THE FREEZING AND STORING OF MEAT IN A HOME STORAGE UNIT

by

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INTRODUCTION

Up to the present era, man has not been as greatly interested in the science of food preservation as he has been in procuring enough to eat each day and in being reasonably sure that he has a sufficient supply for himself and his family for his needs throughout the year. There is ample evidence that from the dawn of history to the present, man's eating habits have been greatly affected by his ability to conserve the available foods during a time of plenty for use during periods of scarcity.

Meat seemed to offer a problem to our pioneers. Within the northern areas, snow and ice-preserved beef and mutton were used in the winter, but the meat portion of the diet was changed in the summer to pork and chicken when the facilities for the preservation of beef and mutton were not workable. In the southern areas pork became the all-year-around meat for the table, since there were no natural means of preservation as found in the north.

There are essentially four ways to accomplish food preservation: (1) drying or dehydration; (2) low temperature chilling and freezing; (3) sterilization and canning, and (4) preservation by curing including pickling, smoking, spicing, and fermentation.

Each of these types of food preservation, with the exception of freezing, has a changing effect upon the physical and chemical nature of the product. A recorded discovery by the Smithsonian Institute (1) in 1901 of mammoth flesh and other animal carcasses sharp frozen many thousands of years ago, yet still in edible condition, is evidence of the permanence of food preservation by freezing.

Meat was first frozen commercially in the United States about 1875 by using crude rooms insulated with sawdust and cooled by ice-salt mixtures. Frozen meat was shipped from the United States to England in 1876 and from Australia to England about five years later. By the early 1920's frozen meats appeared frequently on the retail market in most large cities, but public acceptability was low.

Considerable research has been done and much has been written on the subject of freezing foods and its importance in the preservation of the original quality of the product. Studies in the field of food freezing have been extensive; however, the development of cabinets for the storage of frozen foods has lagged. Only in the past ten years has much progress been made in the development of an efficient cabinet storage unit such as the home freezer cabinet.

Consumer demand for home freezer units has grown tremendously in the past five years. This has resulted in a need for study and research relating to the use of the home freezer in the preservation of foods, particularly meat. Work has been done concerning home freezers using various approaches. Despite the work which has been done, there still remains a degree of uncertainty regarding the efficient use of home freezers.

At the present time there is a need for further information regarding certain aspects of the use of home freezers. Five items relating to the use of home freezers are of primary importance. They are as follows:

1. The amount of meat which can be efficiently frozen at one time without materially affecting the quality.

2. The time required to freeze packages placed at different locations in the home storage cabinet.

3. The efficiency with which different boxes operate.

4. The cost of operation.

5. The effect of the addition of varying amounts of warm meat upon the temperature of the stored meat.

This study was undertaken for the purpose of securing additional information concerning these and other related questions.

REVIEW OF LITERATURE

The major consideration in the process of preserving meat by freezing is the removal of heat. During this period the meat is changed from an unfrozen to a frozen condition.

Fig. 1 graphically illustrates the process of freezing meat. The first step of significance in the process of freezing meat, is lowering the temperature to point "A". This phase is referred to as the cooling period. Because of the temperature difference between the meat and the refrigerating surface, the cooling period is rapid and continues at an accellerated rate until the temperature of the meat is lowered to point "A".

If the freezing point of a particular substance exists, it is that point above which the substance is a liquid and below which it is a solid. The freezing point of meat is represented by point "A" in Fig. 1. Ramsbottom and co-workers (2) contend that the freezing process of meat begins at 29.5 to 30 degrees F. and

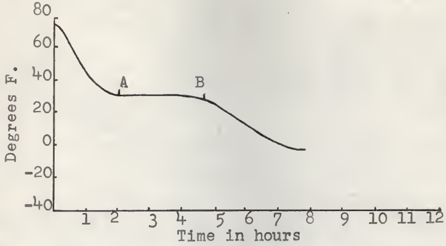


Fig. 1. Typical freezing curve.

continues to a temperature of about 25 degrees F. Beaven (3), who has done considerable work in Australia relative to the freezing of meat and other foods states that most products commence freezing between 31.5 and 27.5 degrees F., and continue until -60 to -80 degrees F. is reached, with about 75 percent of the freezing occurring between 31 and 23 degrees F.

The period between point "A" and "B" in Fig. 1 represents the period of "maximum crystal formation" during the process of freezing meat. During this period the liquids in the meat are crystalized, that is, changed from a liquid to a solid condition. Beaven (3) states that English authorities believe that temperature is not as important as the speed of reduction of temperature. The English believe that the important consideration in freezing is the time required to pass through what is known as the "zone of maximum crystal formation" between 32 and 20 degrees F., and a falling off in speed below 20 degrees F. did not matter too much.

When the temperature reaches point "B" in Fig. 1 the meat is frozen. The temperature will then drop, but at a slower rate than in the cooling period. Due to the diminishing difference between the temperature of the meat and the refrigerating surface, the period following point "B" in Fig. 1 is referred to as the subcooling period. During the subcooling period the temperature of the meat will continue to drop until it reaches the approximate temperature of the box.

Since the rate of freezing has been considered important in the preservation of meat by freezing differences of opinion relative to what constitutes quick freezing, sharp freezing, and slow freezing have developed. According to Moran (4) meat is quick frozen if it is chilled through the temperature range 41 to 23 degrees F. in one-half hour or less. Poole (5) states that meat is quick frozen if its' temperature drops from 31 to 25 degrees F. in 25 minutes. He described this temperature range as the zone of maximum ice crystal formation. Koreneff (6), writing on the technical aspects of quick freezing, makes some very interesting deductions. He concludes that modern methods of freezing may be classified according to two types, slow freezing and quick freezing. Slow freezing is carried out in air in freezing chambers maintained at a temperature of 14 to 5 degrees F. or at a lower temperature of -4 to -40 degrees F., this latter method being called sharp freezing. "However, even at such low temperatures, freezing is comparatively slow because of the low specific heat of the air and its poor thermal conductivity. Under such conditions, it may take 14 to 40 hours for a carcass of beef to cool and from 3 to 5 days to freeze. The rate of freezing in air is, for all practical purposes, approximately proportional to the temperature of freezing. Thus, if a certain carcass will take 70 hours to freeze at 10 degrees F. (22 degrees below freezing) it will take about 36 hours to freeze the same carcass at -12 degrees F. (44 degrees below freezing)."

