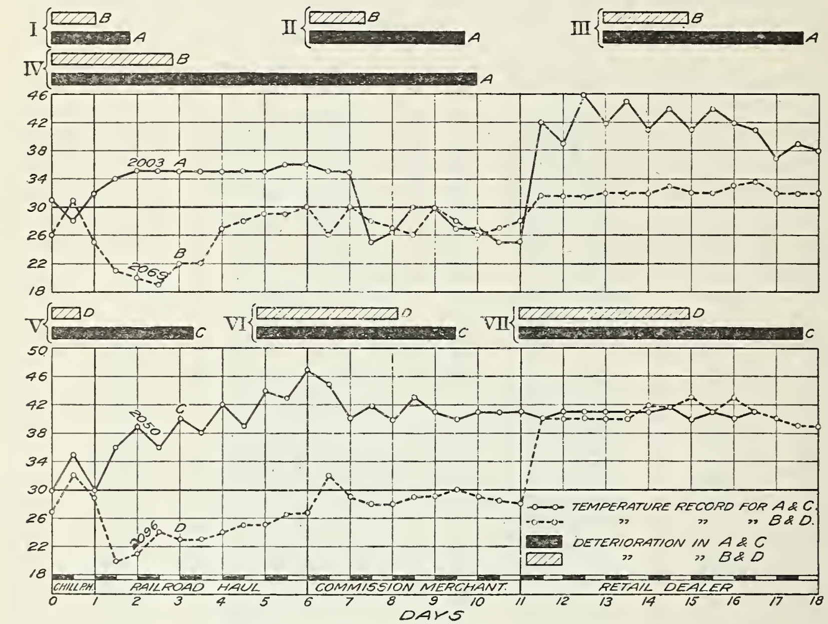

FIG. 1.—Deterioration as shown by ammoniacal nitrogen content of high-temperature and low-temperature shipments; and market temperature records.

Two shipments held at similar temperatures in commission house: No. 2003, A=high-temperature shipment; No. 2069, B=low-temperature shipment. Condition based on analyses: I, At end of railroad haul; II, at end of period at commission house; III, after 4 days at retail store; IV, after 7 days at retail store.

Two shipments held at similar temperatures in retail store: No. 2050, C=high-temperature shipment; No. 2096, D=low-temperature shipment. Condition based on analyses: V, At end of railroad haul; VI, after 4 days at retail store; VII, after 7 days at retail store.

occurring during the first 24 hours. Experiment No. 2069 is a shipment wherein the temperatures during the haul averaged 10 degrees lower. This shipment, which originated in Tennessee, left for New York on November 2, 1911. The haul occupied 5 days, the maximum temperature, which was 30° F. (−1.1° C.), being reached on the day of arrival. The minimum temperature was 19° F. (−7.2° C.), reached about 36 hours after the haul began.

The respective temperature records of these two shipments and a graphic representation of the increase in ammoniacal nitrogen are shown as A and B in figure 1. To make the differences readily observable the two records are parallel on the same chart. The temperature in the packing-house chillroom from which the birds were loaded into the car was nearly the same for both shipments. Here, however, the similarity ceases. During the railroad haul there was a decided difference, especially for the first three days. The relative condition, as determined by analysis at the end of the transit period, is represented by Graph I of figure 1. The amount of change during the haul, where 32° to 36° F. (0° to 2.2° C.) prevailed, is about twice as much as occurred when the temperature was between 19° and 30° F. (−7.2° to −1.1° C.). In the commission man's chillroom the samples were subjected to similar temperatures, but at the end of this period the quality difference is even more pronounced, as seen in Graph II. In this case the impetus given to decay by the higher temperature during the haul could not be checked by subsequent low temperatures. At the retail store shipment No. 2003 was at a great disadvantage as compared with No. 2069, and here the deterioration in the high-temperature shipment was very rapid. The relative deterioration during the first four days is shown in Graph III, that during the subsequent three days in Graph IV.

The transportation temperatures for No. 2050 and No. 2096 differed more than did those for the two previous experiments, and the chemical results were correspondingly different (Graph V). Of the low-temperature shipments, No. 2096 was on the average colder than No. 2069 and its ammoniacal nitrogen is lower. No. 2050 was hauled at a higher temperature than No. 2003 and the nitrogen is also higher (compare Graphs I and V). The temperatures in the commission house for experiments Nos. 2050 and 2096 approximated the temperatures in their respective cars. At the retail shop the temperature records again converge. After four days in the retailer's ice box, where the temperatures fluctuated from 40° to 43° F. (4.4° to 6.1° C.), the relative rate of decomposition, represented in Graph VII, indicates that the impetus given the deteriorative changes in No. 2050 during transportation at high temperatures is still in evidence, and their effect is not lost after the last three days at the retail store, during which the high-temperature shipment gains on its own former rate of change. In the retail shop, experiments Nos. 2050 and 2096 were held at very similar temperatures, fluctuating from 40° to 43° F. (4.4° to 6.1° C.), and this warm environment shows its deteriorating effect on both the high and low temperature shipments (Graphs VI and VII, fig. 1).

AVERAGE RESULTS OF LOW AND HIGH TEMPERATURE SHIPMENTS.

In order to obtain a number of observations, such as are cited for these four individual shipments, the chemical analyses in Table 1 were divided into four groups: First, those in which the record of the thermograph, which was next to the experimental box of poultry, showed an average temperature of 18° to 26° F. (−7.8° to −3.3° C.); second, those which showed an average temperature of 27° to 30° F. (−2.8° to −1.1° C.); third, those at 31° to 34° F. (−0.5° to 1.1° C.); and fourth, those at 35° to 39° F. (1.7° to 3.9° C.). None of the experiments showed an average temperature of over 39° F. (3.9° C.). The temperature during portions of the haul have exceeded these group limits, but the average temperature for the entire period of

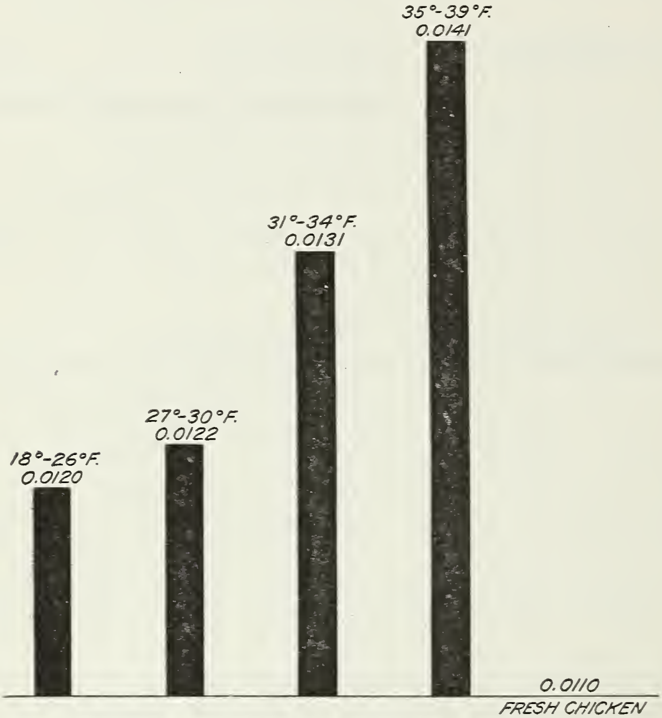

FIG. 2.—Deterioration during haul as affected by car temperatures, as shown by the percentage of ammoniacal nitrogen.

transportation lay between the maximum and minimum limits as given for the group. These groups are shown in Table 2 and the results are represented graphically in figure 2.

Fresh chickens contain about 0.0110 per cent of ammoniacal nitrogen. Amounts distinctly in excess of this figure may be taken as an indication of deterioration, especially when obtained by average, hence it is made the base line of the chart.

When the car temperatures averaged from 18° to 26° F. (−7.8° to −3.3° C.) the deterioration was very slight, the ammoniacal nitrogen having increased to only 0.0120 per cent; but when the car temperatures were from 35° to 39° F. (1.7° to 3.9° C.) the ammoniacal nitrogen had increased to 0.0141 per cent, a deterioration of three times that at the lowest temperature. This difference in composition at the end of the railroad haul continues with increasing magnitude throughout the period at the wholesale commission house and at the retailer's. (See Table 3.)

TABLE 2.—*Content of ammoniacal nitrogen in flesh of chickens after railroad haul.*

Group 1—18° to 26° F.			Group 2—27° to 30° F.			Group 3—31° to 34° F.			Group 4—35° to 39° F.		
Experiment No.	Car line.	Ammoniacal nitrogen.	Experiment No.	Car line.	Ammoniacal nitrogen.	Experiment No.	Car line.	Ammoniacal nitrogen.	Experiment No.	Car line.	Ammoniacal nitrogen.
		Per cent.			*Per cent.*			*Per cent.*			*Per cent.*
2024	A	0.0129	2017	D	0.0127	2001	D	0.0147	2003	D	0.0132
2026	A	.0123	2018	A	.0123	2004	D	.0123	2048	B	.0132
2028	D	.0120	2020	D	.0122	2006	D	.0144	2050	B	.0149
2030	E	.0120	2025	D	.0122	2008	D	.0134	2054	B	.0146
2068	D	.0112	2031	D	.0139	2012	D	.0129	2056	B	.0146
2069	D	.0123	2035	D	.0134	2044	B	.0126	2060	B	.0140
2074	D	.0125	2036	D	.0129	2046	B	.0126	2065	B	.0140
2078	D	.0115	2038	B	.0106	2066	E	.0126	2071	C	.0148
2094	C	.0119	2039	B	.0125	2077	D	.0141	2084	B	.0140
2096	C	.0118	2040	B	.0102	2083	B	.0132			
			2041	B	.0120	2086	D	.0118			
			2042	B	.0129	2087	D	.0137			
			2055	B	.0127	2088	D	.0132			
			2075	D	.0118	2090	D	.0132			
			2079	C	.0112	2091	D	.0130			
			2080	D	.0106						
			2085	C	.0123						
			2089	D	.0126						
			2093	C	.0123						
			2099	C	.0119						
Average.		.0120	....		.0122	....		.0132	....		.0141

TABLE 3.—*Content of ammoniacal nitrogen in flesh of chickens during marketing period after subjection to extreme low temperatures and extreme high temperatures during railroad haul.*