Steel (7) defines quick freezing as, "freezing at the rate of one-half an hour per inch of thickness. Sharp freezing may be defined as the rapid freezing of foods in about 24 hours, as against freezing at ordinary rates of 3 to 5 days." Constable (8), in his writings on quick freezing states that quick freezing is a term often used and misapplied. It is defined according to American and British standards as follows: "Products frozen in cold air blasts tunnels or well-insulated rooms or by direct immersion in a refrigerant or brine, direct contact plates, and many other methods, in a temperature range of -5 degrees F. to -25 degrees F. or below and frozen in a matter of minutes depending on the size of the product or containers. Sharp freezing is the term applied if products are stored in a very cold room (plus 10 degrees F. to minus 20 degrees F.), with no provision made for forced air circulation, and, practically speaking, products are relatively slow frozen."

Pearson and Miller (9), in their work on rate of freezing, used three rates of freezing which they called slow, intermediate, and rapid. The slow rate required approximately 20 hours to reach 20 degrees F., the intermediate rate, 5 hours, and the rapid rate, 1 hour. The meat used in this study consisted of steaks cut one and one-half inches thick.

Many other investigators have defined quick freezing. Ferris and Taylor (10) referred to it as that speed of freezing which would result in the product being completely frozen in about 90 minutes or less. In 1939 Woodroof (11) proposed that it be defined as freezing which progresses through the body of the product at 0.3 cm per minute or faster. Pennington (12) states that the physical chemist would like to define the term quick freezing as the zone of maximum crystal formation, which means solidification must be passed through in 30 minutes or less; that is the fall in temperature from 32 to 25 degrees F.

The effect of freezing rate on the quality of the product appears to be one of the most controversial subjects which has arisen in the field of food freezing. Many investigators are strong in their contention that quick freezing is essential to the production of a high-grade product. Others, though they agree that quick freezing is the best method of preservation by freezing, feel that products frozen slowly are, to the consumer, indistinguishable from those frozen by quick freezing methods.

Woolrich (13), writing on the engineering of food preservation, states that many people have the mistaken idea that very fast freezing is equally desirable for all perisable foods. According to Woolrich, the need for rapid freezing is much greater in the case of some perishable foods than for others. "Furthermore, the colloidal composition of some products is such that even slow freezing affects the structure only slightly." With most foods that are to be cooked as soon as they are partially thawed, slow freezing is as satisfactory as quick freezing.

Tressler (14) summarizes the advantages of quick freezing as follows: (1) the minimizing of destruction of the intact cells by favoring the formation of small ice crystals, (2) a shortening of the period of solidification during which diffusion and osmosis can alter the water and soluble solids relationships in the tissues, (3) the arresting of the growth of micro-organisms of spoilage by a rapid lowering of the temperature, and (4) the retention of equality through a greatly slowed enzyme action.

Pearson and Miller (9) made an extensive and thorough study of the rate of freezing and length of storage upon the quality of frozen beef. In this study 282 steaks cut from 19 different carcasses were frozen to 20 degrees F. at three different rates, slow (approximately 20 hours), intermediate (about 5 hours), or rapid rate (about 1 hour), and held for different lengths of time at 0 degrees F. The results indicated that the rates of freezing studied had little or no effect on the over-all quality of beef while extended freezer-storage resulted in a marked loss of quality. Reiman and co-workers (15) made a similar study in which they used more than 300 sample cuts, including 24 sides of beef grading U. S. Good. It was found that the methods employed in freezing had no significance in the development of "off flavors" or degree of tenderness. The method of freezing, whether by direct contact in the home freezer, or by forced air of the commercial blast type, was not a factor contributing to flavor, taste or tenderness of meat. Such changes occurred in frozen storage.

Brady, Frei, and Hickman (16), using steaks from beef, lamb and pork, found that the quick frozen steaks had the least evaporation rate, and the smallest drip loss. There was no significant difference between the palatability of the steaks. The steaks used weighed from three-quarters to one pound, were slow frozen at 0 degrees F., and quick frozen at -15 degrees F. All samples were lowered to 0 degrees F. It is interesting to note that the time required for slow frozen steaks to reach 0 degrees F. was 15 hours and 20 minutes or a cooling rate of 2.5 degrees F. per hour; for the quick frozen steaks it was 7 hours and 10 minutes, or a cooling rate of 5.3 degrees F. per hour.

Ramsbottom and Koonz (30) states that when meat is rapidly frozen, intrafiber freezing occurs; and when defrosted, the fluids will be retained for the most part by the fibers and the drip will be relatively small. They also observed that if meat is slowly frozen, extrafiber freezing takes place; and upon being defrosted, most of the fluid will be lost as drip before it can be reabsorbed by the partially dehydrated muscle fibers.

Lee and co-workers (17) included the vitamin content of beef as well as appearance and palatability in their study of freezing rate. They concluded that freezing rate had very little effect on flavor, odor, texture, juiciness, or appearance. Neither thiamine, riboflavin, niacin, pantothenic acid, nor pyridoxine were measurably altered by the rate of freezing.