Date of shipment.	Experiment No.	Content of ammoniacal nitrogen.			
		Transportation sample.	Commission house sample.	First sample from retailer.	Second sample from retailer.
Low-temperature shipments, 18° to 26° F. (−7.8° to −3.3° C.):		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Nov. 16, 1910	2024	0.0129	0.0132	0.0144	0.0160
Nov. 26, 1910	2026	.0123	.0139	.0147	.0154
Dec. 6, 1910	2028	.0120	.0136	.0146	.0160
Oct. 23, 1911	2068	.0112	.0112	.0140	.0144
Nov. 2, 1911	2069	.0123	.0126	.0134	.0144
Dec. 19, 1911	2074	.0125	.0106	.0139	.0174
Apr. 16, 1912	2078	.0115	.0126	.0132	.0150
Sept. 18, 1912	2094	.0119	.0142	.0168	.0181
Sept. 26, 1912	2096	.0118	....	.0150	.0157
Average	....	.0120	.0124	.0144	.0158
High-temperature shipments, 35° to 39° F. (1.7° to 3.9° C.):					
Sept. 13, 1910	2003	.0132	.0154	.0165	.0220
Apr. 26, 1911	2048	.0132	.0126	.0179	.0216
May 3, 1911	2050	.0149	.0150	.0165	.0190
May 23, 1911	2054	.0146	.0124	....	.0225
June 15, 1911	2056	.0146	.0140	.0148	.0143
July 13, 1911	2060	.0140	.0146	.0154	.0185
Sept. 21, 1911	2065	.0140	.0141	.0178	.0157
Nov. 20, 1911	2071	.0148	.0168	.0151	.0190
May 13, 1911	2084	.0140	.0137	.0140	.0165
Average	....	.0141	.0143	.0160	.0188

The average temperature at the commission house for the low-temperature shipments was 29.8° F., as compared with 34.2° F. for the high-temperature shipments. The retail store in the interim of low-temperature experiments averaged 35° F., and during high-temperature experiments was 39.3° F. These differences are about half those prevailing during the transit period.

The samples were allowed to remain in the commission house for five days. The first retail sample was withdrawn after four days,

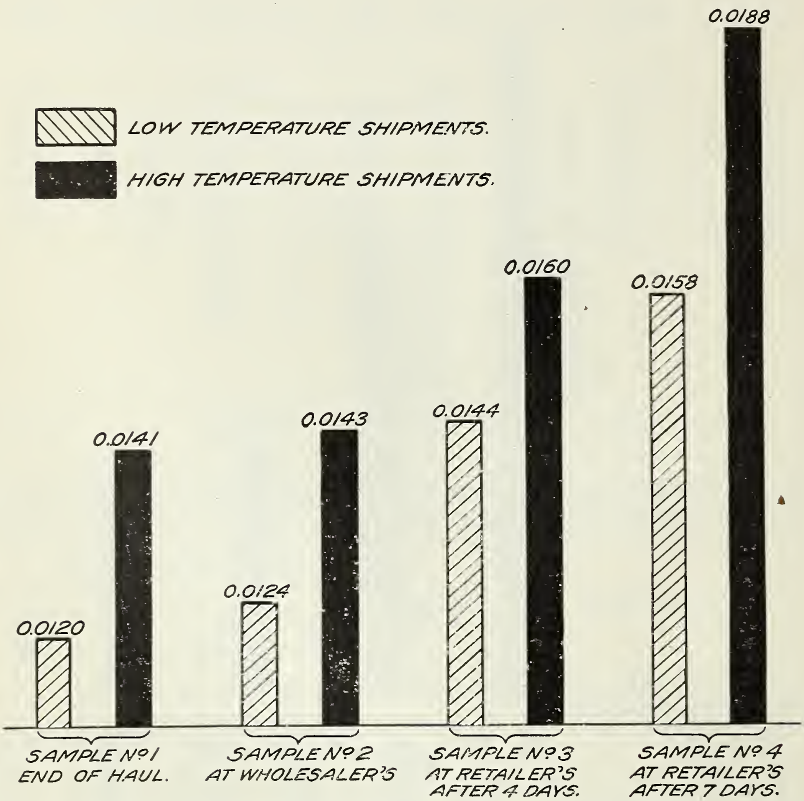

FIG. 3.—Deterioration during marketing period as affected by high and low transportation temperatures, as shown by the percentage of ammoniacal nitrogen.

and the last sample after seven days at the retail store. A graphic representation of the average relative deterioration in low-temperature and high-temperature shipments during the marketing period is given in figure 3. The deterioration in the high-temperature shipments is always at least one stage ahead of the low-temperature shipments. The changes during the commission period are very slight, the temperature in such places being usually low and therefore conducive to preservation. At the end of four days at the retailer's, or nine days after the railroad haul, the ammoniacal nitrogen in the low-temperature shipments increased to 0.0144 per cent, nearly the same as the high-temperature shipments at the end of the transit period. In other words, if the car temperature is above 35° F. the poultry when it reaches the market has the disadvantage of a deterioration equivalent to five or more days in the market, and to be in the same state of freshness it must be consumed five days earlier than that arriving at car temperatures below 26° F.

These results give some idea of the effect of small differences in temperature on poultry during the market period and indicate that the most favorable temperature for poultry transportation is 30° F. or below. It therefore becomes a fundamental problem in the transportation of dressed poultry and similar products to maintain low temperatures in all parts of the car, which finally resolves itself into a question of car construction.

REFRIGERATOR CARS.

SOURCES OF DATA.

The shipments already described and tabulated in Table 1 were hauled by six different car lines. The cars were of so many different series that they furnished a great variety of sizes, insulations, roofs, doors, ice bunkers, and all of those elements which are factors in the sum total of efficiency.

The car number, the amount of ice and salt used in the initial icing, the temperature of the car before and after loading, the position of the thermographs, the prevailing atmospheric temperature and weather conditions, the re-icing instructions, and the route were all noted at the time of loading. A record of the movements of the cars and the time and amount of ice and salt used in re-icing has been generously furnished by the railroad companies. The railroads have also greatly facilitated this study by freely providing detailed blue prints showing the construction and insulation of the cars in which the experimental shipments were carried.

In some of the experiments the atmospheric temperature was obtained by a thermograph fastened to the outside of the car. In the majority, however, the average between the maximum and minimum atmospheric temperatures was taken each day for the region through which the car was passing, as shown by the daily weather maps and monthly reviews issued by the United States Weather Bureau. The temperature records obtained in this manner coincide almost exactly with those obtained by thermograph on the outside of the car. The inside car temperatures during transit were obtained by thermographs. (See Table 4.)

TABLE 4.—*Comparison of thermograph records of atmospheric temperature and the figures obtained by averaging the United States Weather Bureau reports of the maximum and minimum daily records for the region through which the cars were passing.*

Experiment 5005.				Experiment 5006.				Experiment 5007.			
Date.	Place.	Thermograph.	U. S. Weather Bureau report.	Date.	Place.	Thermograph.	U. S. Weather Bureau report.	Date.	Place.	Thermograph.	U. S. Weather Bureau report.
1912.		°F.	°F.	1912.		°F.	°F.	1912.		°F.	°F.
Mar. 20	Nashville	70	69	Mar. 29	Nashville	57	54	June 1	Lexington	72	73
31	Louisville	48	47	30	Louisville	54	50	2	Cincinnati	67	70
22	Cincinnati	30	33	31	Cincinnati	55	58	3	Marion, Ohio	71	69
23	Pittsburgh	35	37	Apr. 1	Pittsburgh	56	54	4	Syracuse	69	66
24	Harrisburg	35	35	2	Philadelphia	60	56	5	New York	67	68
25	New York	34	33								
Average		42	42			56	54			69	69

CALCULATION OF THE INDEX OF EFFICIENCY.

To compare the efficiency of the various cars, constructed on widely divergent lines, it becomes necessary to reduce the variable functions, or influencing factors, to a resultant coefficient. Since the purpose of a refrigerator car is to maintain a fixed temperature on the inside, regardless of external temperatures, the ultimate question is one of heat transmission, or the power of all the contributing factors to overcome the heat transmitted from the outside to the inside. Insulation efficiency is usually expressed as the number of B. t. u.[1] transmitted through 1 square foot of the material in a day, for each degree difference in temperature on the colder and warmer sides. Therefore, knowing the amount of ice and salt used, the duration of the haul, and the average temperatures on the inside and outside, the simplest formula for car efficiency would be

$$R = \frac{142\ I + 40.5\ N}{S\ (T - t)\ D} \qquad (1)$$

I = pounds of ice used.

142 = B. t. u. required to melt 1 pound of ice.

N = pounds of salt used.

40.5 = the endothermic heat of solution of 1 pound of salt in a 10 per cent solution at 32° F.

S = the surface exposure of the car.

T = the average atmospheric temperature.

t = the average temperature inside of car.

D = the number of days in the test.

[1] A British thermal unit (B. t. u.) is the quantity of heat required to raise the temperature of a pound of pure water 1 degree Fahrenheit.

R = B. t. u. of heat transmitted through 1 square foot in one day, for each degree difference in temperature; or the amount of refrigeration which must be supplied for each square foot of car surface in a day, for each degree difference in temperature between the atmosphere and the inside.

With thermograph records of the temperature at both bunker and center of car, a fairly accurate average inside temperature may be obtained. The daily maps of the Weather Bureau afford excellent atmospheric data, and with accurate re-icing records the formula gives a very serviceable working comparison of refrigerator cars. The commercial re-icing records are not sufficiently exact for mathematical calculations of efficiency. It is also very difficult to determine from commercial records the weight of the ice which remained in the car bunkers at the end of the haul, and it is consequently impossible to calculate the amount of ice melted. But as it was extremely desirable to make some kind of a comparison of cars which might serve as a working basis or beginning for future experiments, it became necessary to devise a formula which would make R a function of the initial icing, which in these experimental shipments is of acceptable accuracy.

Other factors being constant, a comparative efficiency of cars could be calculated by noting the length of time between the initial icing and the hour at which the temperature on the inside of the car begins to rise; this hour indicates that the ice has spent its maximum strength. No ice is put into the car during this interval. The formula then becomes

$$R^1 = \frac{142\ I + 40.5\ N}{S(T - t)H} \tag{2}$$

H = the number of hours between icing and the moment at which the temperature in the car begins to rise. R^1, no longer properly designated as B. t. u. because the car still contains unmelted ice, becomes an arbitrary number, but still remains a comparative index of efficiency.