While studying the chemical changes taking place in the preservation and defrosting of meat, Smorodintsev (18) found that proteins are not split out or denatured by the freezing process. The changes which occurred were caused by enzymic action. Glucose progressively decreased, while lactic acid increases and accumulates. In stored quick-frozen meat the changes occur more extensively than in slow-frozen meat.

The freezing and storage of meat in the home unit on the farm and in the home has become a reality for many famililtes. Although there are no accurate statistics available as to the number of home freezers in use today, reports of the National Electrical Manufactures Association (29) indicate that there were approximately 1,200,000 freezer units of all types in use in the United States in the early part of 1949. During the war years of 1942 through 1945, the manufacture of home units was greatly reduced. However, production increased to approximately 200,000 in 1946, and 400,000 in 1947.

Home storage and freezing units are used in many ways and for various purposes. Some of these are: (1) for storage of commercially frozen foods; (2) to store products frozen in locker plants; (3) to freeze and store farm products for home use; and (4) to freeze and store farm and garden products for sale.

One of the first questions to be answered concerning a home unit is the storage capacity per cubic foot of space. By close packing, Woodroof (19) found that 50 pounds of frozen foods could be placed in each cubic foot of space, and with a turnover on an average of four times per year, a 10 cubic foot cabinet should preserve 2000 pounds of food annually. Masterman (20) states that it is generally possible to store from 30 to 36 pounds per cubic foot of space in a cabinet at one time, according to the food and manner in which it is packaged. Greene and Sater (21) made a very detailed and extensive study relative to the storage capacity of home freezers. They found that an average of 31 pounds of meat could be stored per cubic foot of space.

Studies relative to the performance characteristics of commercial home freezers have not been so extensive as have studies considering methods, characteristics, and quality control. Erwin (22) made an extensive study of several points to be considered in selecting and operating a home freezer. Three identical 25 cubic-foot, chest-type cabinets with 4 inches, 6 inches, and 8 inches of insulation were built and used. It was found that an insulation thickness of 6 inches was the most economical from the standpoint of cost of operation, space occupied, and convenience of using. Extensive tests were conducted to determine the freezing rates of foods in these cabinets. The packages were placed against the cold plates which were held at about -10 degrees F. The recommended maximum load in pounds that should be frozen in a 25 cubic-foot chest-type cabinet freezer with a one-third horse power compressor is given in the following chart.

	Thickness of insulation		
Room Temp. F.	4 in.	6 in.	8 in.
70	81 lbs.	97 lbs.	107 lbs.
80	59 "	71 "	79 "
90	35 "	41 "	47 "
100	12 "	14 "	16 "

Another factor studied was the ability of these cabinets to hold a load of food without thawing after a power failure or other cause. This holding time was influenced by the insulation thickness, air temperature, and the amount of food in storage. The time in hours for the temperature in a 25 cubic-foot chest-type freezer storage cabinet to rise to 28 degrees F. after the power was turned off is given in the following chart.

	Thickness of insulation		
	4 in.	6 in.	8 in.
Empty	15 hrs.	18½ hrs.	21 hrs.
6% loaded	20 "	23 "	24 "
32% loaded	28 "	30 "	35 "
69% loaded	40 "	44 "	46 "
97% loaded	49 "	60 "	62 "

The cabinet freezer with 4 inches of insulation used an average of 110 kilowatt-hours per month; the box with 6 inches, used 87 kilowatt-hours per month, and the one with 8 inches, used 77 kilowatt-hours per month. From tests covering several conditions it was found that the power used in freezing a pound of food and lowering it to a storage temperature was 0.072 kilowatt-hours.

The conclusions drawn from this study were: (1) the larger the freezer the more efficient it was in use of electric current; (2) the amount of electricity used per day in kilowatt-hours per cubic foot of space decreased as the size of the freezer increased; (3) location of the box seemed to have little effect on power use; (4) the estimated power used in freezing a pound of food and lowering it to storage temperature was 0.072 kilowatt-hours.

Masterman (23) made a very extensive study on the power consumption of home freezers. Power consumption figures were collected on 74 freezers over a 12 months period. The freezers ranged in size from 5 to 30 cubic feet and were placed in various locations such as, kitchens, garages, woodsheds, basements, and utility rooms.

An analysis of the data showed that the size of the freezer had a highly significant effect upon the use of electricity. The larger the freezer the more efficient it was in use of current. The amount of current used in 24 hours in kilowatt-hours per cubic foot of space decreased as the size of the freezer increased. According to statistical analysis, location had very little effect upon the power use. The important factor about location was convenience rather than the possible effect of temperature of the location on increasing operation costs. Data indicated that freezers under 6 cubic feet capacity averaged less than one kilowatt-hour a day. Freezers of 6, 9, 12, and 15 cubic feet used less than two kilowatt-hours per day.

Lund (24) summarized his findings on the performance characteristics of home freezers of different capacities as follows:

Cabinet capacity, cu. ft.	6	9	12
Cabinet air temperature, ^{o}F.	0	0	0
Power consumption KWH/24 hr.	1.12	1.70	2.0

These results were based upon an unloaded cabinet. Donnalley (25) found the power consumption of a 9 and 6 cubic foot box per 24 hours to be 2.38 and 2.38 kilowatt-hours respectively. There was, however, a tendency toward lower power consumption per unit volume with increased capacity of the box. Other tests showed that opening the doors for a total time of about thirty minutes each day increased the power consumption by not more than about 0.1 kilowatt-hours per twenty-four hours.

Donnalley (25) calculated the freezing rates of meat by using the following equation:

$$y = \frac{tm}{2} \times \frac{1}{H}$$

Where

y = rate of travel of the freezing zone, inches per hour.
tm = thickness of the meat, inches.
H = time to pass through freezing zone, hours.