One other correction must be introduced. If the salt, on account of physical conditions in the ice bunker, melts very rapidly and dissolves in the smallest possible amount of water or melted ice, it will lower the temperature of the resulting solution very much more than when it dissolves more slowly and in a larger quantity of water. One per cent of salt with snow or crushed ice lowers the temperature of the mixture on an average of about 1.1° F. between 0° concentration and the point of saturation. If sufficient salt is added to completely saturate the resulting solution, it is possible to reduce the temperature to about −6° F. (−21.1° C.). It is evident that if very low temperatures are produced, the ice will begin to lose its force sooner than if higher temperatures had prevailed, because the total amount of refrigeration available is the same in each case.

In order to give credit to those cars in which low temperatures prevailed at the bunker, H in formula 2 must be a function of the car temperature. The cars were iced 24 hours before loading, and the inside car temperature decreases continually from the time of icing until the door is opened for loading. Therefore 24 of the total number of hours are constant. The variable portion then becomes H^1 where

$$H = 24 + H^1 \qquad (3)$$

H^1 represents the number of hours between loading and the time at which the temperature at the bunker begins to rise.

The bunker should cool the air from the temperature prevailing at the center of the car to that prevailing at the bunker, the temperature maintained at the center depending on the insulation of the car and the circulation of air. The total refrigerating effect might be expressed as degree-hours; that is, if the temperature at the center is C and that at the bunker is B and this difference in temperature is maintained for H^1 hours, the refrigerating effect is H^1 $(C-B)$ degree-hours. If no salt had been used on the ice the bunker air would be 32° F.; but the total refrigerating effect is the same whether the ice melts slowly or rapidly, and therefore the degree-hours at this temperature are $(C-32)\ H^{11}$. Hence

$$H^{11} = \frac{(C-B)\ H^1}{C-32} \qquad (4)$$

As shown by Table 2, 32° F. (0° C.) is too warm for the best results in poultry transportation. The temperature should be 30° F. (−1.1° C.) or lower. In determining the efficiency of the car for maintaining a temperature of 30° F., this number should be substituted in the formula, which then becomes

$$H^{11} = \frac{(C-B)\ H^1}{C-30} \qquad (5)$$

H^{11} represents the number of hours after loading at which the bunker temperature would have started to rise if the bunker had been producing air at 30° F. (−1.1° C.). This reduces all of the car temperatures to a comparative basis; the compensating formula would then be

$$R^1 = \frac{142\ I + 40.5\ N}{S\ (T-t)\ (24 + H)^{11}}$$

and, by substitution, the efficiency formula becomes

$$R^1 = \frac{142\ I + 40.5\ N}{S\ (T-t)\left(24 + H^1\ \dfrac{C-B}{C-30}\right)} \qquad (6)$$

The efficiency of the car will vary inversely as R^1, since the greater amount of heat transmitted indicates lower efficiency. If E is the index of efficiency, then $E = \frac{1}{R^1}$

The indices of efficiency obtained by the use of the foregoing formula have served as a basis on which to compare cars of different construction. They are not claimed to be an accurate expression of the resistance of the car to heat transmission nor of its exact capacity for utilizing the refrigerant supplied. To obtain figures mathematically and physically exact would necessitate the recording of the amount of ice and salt used during the period of observation and other data not readily secured from cars in commercial service. It is highly desirable that such accurate figures should be obtained, and it is hoped that the information which this report is able to furnish may lead to the compilation and utilization of such data.

COMPARISON OF CAR EFFICIENCY.

The magnitude of the field of operation covered by this investigation and the complexity of the factors uniting to determine the efficiency of the refrigerated carrier made it highly desirable that some concrete expression be worked out whereby a comparison of the various types of cars studied might be made.

The application of the formula to the cars used in the experimental shipments results in a wide difference of efficiency indices (see Table 5) for the various types of cars. All of the cars of type A are identical in original construction and are operated by a single company. The cars of type B are alike in ice bunkers and insulation, but, belonging to a different series, they vary in size. The cars of type C are all of the same dimension; likewise those of type D. Each type is operated by one railroad or car company. The four types are unlike each other in many of the essential elements of refrigerator construction, such as the kind and thickness of insulation, its manner of application, ice bunkers, and doors. For the sake of a clearer understanding, the efficiency indices of Table 5 are presented graphically as figure 4, in which the height of the columns increases directly as the efficiency.

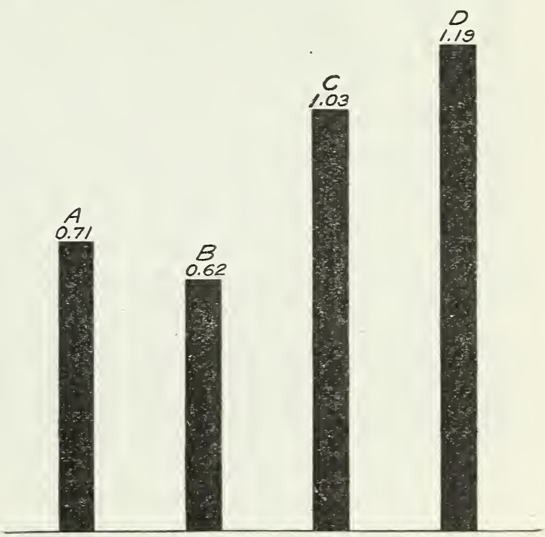

FIG. 4.—Comparative efficiency of cars of types A, B, C, and D.

TABLE 5.—*Prevailing temperatures and icing records during efficiency tests.*

Experiment No.	Date of loading.	Temperature of atmosphere.				Time after loading before temperature began to rise.	Lowest temperature attained at bunker after loading.	Temperature of car.			Ice added.	Salt added.	Index of efficiency $\left(E=\frac{1}{R^1}\right)$.
		Day before loading.	Day of loading.	Day after loading.	Second day after loading.			Average at center after loading.	Before loading.	After loading.			
Type A:	1910.	°*F.*	°*F.*	°*F.*	°*F.*	*Hrs.*	°*F.*	°*F.*	°*F.*	°*F.*	*Pounds.*	*Per cent.*	
1017....	Mar. 15	43	44	56	56	20	22	33	28	39	8,400	8	0.72
1021....	Apr. 6	45	53	56	56	13	14	34	28	50	7,200	10	.72
1025....	Apr. 21	58	69	57	35	14	17	40	32	54	9,600	10	.72
1027....	May 4	49	52	52	52	14	14	34	31	47	9,600	10	.70
1029....	May 13	55	57	57	57	15	15	33	35	50	11,900	10	.71
Aver.													.71
Type B:	1911.												
2056....	June 16	76	81	81	72	10	25	35	37	52	16,000	15	.60
2060....	July 14	80	80	81	75	32	36	39	37	52	10,000	10	.60
2062....	Sept. 1	74	73	78	75	22	35	39	34	42	12,000	15	.58
2064....	Sept. 15	81	84	76	72	12	34	38	41	54	10,000	10	.65
2081....	Apr. 30	64	53	66	69	20	35	41	36	48	6,000	10	.63
2083....	May 4	72	72	75	67	8	27	36	36	46	10,000	10	.64
2084....	May 14	57	56	59	55	9	21	35	30	44	8,000	10	.65
Aver.													.62
Type C:	1912.												
2085....	May 25	79	76	67	70	13	24	37	38	50	9,000	10	1.01
2092....	Aug. 24	77	77	79	80	18	24	40	38	68	10,000	10	1.04
2093....	Aug. 29	82	81	84	84	13	24	37	36	46	10,000	10	1.04
2094....	Sept. 20	63	67	70	63	15	19	38	33	48	8,000	10	1.04
2096....	Sept. 27	60	61	60	54	18	20	38	31	47	7,000	10	1.05
2099....	Oct. 18	63	66	57	55	14	22	36	31	48	7,000	10	1.02
Aver.													1.03
Type D:	1911.												
2059....	July 7	81	80	84	80	27	27	41	43	50	10,000	10	1.19
2063....	Sept. 8	78	80	77	77	43	37	39	42	47	6,000	10	1.17
	1912.												
2077....	Apr. 13	68	69	71	73	16	28	34	41	52	5,800	10	1.22
2078....	Apr. 17	63	61	42	46	18	25	34	34	48	5,000	10	1.23
2080....	Apr. 16	64	66	64	55	16	27	36	36	48	5,000	10	1.17
2082....	May 1	53	64	73	71	27	34	40	31	40	5,000	10	1.17
2089....	July 11	76	76	82	82	10	26	33	35	50	7,000	10	1.25
2090....	July 26	84	77	74	76	18	29	40	40	60	7,000	10	1.17
2091....	Aug. 2	73	78	65	62	40	28	38	40	58	11,000	10	1.12
Aver.													1.19

COMPARISON OF CAR CONSTRUCTION.

With a measure of the gross efficiency of the different types of cars as a working basis, an analysis of the construction of these types will reveal certain features which appear indispensable in effective refrigerator cars.

INSULATION.

There are many kinds of insulating material now in common use, cork, hair felt, wool felt, mineral wool, and various vegetable fibrous materials. The old-time idea of a dead-air space in refrigerator cars is no longer plausible. The car builder has been unable to construct a car with a dead-air space which will remain air and moisture proof under the continual stress and strain to which refrigerator cars are subjected. Cracks in the boards and punctures in the paper lining soon appear and, with the resulting air circulation, heat is directly transferred from the outside to the inside. A heat insulator is a nonconductor of heat. Heat is a form of energy transferred in waves of extremely small length from one molecule to another. Since the molecules in solid bodies are closer together than those of gases, the solids are the better heat conductors. The more numerous the air spaces in a solid body the more efficient it will be as an insulator.

Cork, the best known insulator, contains innumerable air spaces, and its texture renders it almost impervious to water. It contains but small amounts of gums and resins and practically no nitrogenous material which might serve as a medium for bacterial growth and thus produce decay. Cork, however, has not been used to any extent in car construction, perhaps on account of its expense and the difficulty of its application.

Wool and hair felt are good insulators as long as they are kept dry, but their high percentage of nitrogenous material makes them good bacterial media when moist. Organic oils and acids also aid in their decomposition. These materials, when once moist, seldom dry out, and the result is putrefaction, giving rise to offensive odors, which contaminate the goods in the car. This decomposition not only destroys the insulator itself but rots the board lining with which it comes in contact. Some of the vegetable or cellulose fiber insulators are perhaps slightly more resistant to moisture and bacterial action, but in time they also become moist and their chemical decomposition is hastened by the alkalies present in such material. Of the insulators mentioned, mineral wool is the least subject to decay, but, on the other hand, its physical nonadhesive properties hinder the manufacture of strong material, and its insulating qualities are not as good as those of some of the other nonconductors, although it has the advantage of being fireproof.

Careful consideration of insulation is therefore one of the prime factors in car construction. The material must be of such a nature that it will remain in position, not settling down and leaving hollow spaces in the upper portion of the side walls. It should be impervious to moisture, or be securely protected by moisture-proof material, and as free as possible from decomposable organic matter. The necessary thickness of the insulation depends on the nature of the goods to be transported. Investigations in fruit transportation have shown that temperatures as low as 40° F. are very satisfactory for citrus fruits, but the results with poultry indicate that lower temperatures are essential for a maximum preservation of this class of goods. Aside from the nature of the lading, the question of insulation is one of economy. Will the saving in ice, resulting from extra insulation, be sufficient to pay for the additional insulation?

Walls.—Figure 5, *a*, *b*, *c*, and *d*, illustrates cross sections through the side walls of the cars of types A, B, C, and D, respectively. Type A is insulated with two thicknesses of half-inch linofelt, one layer on each side of the main frame. There is but one thickness of paper and one sublining in this wall. Type B is insulated in nearly the same manner, except that wool felt is used instead of linofelt. Type C uses one thickness of 1-inch hair felt, compactly arranged between the lining and sublining. There is no attempt in this type to maintain a dead-air space. Type D likewise has a 1-inch layer

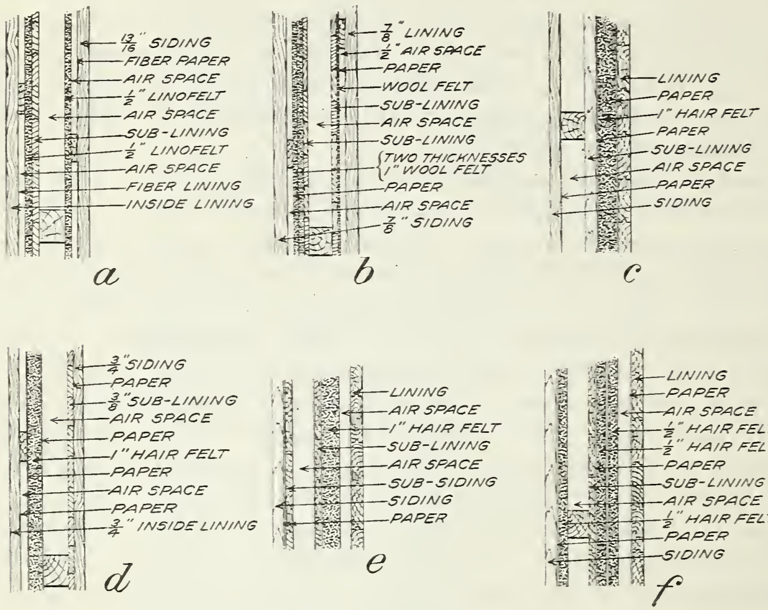

FIG. 5.—Cross sections showing wall construction of different types of refrigerator cars. *a*, Type A; *b*, type B; *c*, type C; *d*, type D; *e*, wall having a 1-inch layer of hair felt; *f*, wall having three half-inch layers of hair felt.

of hair felt, but has not the same solidity; there is an air space on each side of the insulation. Figure 5, *e*, illustrates a side wall with a 1-inch layer of hair felt, supported on one side by a sublining. In this wall there is an additional sublining next to the siding. Figure 5, *f*, shows three half-inch thicknesses of hair felt, two of which are together on the inside of the frame, the other being on the outside of the frame.

Roof.—Figure 6, *a*, illustrates the roof insulation of type A cars. Two thicknesses of one-half inch linofelt are separated by a wide air space. The edges of the insulation are turned up along the sides of the car to give a more compact joint. In appearance this roof presents a general openness. Type B, with the same thickness of insulation, is more compact, but does not have the upturned edges to protect the corners (fig. 6, *b*). Type C is characterized by a heavy layer of hair felt, 1½ inches thick, packed closely between the ceiling and subceiling with no intervening air space (fig. 6, *c*). In figure 6, *d*, is shown a roof with insulation of the same thickness as the preceding one, but separated into three layers with intervening air spaces. Figure 6, *e*, represents a roof with 2 inches of hair felt insulation, each of the two layers being protected on both sides with

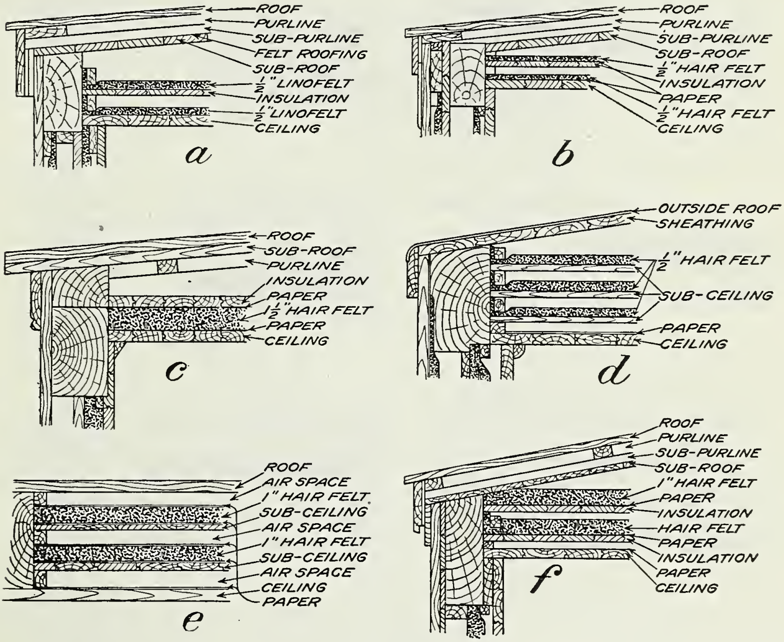

FIG. 6.—Cross sections showing roof insulation of different types of refrigerator cars: *a*, Type A; *b*, type B; *c*, type C; *d*, roof insulation separated into three layers; *e*, roof insulation with 2 inches of hair felt; *f*, type D.

insulation paper. Type D (fig. 6, *f*) also has two thicknesses of 1-inch hair felt, with the additional precaution of upturned edges.

Floor.—The floors of types A and B (fig. 7, *a*, *b*) are equipped with two thicknesses of half-inch insulation separated by air spaces. Types C, D, and F (fig. 7, *c*, *d*, *f*) have one layer 1 inch thick, and type E (fig. 7, *e*) has three layers one-half inch thick, with well-protected joints.

Comparison.—There is but very little difference in the side-wall insulation of the four types of cars whose efficiency indices are given in Table 5. Each type is provided with 1 inch of the non-conducting material. Although the insulation of A and B is divided into two half-inch layers in contrast to the single 1-inch layer of C and D, the difference in side-wall insulation does not seem sufficient to account for the difference in efficiency. The striking difference in the four types of cars is in the roof insulation. Types A and B, with the low efficiency, have but 1 inch of insulation, and that is divided into two layers with intervening air space. Type C has 1½ inches of solid insulation, and D has two layers, each 1 inch thick. There are undoubtedly several factors which govern the efficiency of a car, but it is worthy of note that the indices of efficiency of Table 5 seem to vary in about the same way as the

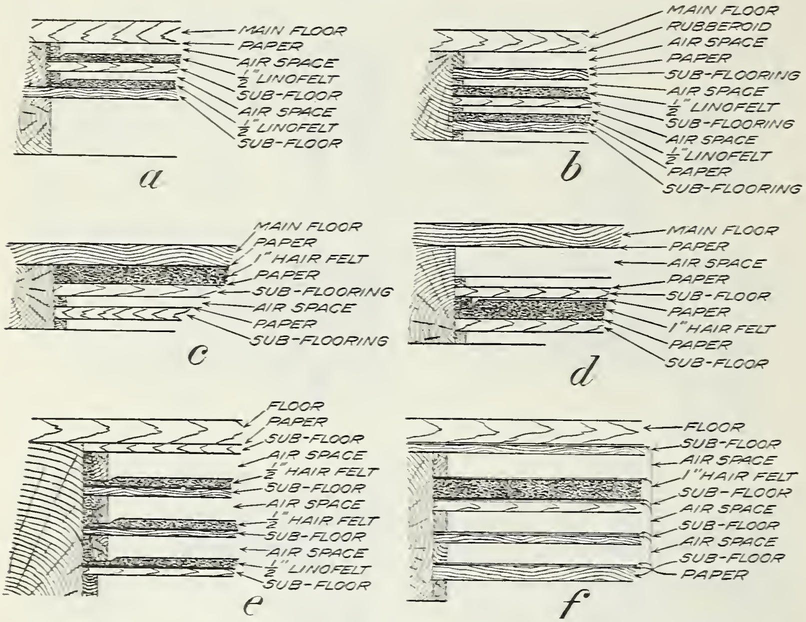

FIG. 7.—Cross sections showing floor insulation of different types of refrigerator cars: *a*, Type A; *b*, type B; *c*, type C; *d*, type D; *e*, floor insulation separated into three layers; *f*, 1-inch layer of hair felt with two uninsulated subfloors.

roof insulation. The floor insulations of the four types are about the same and are very similar in thickness to the walls.

ICE BUNKERS.

Each of the types A, B, C, and D is equipped with a characteristic ice bunker. Type A uses the siphon bunker shown in figure 8. Type B has the galvanized-iron box shown in figure 9, the box being perforated to allow the air to come in contact with the ice. Type C has two large, reenforced wire baskets (fig. 10), which permit free contact with the air. In front of the basket ice holder there is an insulated wall, with an open space at the top of the car for the admission of warm air and a similar space at the bottom for the escape of the cold air. Type D uses the iron tanks shown in figure 11. With such tanks the ice can be crushed very fine, permitting a uniform and thorough mixing of the salt, which produces very low temperatures. These four, together with the simple box arrangement shown in figure 12, are the types of ice bunkers now in common use. Most of the others are minor modifications of these five.