The freezing rate, the rate at which the freezing zone travels from the outside of the meat toward the center, increases linearly, with a lowering in the air temperature of the cabinet for "still air" freezing. "Still air" freezing is defined as freezing with refrigerated air under conditions where no mechanical agitation is applied to the air. The equation correlating the rate and temperature is:

$$y = 0.102 - 0.003\ Tf$$

Where

y = freezing rate, inches per hour.
Tf = average air temperature in freezer, ^{o}F.

From the above equation, rates of freezing for pieces of meat under comparable conditions can be calculated for any type of box as long as still air freezing is used.

Fluctuating temperatures of frozen foods during storage may be encountered in the operation of a home unit. Excessive loads during freezing, frequent opening of the cabinet, and improper response of temperature control devises, all may lead to a temporary rise in the temperature of the stored food.

Work done by Shrewsbury and co-workers (26) indicated that temperature fluctuation over the range of -5 degrees to -15 degrees F. was not injurious to frozen pork. Hustrulid and Winter (27) observed that where the temperature fluctuation was infrequent and in the range of 0 degrees to -20 degrees F., no significant change in the extent of desiccation, appearance, or palatability of fruits or vegetables was evident during the course of 6 months storage. Gortner and co-workers (28) found that exposure of frozen pork to temperatures fluctuating between 0 degrees and 20 degrees F. resulted in deterioration of quality, while storage at 0 degrees F. resulted in essentially no change. The data from this study as well as Hustrulid and Winter (27) suggest that the quality of the food will not undergo a significant change caused by temperature fluctuation if the temperature of the packages does not rise above 3 degrees to 5 degrees F. during storage; that is, provided that the majority of the time the storage temperature is below 0 degrees F.

METHODS AND PROCEDURE

This study was undertaken to secure information concerning the performance characteristics of commercial home freezers. Three commercial units of the top-opening type were studied (Plate I). The units were designated as Box A, B, and C.

Box A was a one compartment, top-opening type unit having 8 cubic feet of storage space. The refrigerating mechanism was located directly under and in the center of the cabinet. Freon-12 was used as the refrigerant, and was circulated by a one-sixth horsepower motor. Coils were arranged around the sides and ends of the cabinet. The box was insulated with 4 inches of spun glass insulation.

Box B was similar to Box A in that it was a one compartment, top-opening type unit. However, it had 11.1 cubic feet of storage space. The refrigerating mechanism was located at the right end of the cabinet. As in Box A, the refrigerant was Freon-12. The power unit was a one-fourth horsepower motor. In addition to having coils located around the sides and ends, it had coils located on the bottom of the left end of the storage compartment. This space was 16 by 20 inches in size and was referred to as the "Freez-Area" by the concern which manufactured the cabinet. The manufacturer contended that foods placed in this area would freeze solid within 24 hours, and that 100 pounds of meat could be frozen in the box at one time. The insulation used in the construction of the box was spun glass, four and one-half inches thick on the sides, 3 inches thick on the door, and 4 inches thick on the bottom. According to the manufacturer, the capacity of the box was 385 pounds of frozen foods, which would be 34.77 pounds of frozen food per cubic foot of space.

Box C was more on the order of Box A, since it too was a one compartment top-opening type unit having 8 cubic feet of storage space. As in Box A, the refrigerating mechanism was located directly under and in the center of the cabinet. The refrigerant used was Freon-12. A one-fourth horse power motor was used to operate the unit. Coils were located on all four walls, as in Box A. The insulation used was fiber glass and was 4 inches thick on the walls and 3 inches thick on the top. According to the manufacturer, the storage capacity of the box was 280 pounds or 35 pounds per cubic foot of cabinet space. The freezing capacity was listed as 50 pounds per 24 hours, and an average power consumption of 40 kilowatt-hours per month.

The meat used in this study was ground beef and pork sausage. Both were made in a ratio of approximately 25 percent fat and 75 percent lean. The sausage was seasoned with one pound of salt, two ounces of sage, and two ounces of pepper per 50 pounds of meat. Both the ground beef and pork sausage were ground twice through a three-eighth inch plate followed by grinding through a three-sixteenth inch plate. The meat was then cooled in a 34 to 36 degree F. cooler. Twelve to twenty-four hours later, the meat was packaged in two pound packages and wrapped in approved wrapping papers, Watt and Mackintosh (31).

The trials made in each unit were as follows:

Lot 1. No-load, in which each of the three empty boxes were connected to the power and the temperature of the box lowered from room temperature to 0 degrees F.

Lot 2. 40 pound load, in which each box was loaded with 40 pounds of the packaged meat and the temperature of the meat lowered to 0 degrees F.

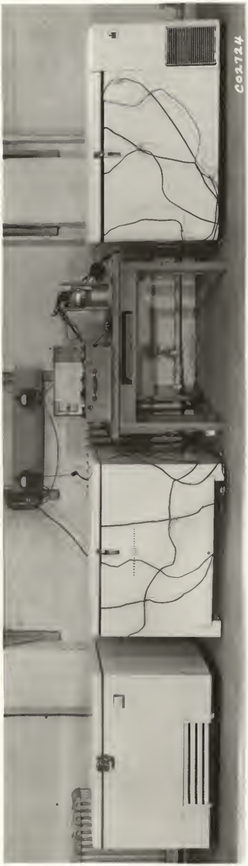
Lot 3. 40-40 load, in which each box was loaded with 40 pounds of unfrozen packaged meat, while Lot 2, the 40 pounds previously frozen, remained in the box as storage. In this Lot, the temperature of Lot 2 was observed, as well as the temperature of the 40 pounds to be frozen and lowered to 0 degrees F.

Lot 4. 60-80 load, in which 60 pounds of packaged meat were loaded into each box while the 40 pounds of meat from Lot 2, plus 40 pounds from Lot 3, remained in the box. As in Lot 3, the

EXPLANATION OF PLATE I

Home storage units used in the study. The Leeds-Northrup type potentiometer and thermocouple leads used to indicate temperature of meat are shown.