The various types of cars studied show that there is a wider divergence in the construction of the ice bunkers than in any other single refrigerator-car essential. This is undoubtedly due to a recognition on the part of the car builder of the importance of this fitting in the performance of the car, and the varying forms of the bunker represent the endeavors of the builders to meet modern requirements in the transportation of refrigerated freight. The ice bunker in a refrigerated car holds a place analogous to that of the refrigerating machinery in a stationary plant. It must chill every inch of working space in the compartment depending upon it. It would seem, from the observations made on the types of cars described, that the aim of the builder must be to induce a circulation of air which will convey the lower temperatures at the bunker ends to the center of the car. To do this efficiently the bunker must be assisted by proper insulation on the surfaces of the car.

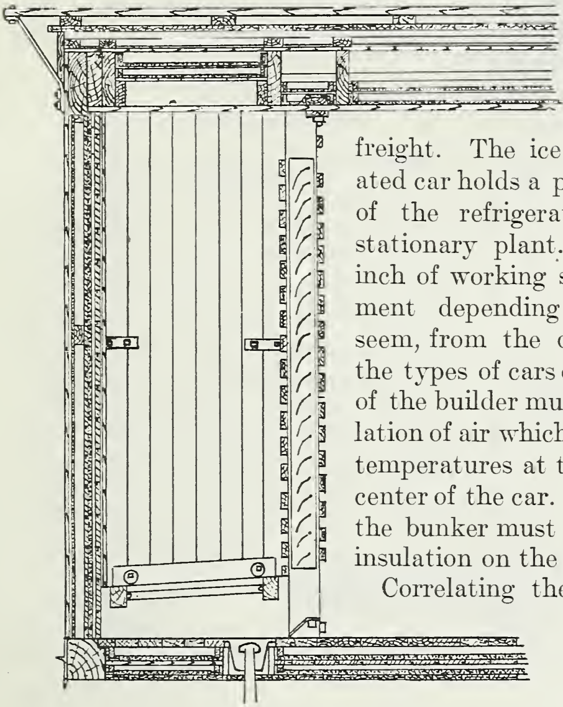

Fig. 8.—Siphon bunker used in type A car.

Correlating the construction of the bunkers with the table of efficiencies of the four types of cars, two essential principles for the production of low temperatures stand out prominently. First, the bunker must permit of the ice being finely crushed and evenly mixed with the salt; and, second, there must be a free admittance of the warm air of the car at the top of the bunker and a free exit of the cold air at the bottom. Such requirements are apparently met most successfully by the tank on the one hand and the wire basket on the other. In this case simplicity of construction has been compatible with efficiency.

Various attempts have been made to use overhead ice bunkers and, in a few instances, brine pipes for circulation have been tried, but in most cases the objectionable features were so numerous that these systems were soon discarded. Even the best arrangements now in common use leave much to be desired in the way of circulation. Cars of type B (Table 5) show an average difference of 7 degrees between the bunker end and center of the car under ordinary icing. The cars of type D, with heavier insulation, maintain a lower average temperature throughout the car, but, even in this case, the center of the car averages 5° F. warmer than the bunker end. These differences are sometimes disastrous in their effects on poultry shipments.

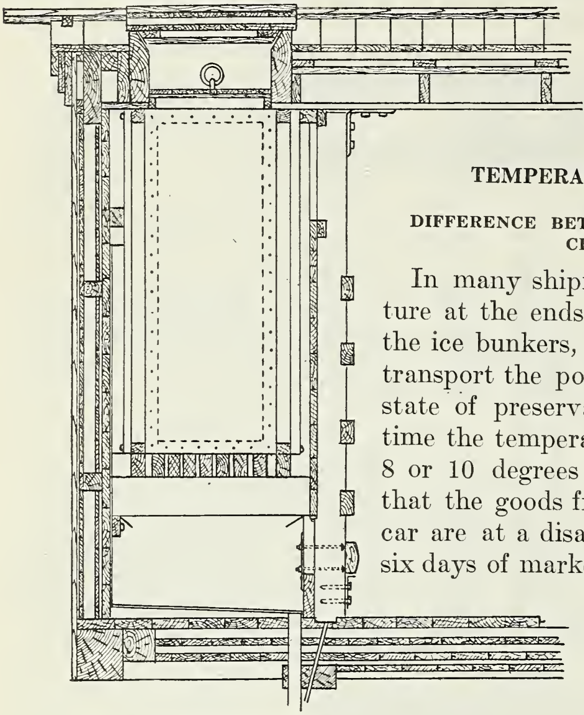

Fig. 9.—Galvanized-iron bunker used in type B car.

TEMPERATURE IN CAR.

DIFFERENCE BETWEEN BUNKER AND CENTER.

In many shipments the temperature at the ends of the car, next to the ice bunkers, is sufficiently low to transport the poultry in an excellent state of preservation. At the same time the temperature at the center, 8 or 10 degrees warmer, is so high that the goods from this part of the car are at a disadvantage of five or six days of market time as compared with the bunker goods.

In figure 13, *a*, is presented the temperature record for the end and center of the car in Experiment 2078, car type D. The atmospheric temperature during the haul averaged 50° F. (10° C.), with a minimum of 42° F. (5.5° C.) and a maximum of 61° F. (16.1° C.). The differences in temperature between the bunker and the center of the car were comparatively small in this shipment, and the analyses of the samples carried at the bunker show good preservation. The findings of the chemical laboratory are in group 1 of Table 2. The efficiency of this car was 1.23.

Figure 13, *b*, shows another shipment, Experiment 2096, car type C, where a wide difference in temperature is manifest between the two positions in the car. The atmospheric temperature averaged 54° F. (12.2° C.), with a minimum of 49° F. (9.4° C.) and a maximum of 61° F. (16.1° C.). The temperature at the bunker was low at the beginning of the haul, but failed to hold. Samples from this position fall, by chemical analysis, into group 1, Table 2. The efficiency of the car is represented by 1.05.

Figure 13, *c*, *d*, of cars belonging to type C, are the records of Experiments 2085 and 2099, respectively. Experiment 2085, with an outside temperature averaging 72° F. (22.2° C.), gave an efficiency of 1.01; Experiment 2099, with the atmosphere averaging 61° F. (16.1° C.), is represented by 1.02. The analyses of the poultry carried at the bunker ends of these cars are found in group 2, Table 2.

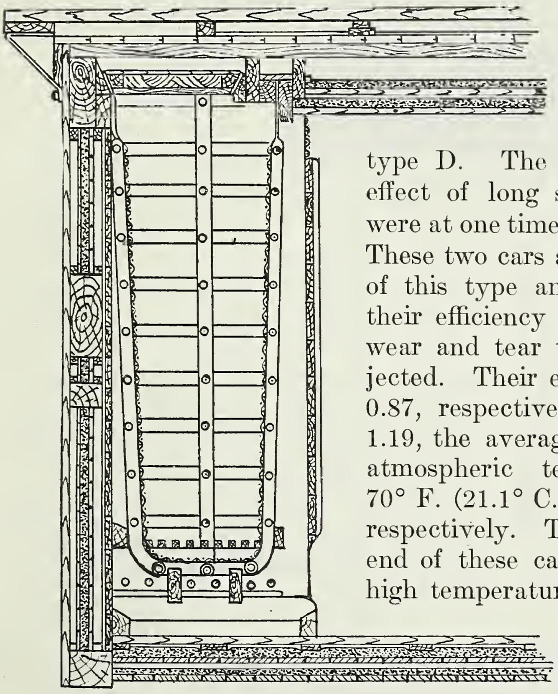

Fig. 10.—Wire basket bunker used in type C car.

Figure 13, *e*, *f*, presents records of samples belonging to Group III, figure 1. The cars were of type D. The records illustrate the effect of long service on cars which were at one time excellent refrigerators. These two cars are of a very old series of this type and seem to have lost their efficiency through the continual wear and tear to which they are subjected. Their efficiency was 0.56 and 0.87, respectively, as compared with 1.19, the average for their type. The atmospheric temperatures averaged 70° F. (21.1° C.) and 77° F. (25° C.), respectively. The goods at the bunker end of these cars show the effects of high temperatures, as may be seen by reference to group 3 of Table 2, or column 3 of figure 2.

Figure 13, *g*, *h*, shows records of shipments which yielded samples of Group IV, figure 1. The cars were of type B, efficiency, 0.60 in each case. The records shown as figure 13, *g*, were made in a comparatively new car, when the outside temperature averaged 74° F. (23.3° C). It was possible to reduce the bunker to a low temperature at the beginning, but as soon as the car started on the trip the temperature began to rise and never receded. The temperature at the center was never low. The records in figure 13, *h*, were both high at all times. This was an older car of type B. The outside temperature averaged 73° F. (22.7° C.), with a maximum variation of 17° F. The differences between bunker end and center are practically lost in this shipment, the whole car being warmer than is a good refrigerator, even at the bunker. It seems impossible during warm weather to reduce the air at the center of thinly insulated cars to the temperature best suited to the transportation of dressed poultry.

EFFECT OF CAPACITY.

The cars of type D, which are the most efficient of those studied, are likewise the smallest in point of cubic capacity. The total available space in these cars is about 1,640 cubic feet. Type C provides about 1,833 cubic feet of space, but with this increased loading capacity there is a decrease in the power to maintain low temperatures. Type C, however, has one-half inch less insulation on the roof than type D. The cars of type B, which reduce the roof insulation by still another one-half inch, offer about 2,050 cubic feet of space, but at a big sacrifice in efficiency. Type A, with the same insulation as type B, is smaller, 1,909 cubic feet, and is correspondingly higher in efficiency.

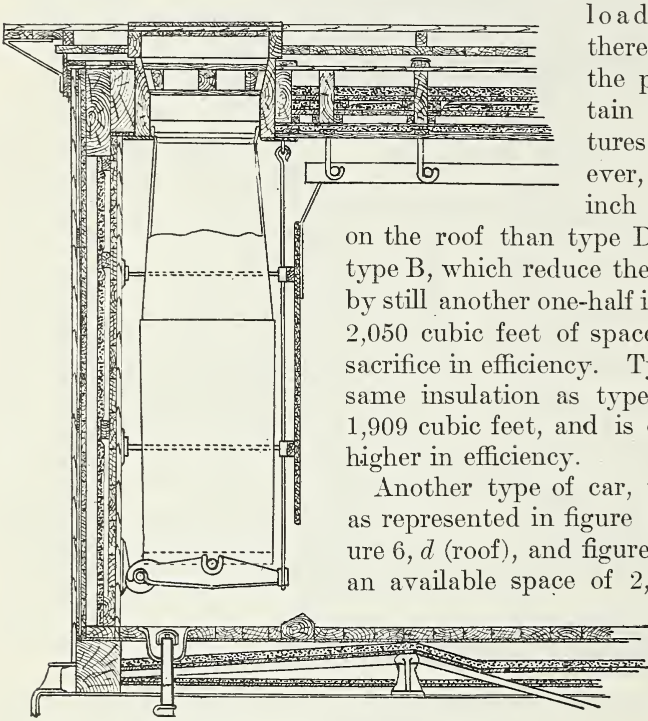

Fig. 11.—Iron tank bunker used in type D car.

Another type of car, with insulation as represented in figure 5, *f* (sides), figure 6, *d* (roof), and figure 7, *e* (floor), has an available space of 2,010 cubic feet. Even with the three layers of one-half inch insulation throughout, there is a wide difference in temperature between the center and ends of the car during warm weather (fig. 14). From this figure it is evident that, in the very large cars, one and one-half inches of insulation is not enough to insure the best temperatures for poultry transportation while comparatively high atmospheric temperatures prevail. Figure 15 gives temperature records in cars insulated, as shown in figure 5, *e* (sides), figure 6, *e* (roof), and figure 7, *f* (floor). These cars are of the large type, but with the 2 inches of insulation on the roof the interior temperatures at the bunker were fairly satisfactory.

The results, as a whole, indicate that large cars require additional insulation to yield the same efficiency as the small cars.

TEMPERATURE OF PACKAGES IN CAR.

During the late winter and spring of 1912 an investigation was made of the variations in the temperature of the poultry in different parts of the barrel and box packages, of the inequalities in temperature in different parts of the car, and of the fluctuations of car temperature as affected by outside atmospheric changes. J. F. Fernald, mechanical assistant, Bureau of Plant Industry, made several trips, accompanying carloads of dressed poultry from Tennessee to the New York and Philadelphia markets. The necessary thermometer readings were made at intervals of three or four hours during the day, at times when the train happened to be at rest.

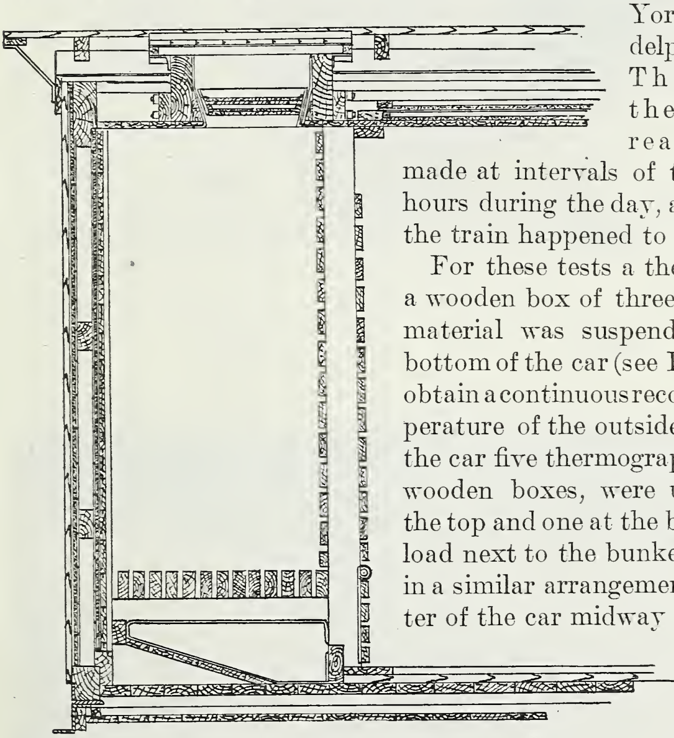

Fig. 12.—Simple box bunker.

For these tests a thermograph in a wooden box of three-fourths inch material was suspended from the bottom of the car (see Pl. I, fig. 1), to obtain a continuous record of the temperature of the outside air. Inside the car five thermographs, in similar wooden boxes, were used—one at the top and one at the bottom of the load next to the bunker, two others in a similar arrangement at the center of the car midway between the doors, and the fifth next to the side wall of the car.

These thermograph records were supplemented with the readings of eight electric thermometers, located at similar positions in the car (see Pl. I, fig. 2). The conduit wires from the thermometers converged in a small holder or box which was suspended just beneath the lid of the ice hatch at a point which would be easily accessible from the top of the car. From this position the thermometers were read by means of an electric apparatus carried by the messenger in charge. This operation was performed without opening the car doors, and was thus protected against the admission of warm air and artificial air currents. These electric thermometers are about 10 inches long and one-half inch in diameter, and when used to determine the temperature of the poultry they were inserted entirely into the box or barrel, and not disturbed during the transit period.

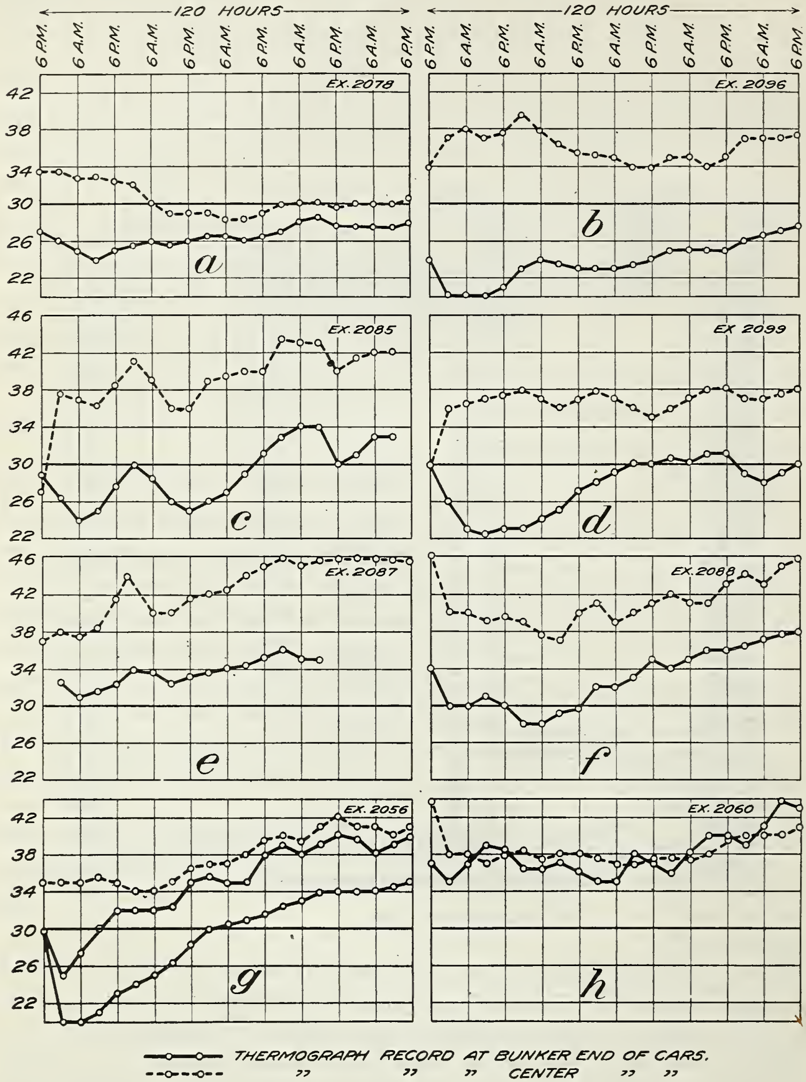

FIG. 13.—Typical car records for routine shipments. Data for these shipments will be found in Table 2, as follows: *a*, *b*, in group 1; *c*, *d*, in group 2; *c*, *f*, in group 3; *g*, *h*, in group 4.

COLD WEATHER SHIPMENTS.

The chart shown as figure 16 presents the record of a car shipped in February, 1912, from Tennessee to New York City. The weather was cold during the entire trip. The thermographs, in wooden boxes,

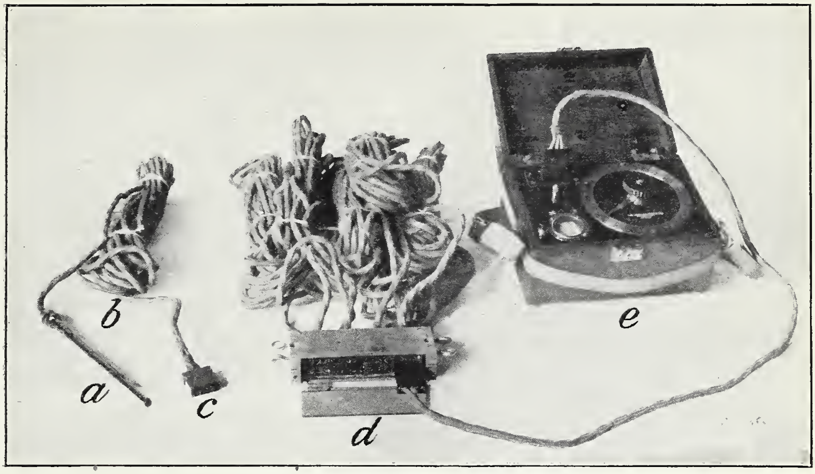

FIG. 1.—RESISTANCE THERMOMETER.

a, Thermometer; *b*, leader; *c*, plug; *d*, plug box; *e*, indicator.