PLATE I



temperature of Lot 2, as well as the 60 pounds was observed.

Lot 5. 120-60 load, in which 120 pounds of meat were loaded into each box. 60 pounds of previously frozen meat from Lot 4, including the original 40 pounds from Lot 2, remained in the box. Temperatures were taken on both Lot 2 and the 120 pounds. Box A was omitted from this portion of the study because of its' apparent lack of efficiency in freezing Lot 4.

The temperature of the meat to be frozen, as well as the previously frozen meat, was taken by means of thermocouples connected to a Leeds-Northrup type potentiometer, as shown in Plate I. The thermocouples used were iron vs. constantan type. A reference junction or constant of 32 degrees F. was used and all readings were made in millivolts. These readings were then changed to degrees F. by using an iron vs. constantan chart.

The terminal of a thermocouple was inserted into the center of representative packages as the packages were placed into each box. Readings of the temperatures indicated by the various thermocouples were usually recorded in fifteen minute to three hour intervals for the duration of the run. The frequency with which readings were taken depended upon the rapidity of the change in temperature. Readings were continued until the temperature of the last package of meat reached 0 degrees F.

The location of the thermocouples in each unit during the no-load run was as follows:

1. Right end center, on the bottom.

2. Against the center of the front wall, 12 inches from the bottom.

3. Suspended, approximate center of the unit.

4. Left end center, on the bottom.

5. Against the center of the back wall, 12 inches from the bottom.

The packages in Lot 2 were arranged in the middle of Boxes A, B, and C during the freezing period. Lots 3, 4, and 5 were frozen in the right end of Boxes A and C, and in the left end of Box B. A space of approximately one-half inch separated each package in all lots during the freezing period in order that the air could circulate around each package.

The packages containing thermocouples were placed in the same relative location in each of the three boxes during the freezing of Lots 2, 3, 4, and 5. Figure 2 shows the location of the packages in Lot 2. Packages containing thermocouples number 5 and 6 were placed next to the walls, and the package containing thermocouple 8 was placed in the middle of the bottom layer. Thermocouple number 10 was located in a package on the top layer of packages. Thermocouple number 7 was placed in the middle of the box in all lots to indicate the box temperature during the freezing period. This arrangement of thermocouples produced temperature readings from packages in three locations: (1) bottom, against the walls, (2) bottom, completely surrounded by other packages, and (3) top layer of packages. Lot 2, when frozen, was moved to allow space for the unfrozen packages, and became a part of Lots 3, 4, and 5.

Figure 3 shows the relative location of the packages containing thermocouples in Lots 3, 4, and 5. This arrangement of thermocouples made it possible to record temperature readings from frozen and unfrozen packages placed side by side. The package containing thermocouple number 3 was across from and on the same level with the packages containing number 5, and the package containing number 9 was across from and on the same level with the packages containing number 10. The package containing thermocouple number 2 was completely surrounded by packages and was located in the middle of the bottom layer of packages. The package containing thermocouple number 4 was located in the middle layer of packages regardless of the number of packages in the lot. It was surrounded by packages with the exception of one end which was exposed. The package containing thermocouple number 9 was placed on the top of the arrangement of packages. This thermocouple arrangement in Lots 3, 4, and 5 permitted temperature readings to be made from packages in four different locations, which were as follows: (1) bottom against the walls, (2) bottom completely surrounded by packages, (3) center of the arrangement of packages, and (4) the top layer of packages.

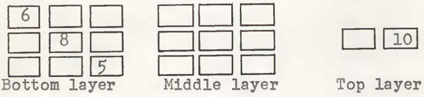


Fig. 2. Location of thermocouples in lot 2.

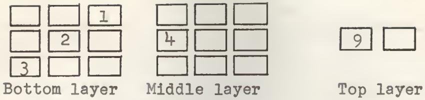


Fig. 3. Relative location of thermocouples in lots 3, 4, and 5.

Figures 2 and 3, showing the location of thermocouples in all lots, are diagrammatical and show relative location regardless of the amount of meat placed in the box.

Each box was prepared for a Lot by setting the temperature control at maximum immediately before the meat was to be placed into the unit with the exception of Lot 2 in Box A and B. This Lot was frozen at one-half maximum to obtain the effect of temperature control setting on temperature of the box and the freezing time. The maximum setting was maintained throughout the time required to lower the temperature of the meat to 0 degrees F. When the last package reached 0 degrees F., the temperature control was moved to one-half maximum, and allowed to remain at this point during the storage period. The storage period extended for a sufficient length of time to allow a power consumption large enough to arrive at an average kilowatt-hour requirement.

The power consumption was measured during freezing and storage by connection kilowatt-hour meters into the power line leading to the boxes. Meter readings were made at the beginning and end of each freezing period, and at the beginning and end of each storage period.

OBSERVATIONS AND DISCUSSIONS

The average freezing time of the packages in Lots 2, 3, 4, and 5 in each box are graphically illustrated in Figs. 4, 5, 6, and 7, respectively, and in tabular form in Table 1. Figure 4 also illustrates the effect of temperature control setting on the temperature of the box and the freezing time. The control was set at one-half maximum on Boxes A and B, and in Box C the control was set at maximum. The box temperature and the temperature of the packages in storage are also graphically illustrated in Figs. 5, 6, and 7. Figures 4, 5, 6, and 7 show a freezing time of only 24 hours. A total freezing time of 24 hours was selected as the maximum allowable time to freeze Lots 2, 3, 4, and 5 in order that sharp freezing may be accomplished as defined by Steel (7) and Constable (8).