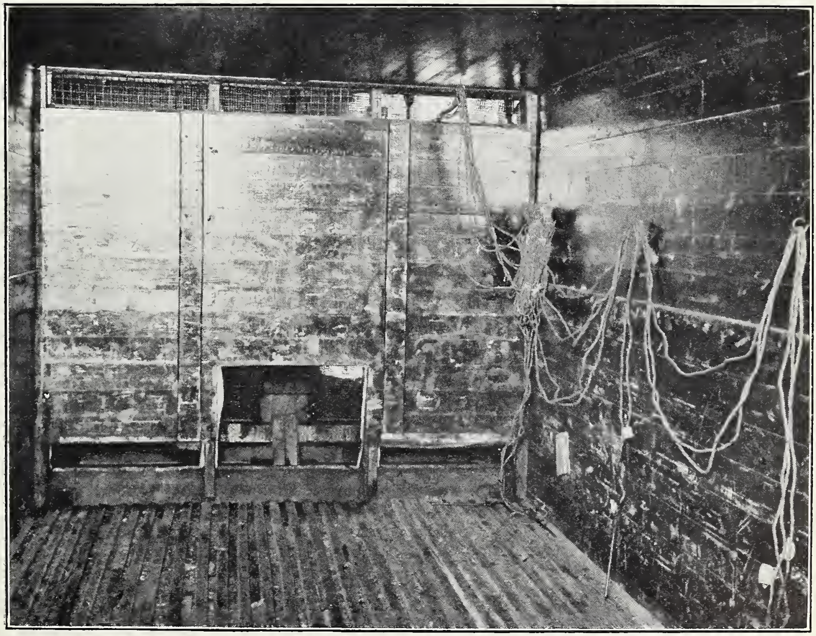

FIG. 2.—ELECTRIC THERMOMETERS IN CAR.

were in immediate contact with the poultry packages containing the electric thermometers. The records are given in pairs, thermograph and thermometer, according to their position in the car. The temperature of the air in the car was not appreciably affected by the small changes which occurred in the atmospheric temperature. The temperature inside the poultry boxes was almost constant, even in those packages next to the bunker where the temperature of the air was 7 or 8 degrees lower for a day or two. The car in which this shipment was made was of type C (Table 5). Figure 17 presents the records of a shipment made in a type B car in very cold weather. The fluctuation in car temperature was marked and was very similar in all parts of the car.

WARM WEATHER SHIPMENTS.

The records of a shipment made in April are shown as figure 18. The weather was warmer than that which prevailed during the two shipments previously described. This experiment again shows that the temperature of the poultry does not fluctuate with the wide changes of the air of the car. Its fluctuations are much slower and smaller. The lower chart indicates the usual prevailing difference in temperature between the bunker end and center of the car.

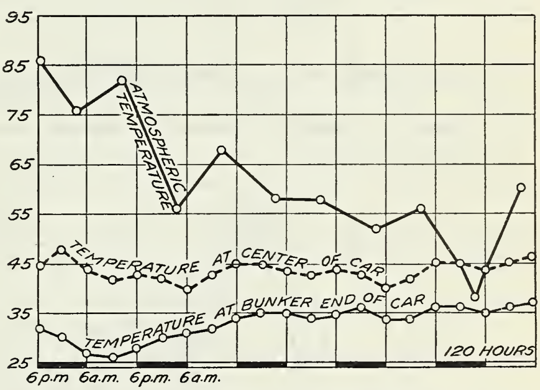

FIG. 14.—Temperatures in large car with three layers of half-inch insulation on roof, walls, and floor.

The charts shown as figure 19 are a detailed representation of the temperature records of a shipment made in April, 1912. This car was accompanied throughout the trip by two messengers. The poultry was packed in small barrels, or kegs, which were loaded in a single course, one barrel high. Sections I, II, and III of this chart are thermograph records, and IV, V, and VI are electric thermometer records.

The car, which was of type C, was insulated with hair felt, which in the floor was water soaked and very much decomposed. This faulty floor reduced the efficiency of the car to 0.71 as compared with 1.03, the average for this type. It resulted, in some instances, in higher temperatures at the floor than at the top of the barrel.

The temperature (F) of the poultry in the middle of the barrel next to the bunker changed very little, the change being much slower than in the air outside of the barrel (K and L). Thermometers, G and H, on the inside of the barrel next to the side wall of the car, half way between the bunker and door, showed a gradual rise of temperature, G reaching 36.5° F. (2.2° C.). It is interesting to note that on account of the wet floor the poultry in the bottom half of the barrel was sometimes 2 or 3 degrees warmer than that in the top half. The poultry in the middle portion of the car, away from the side walls, was likewise gradually increasing in temperature (J), but lagged far behind the temperature of the air in the car. The air in the car became warmer

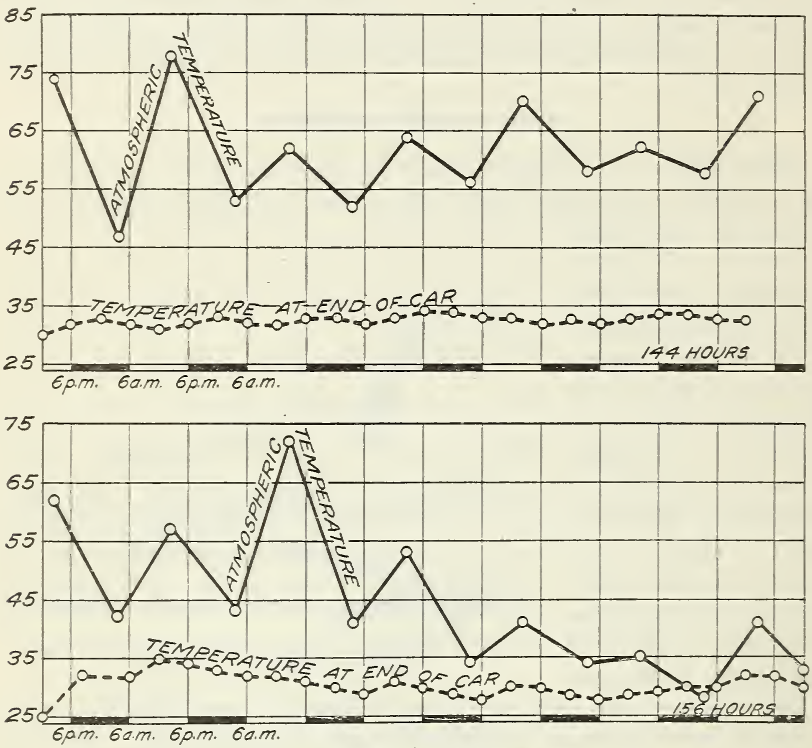

FIG. 15.—Temperatures in large cars with 2 inches of insulation on roof.

during the day and again colder at night (III, VI). Even the temperature inside the poultry barrel along the side of the car was noticeably influenced (V, G) by the warm atmosphere during the day.

CONCLUSIONS.

The chemical data obtained by analyzing well-handled, dry-packed, dressed poultry after transportation in refrigerator cars indicate that the condition of this commodity is greatly influenced by the temperatures prevailing in the car throughout the transit period. The railroads have recognized that "dairy freight," which includes dressed poultry, eggs, and butter, requires refrigerator service for the greater part of the year. Because of the fact that this class of goods is admittedly extremely perishable, the railroads have endeavored to perfect its transportation, but, lacking definite information concerning either the detriment or the benefit of present equipment and practices, the advances have of necessity been slow.

Temperatures for dressed poultry.—The experiments indicate that less than 31° F. is the most satisfactory temperature of dressed poultry for long hauls. It will be seen, by referring to figure 2, that

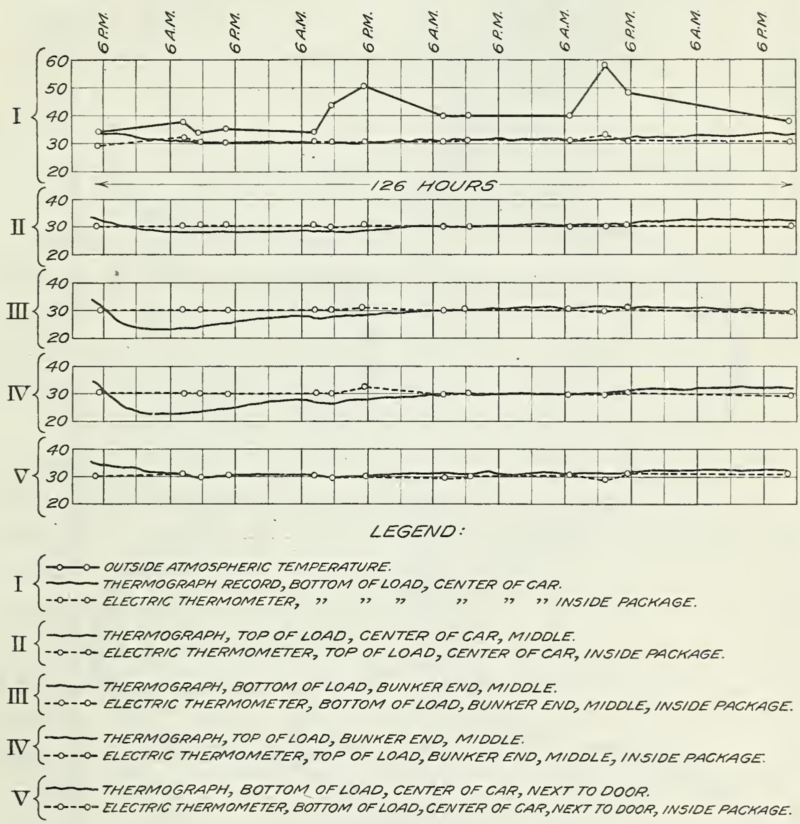

FIG. 16.—Thermograph and electric thermometer records in cold-weather shipment.

a 10-degree rise in the temperature of the car during the haul makes a difference in keeping time of at least five days on the New York market when the market environment is favorable. Such an observation is worthy of the serious attention of shippers, receivers, and carriers, since all feel the depression that ultimately results from putting poor goods on the market. More far-reaching, however, is the further observation, pictured in figure 3, that even such excellently handled poultry as comprised these experimental shipments, if exposed to unfavorable temperatures during transportation, receive an impetus toward decay that can not be overcome by subsequent irreproachable treatment on the market. It is a comparatively simple matter to prevent decay; it is, at the present time, impossible to stop it by the use of low temperatures once a foothold has been gained. Imperfect

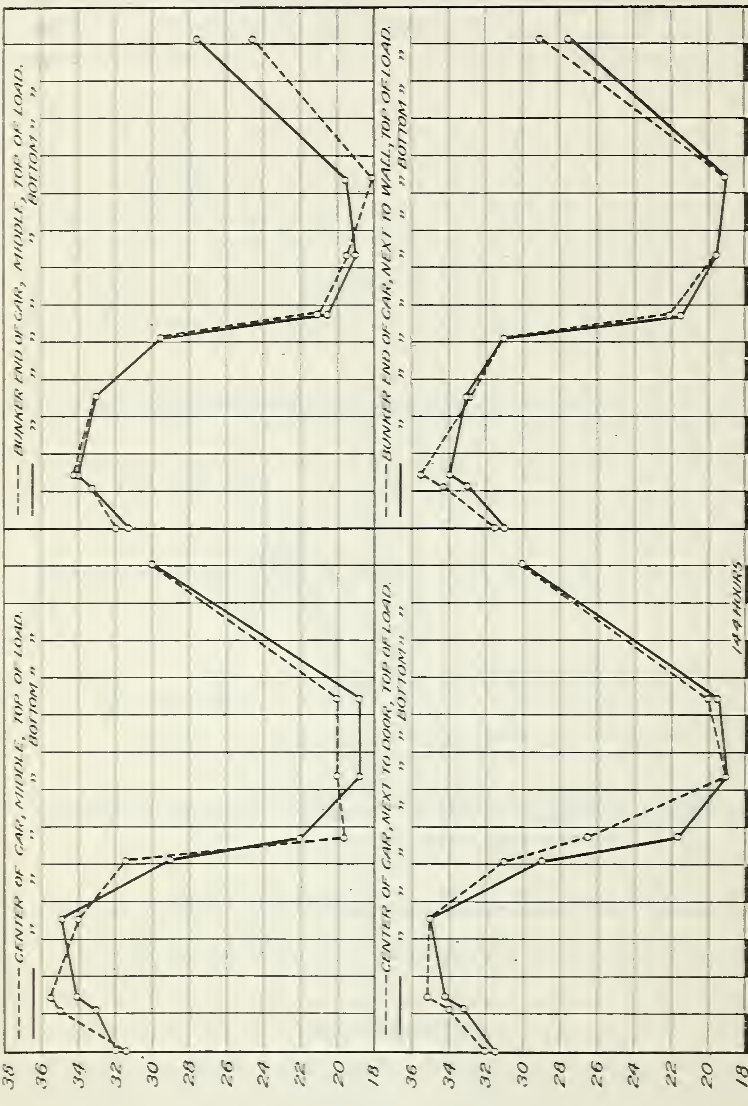

FIG. 17.—Electric thermometer records inside of packages in cold-weather shipment.

work by the carrier nullifies to a certain extent the work of the shipper and the wholesaler or retailer handling the goods on the market. The temperatures indicated by this investigation to be most desirable for the transportation of dressed poultry are considerably lower than those generally accepte as satisfactory. They are, however, quite in line with scientific findings and practical experience in the preservation of dressed poultry by refrigeration in the packing plants and warehouses. That definite standards have not heretofore been applied to the performance of a refrigerator car is due to the difficulty of accurately determining what takes place between the closing of the car doors and its arrival at its destination. Without such information car builders were working more or less in the dark.

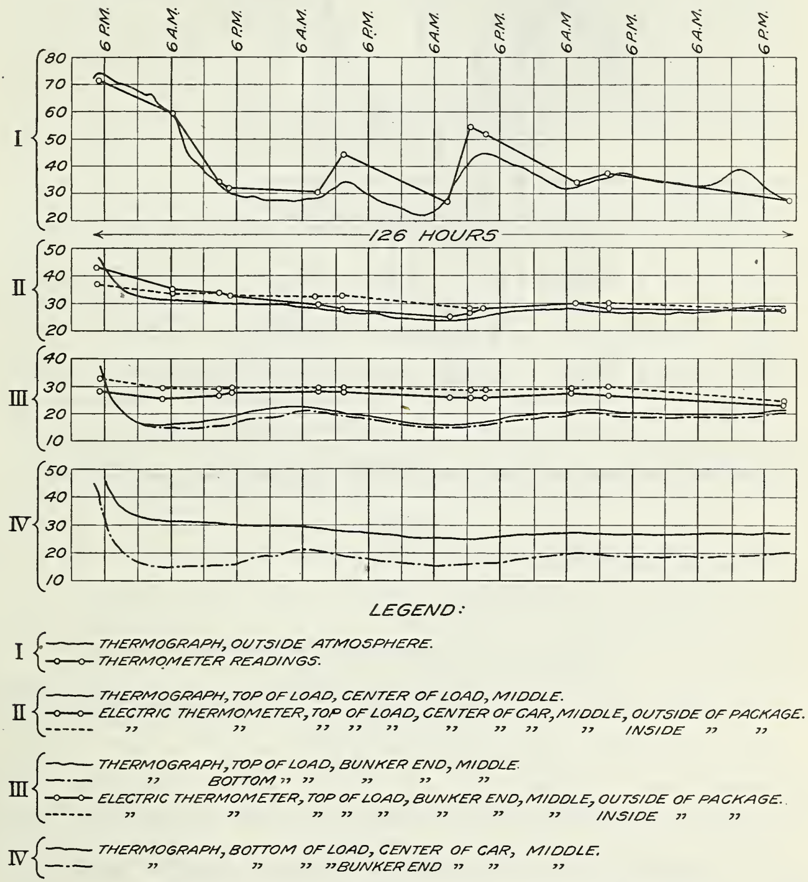

Fig. 18.—Thermograph and electric thermometer records (April shipment).

Efficiency of cars.—If the information furnished by 120 car-lot shipments of dressed poultry in 120 individual cars of six different lines can be accepted as conclusive, we must infer that most of the refrigerated carriers of the United States are not able to maintain sufficiently low temperatures during warm weather to transport a low-temperature commodity, such as dressed poultry, under the best of conditions. It is encouraging to observe that certain refrigerator cars are much more efficient than others, and that their increased efficiency apparently depends upon their construction.

The insulation of the car in relation to temperature is its most vulnerable and its most important part, the construction of the ice bunker coming next in importance. In the past the insulation has not been sufficiently heavy to maintain the low temperatures produced by the refrigerant, and the source of refrigeration, the bunker, has not been able to distribute its product evenly throughout the car.

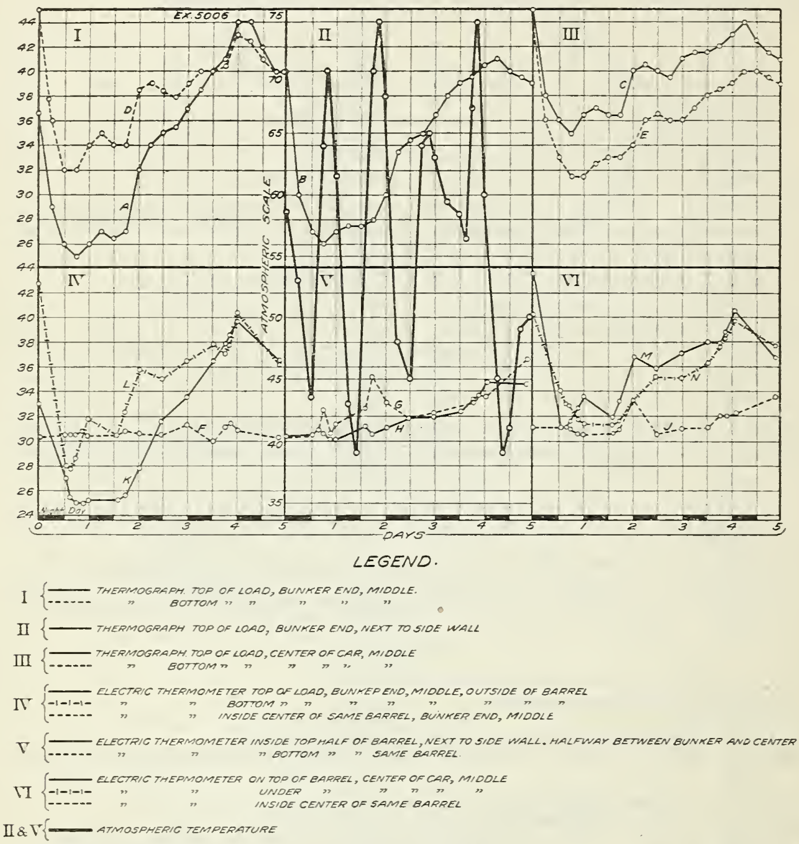

FIG. 19.—Thermograph and electric thermometer records (warm weather), floor insulation of car wet.

The insulation in the side walls and floors of the cars used by six different lines shows no radical differences in quantity or quality, though the general construction in certain cases is preferable. The roofs are varied in the essentials of construction. Theoretically it is the roof of the car which is most severely taxed to prevent the transmission of heat. A critical study of the types of roof construction as given in the foregoing pages indicates that the most efficient cars studied were those with the roofs which were the best insulated and built. It is probable that in the future more attention will be paid to both roof and floor insulation and that the floor will be built with the insulation more effectively protected against moisture.

The ice bunker.—Looking into the future through the glasses of the present, one sees trains of classified freight supplied with refrigeration from a portable, mechanical source. Until that dream is a reality it behooves us to raise the work of the ice bunker to its maximum capacity. The types of bunker most commonly used are sketched and described in this report. The most efficient would seem to be an emphatic indorsement of simplicity of construction based upon a sound scientific foundation. We know that abundant air access to ice and salt results in increased efficiency; hence the principle of the wire basket is sound. We know also that the brine resulting from the solution of the salt in the melted ice contains available cold; hence the holding back of the brine in the tank bunker increases the ability of the bunker to chill the car.

Equality of temperatures in iced cars.—A serious shortcoming of the present types of refrigerator cars is their almost universal inability to equalize the temperature at the center and at the bunker, keeping both sufficiently low. Undoubtedly good bunkers and additional insulation, assisted by a stowing of the load in such a way that runways for cold air are left between packages, will materially help to improve results, but whether these remedies will suffice is still an open question.

Fortunately for the preservation of the poultry shipped, the well-cooled package does not show fluctuations of temperature corresponding to those in the air of the car. A long-continued increase of temperature, or a direct contact between the package and the source of the heat, as, for example, the wall of the car, affects the temperature of the goods in the course of time. Sometimes the packages show slight evidences of the daily rise and nightly fall of temperature, but more often it is the gradual but constant or maintained rise in the temperature of the car that is responsible for the objectionable results seen at the expiration of the haul.

Future work.—The investigation which is here chronicled is only a small beginning in the solution of the problems confronting the shipper, the carrier, and the receiver in the handling of refrigerated perishable products. It is eminently necessary that such questions as the most efficient and economic size of the refrigerated car, the exact amount of insulation required to insure the maintenance of low temperatures, or, conversely, to protect the contents of the car against frost, the equalization of temperatures in all parts of the car, and many others, be pressed for more exact and far-reaching answers. It is hoped that the present report will stimulate further research in these and in other directions.

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