The average freezing time of Lot 2, as indicated in Table 1, was 54, 23, and 12 hours for Boxes A, B, and C, respectively. A 24 hour freezing curve for Lot 2 in each box is graphically illustrated in Fig. 4. Figure 4 also shows the effect of temperature on freezing time.

The extended freezing time for Lot 2 in Boxes A and B was due, at least in part, to a temperature control setting of one-half maximum. As a result of this setting, the box temperature, as shown in Fig. 4, did not become low enough during the freezing period to cause a rapid transfer of heat from the packages of meat to the refrigerating surface. Lot 2, when compared with Lot 3 in freezing time, produces the following observations. Table 1 shows that the freezing time of Lot 3 in Boxes A and B was 23 and 16 hours, respectively. This is graphically illustrated in Fig. 5. The temperature setting on Boxes A and B while freezing Lot 3 was maximum. It will be noticed in Fig. 5 that even though the box temperature at the start of the freezing time was considerably higher as the result of the addition of Lot 3, the total freezing time was reduced by 31 hours for Box A, and 8 hours for Box B. These data are presented in tabular form in Table 1. The reduced freezing time was the result of lower box temperatures during the later stages of the freezing period as shown in Fig. 5. This is a reduction in freezing time of 57 percent for Box A and 33 percent for Box B.

A duplication of Lot 2 using a temperature control setting of maximum was not made due to an inadequate supply of meat; however, from the data presented in Table 1 and Figs. 4 and 5, it can be recommended that when freezing comparable amounts of meat, a temperature control setting of maximum during the freezing period is necessary for efficient freezing.

The freezing rates illustrated in Figs. 4, 5, 6, and 7 do not constitute quick freezing as defined by Moran (4), Poole (5), Ferris and Taylor (10), Woodroof (11), and Pennington (12). Moran (4) defines quick freezing as chilling through the temperature range 41 to 23 degrees F. in one-half hour or less. Poole (5) states that if the temperature of meat drops from 31 to 25 degrees F. in 25 minutes, the meat is quick frozen. Ferris and Taylor (10) referred to quick freezing as that speed of freezing which would result in the product being completely frozen in about 90 minutes or less. Woodroof (11) proposed that it be defined as freezing which progresses through the body of the product at 0.3 cm per minute or faster. Pennington (12) states that the fall in temperature from 32 to 25 degrees F. must be accomplished in 30 minutes or less to be called quick freezing. Table 1 presents the average freezing time of all lots. These data show that quick freezing was not accomplished by any of the three boxes while freezing Lots 2, 3, 4, and 5.

The average freezing time of Lots 3 and 4 are illustrated graphically in Figs. 5 and 6, respectively, and in tabular form in Table 1. Lot 3, in which 40 pounds of meat was frozen in Boxes A, B, and C, required 23, 16, and 15 hours, respectively, for the temperature to be lowered to 0 degrees F. Lot 4, in which 60 pounds of meat were frozen in each of the three boxes, required 29, 20, and 19 hours respectively for the temperature to be lowered to 0 degrees F.

According to Steel (7) sharp freezing is the rapid freezing of foods in about 24 hours. Constable (8) states that, according to American and British standards, sharp freezing is the term applied if products to be frozen are placed in a very cold room (plus 10 degrees F. to minus 20 degrees F.) with no provisions made for forced air circulation.

Therefore, it can be concluded that 40 pounds of meat in Boxes A, B, and C, and 60 pounds of meat in Boxes B and C were sharp frozen. Box A, which required 29 hours to freeze 60 pounds of meat, was considered to have passed the maximum amount of meat that could be efficiently frozen at one time.

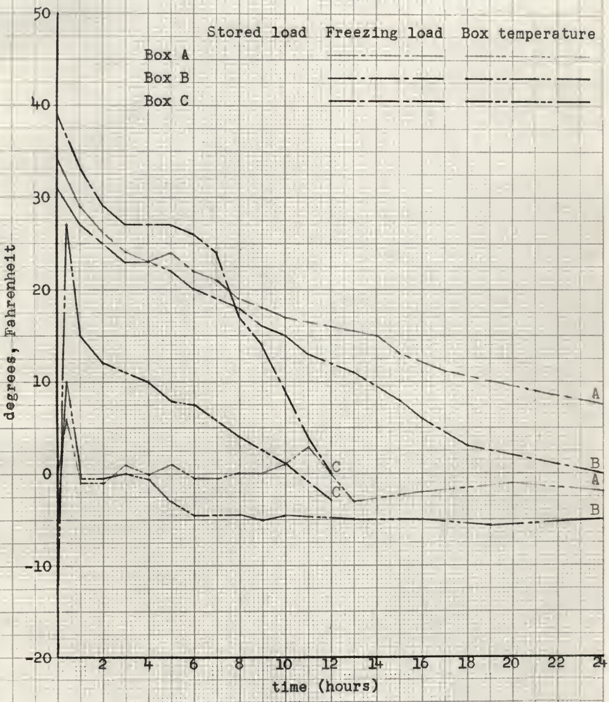


Fig. 4. Effect of load and box temperature on rate of freezing.
Lot 2. Freezing load - 40 pounds.

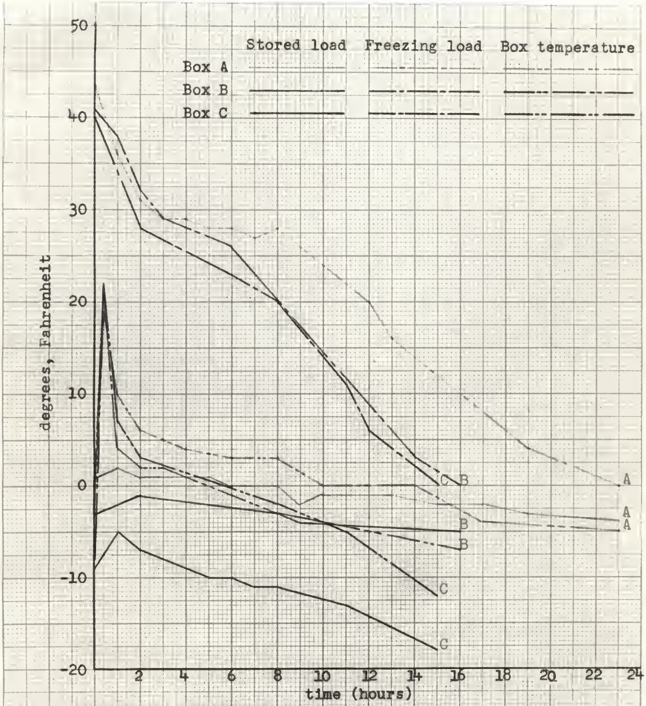


Fig. 5. Effect of load and box temperature on rate of freezing and temperature of stored packages.
Lot 3. Freezing load - 40 pounds, stored load 40 pounds.

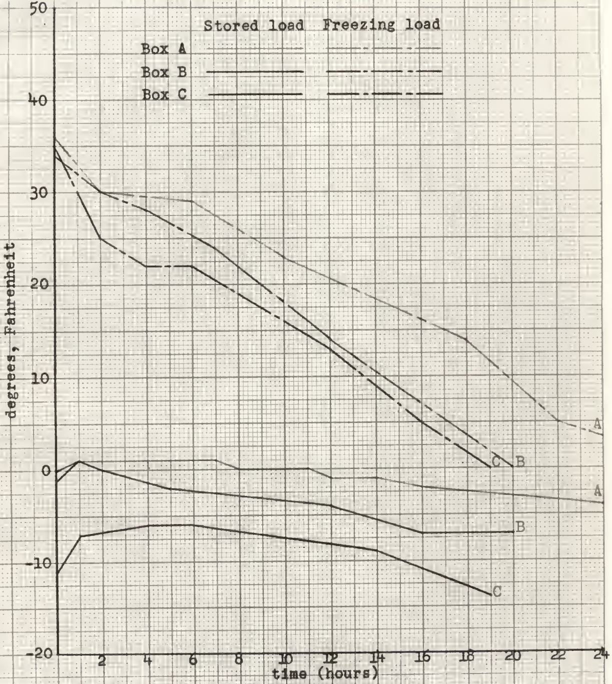


Fig. 6. Effect of load on rate of freezing and temperature of stored packages.
Lot 4. Freezing load - 60 pounds, stored load 80 pounds.

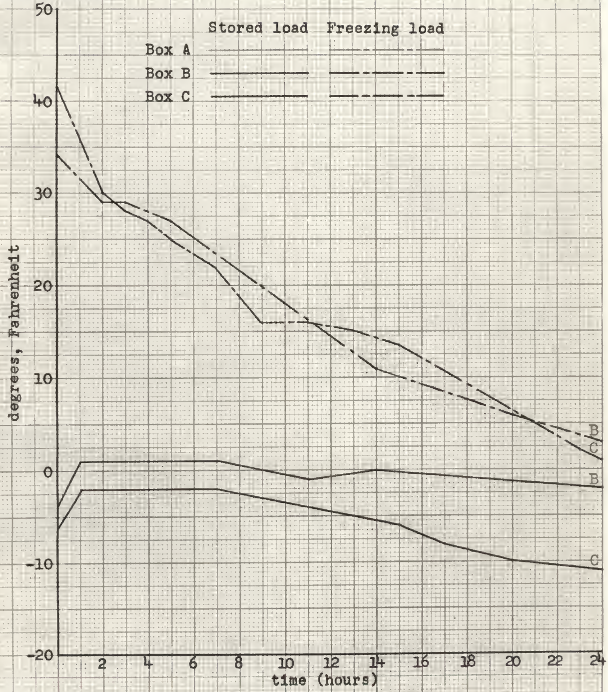


Fig. 7. Effect of load on rate of freezing and temperature of stored packages.
Lot 5. Freezing load - 120 pounds; stored 60 pounds.

The freezing time for Lot 5 in Boxes B and C is graphically illustrated in Fig. 7 and appears in Table 1. Box A was not included in this portion of the experiment because the time required to freeze 60 pounds in Lot 4 was beyond the limits of sharp freezing.

The time required to lower the temperature of 120 pounds of meat to 0 degrees F. for both Box B and C was 28 hours as illustrated in Fig. 7 and Table 1. The time required to freeze 120 pounds was beyond the limits of sharp freezing. Therefore, it is concluded that a freezing load of 60 to 120 pounds is the maximum amount of meat that can be sharp frozen in Boxes B and C.

The average freezing time in hours for all Lots in each box and a summary of Fig. 4, 5, 6, and 7 is presented in tabular form in Table 1. The temperature control setting indicates the setting used during the freezing period of each Lot. As previously indicated, all Lots, with the exception of Lot 2 in Boxes A and B, were frozen with the temperature control set at maximum. The cooling time was the time required to lower tne temperature of the meat to 30 degrees F. The temperature of the meat when placed in each box varied from 43 to 31 degrees F. as is indicated in Figs. 4, 5, 6, 7, and the cooling time varied from 0.5 to 2.5 hours. Meat, in amounts up to 120 pounds, that has been chilled for 24 hours at a temperature of 34 to 36 degrees F. will start freezing in approximately 2 hours after being placed in the home freezer unit. The cooling time had a tendency to decrease slightly as the amount of meat in storage increased.

The freezing time was the time required to lower the temperature of the packages being frozen from 30 to 25 degrees F. This

Table 1. Freezing time in hours. Average, all lots, and all boxes.

Lot number	Box A 8 cu. ft.	Box B 11.1 cu. ft.	Box C 8 cu. ft.
Lot 2 - Freeze 40 lbs.			
Temperature control setting	½ maximum	½ maximum	maximum
Cooling time - to 30° F.	1.0	0.5	2.0
Freezing time - 30° F. to 25° F.	2.0	2.0	5.0
Total freezing time - to 0° F.	54.0	24.0	12.0
Lot 3 - Freeze 40 lbs., Store 40 lbs.			
Temperature control setting	maximum	maximum	maximum
Cooling time - to 30° F.	2.5	2.5	1.5
Freezing time - 30° F. to 25° F.	7.0	4.0	2.5
Total freezing time - to 0° F.	23.0	16.0	15.0
Lot 4 - Freeze 60 lbs., Store 80 lbs.			
Temperature control setting	maximum	maximum	maximum
Cooling time - to 30° F.	2.0	2.0	1.0
Freezing time - 30° F. to 25° F.	7.5	4.5	1.0
Total freezing time - to 0° F.	29.0	20.0	19.0
Lot 5 - Freeze 120 lbs., Store 60 lbs.			
Temperature control setting		maximum	maximum
Cooling time - to 30° F.		1.5	2.0
Freezing time - 30° F. to 25° F.		5.5	3.0
Total freezing time - to 0° F.		28.0	28.0

period is commonly referred to as the "zone of maximum crystal formation". The freezing time varied from a high of 7.5 hours for Lot 4 in Box A to a low of 1 hour for Lot 4 in Box C; however, the freezing time for any of the lots was not within the limits of quick freezing.

The total freezing time in Table 1 represents the total time required to lower the temperature of the meat to 0 degrees F. There was a variation from 12 hours for Lot 2 in Box C, to 54 hours for Lot 2 in Box A. A comparison of Boxes A, B, and C in respect to freezing time indicates that Boxes B and C were approximately equal in efficiency of freezing. Boxes B and C required essentially the same time to freeze Lots 3, 4, and 5, the time being 16 and 15 hours, 20 and 19 hours, and 28 and 28 hours, respectively. Box A required the longest time to freeze all Lots and was the least efficient of the three boxes in freezing time. Lots 3 and 4 were frozen in 23 and 29 hours, respectively, in Box A. Based on these data it may be concluded that from 40 to 60 pounds of meat may be sharp frozen in Box A. In Boxes B and C it is possible to sharp freeze from 60 to 120 pounds of meat.

In some cases, the total freezing time was extended beyond what is termed as sharp freezing. Beyond the point of sharp freezing, the freezing rate is generally referred to as slow freezing. The probability of slow freezing in home units introduces the question of the effect of slow freezing upon the quality of the product.

In this study, no attempt was made to determine the effect of rate of freezing upon quality. A review of the research work done on the subject seems to indicate that the rate of freezing does not effect the quality of meat to any marked degree. Pearson and Miller (9), Brady, Frei, and Hickman (16), Lee and co-workers (17), and Reiman and co-workers (15) concluded that the methods employed in freezing had no significant effect upon flavor, odor, texture, juiciness, tenderness, and palatability of meat. However, Brady, Frei and Hickman (16) found that quick frozen steaks had the least evaporation rate, and the smallest drip loss. Ramsbottom and Koonz (30) concluded that the drip loss from rapidly frozen meat, is relatively small whereas, the drip loss from slowly frozen meat is relatively large.

Fluctuation in temperature of stored meat has frequently been referred to as having some effect upon the quality. According to Shrewsbury and co-workers (26), Gortner and co-workers (28), and Hustrulid and Winter (27), temperature fluctuations below 0 degrees F. do not significantly influence the quality of the frozen product. However, a material fluctuation above 0 degrees F. resulted in deterioration in quality. These studies indicated that the allowable fluctuation above 0 degrees F. was 3 degrees to 5 degrees F. when the majority of the storage was at a temperature of 0 degrees F. Figures 5, 6, and 7, as well as illustrating the freezing time of each Lot, graphically illustrates temperature fluctuations of stored frozen meat during the time each Lot was frozen. The greatest fluctuation of temperature appears in Fig. 5 and occurred in Box A while freezing 40 pounds of meat. One hour after the 40 pounds of meat to be frozen was added to Box A, the temperature of the previously frozen 40 pounds from Lot 2 had risen to 2 degrees F. However, there was a gradual decline in temperature from 2 degrees

F. and at the end of six hours the temperature of the stored meat was 0 degrees F.

In this study, as is indicated in Figs. 5, 6, and 7, the temperature fluctuation of the stored meat in each Lot was not enough to materially effect the quality of the frozen meat.

The location of packages to be frozen in the home freezer unit during freezing was considered. Data indicated that packages placed next to the walls were the first to freeze, followed by the packages in the middle of the bottom layer. The next packages to freeze were those placed in the middle layer of the arrangement of packages. The slowest rate of freezing occurred in those packages placed near the top. Therefore, the following deducations may be made:

1. The fastest rate of freezing is to be found against the walls or coils.

2. Foods placed in a home freezer unit for freezing should be placed as deep into the box as possible to insure sharp freezing.

3. In order to accomplish 1 and 2 above, a space should be reserved at one end of the home freezer to be used as a freezing area, unless a separate freezing compartment is provided for.

The power consumption of home freezer cabinets is effected by such factors as, (1) the size of the box, (2) the kind and thickness of insulation, (3) the horsepower of the motor on the refrigerating unit, (4) the quantity of foods to be frozen, (5) the efficiency of the refrigerating machinery, and (6) the surrounding temperature during various seasons.

The power consumption of Boxes A, B, and C for Lots 2, 3, 4, and 5 are presented in Tables 2, 3, and 4, and the average power consumption for all boxes and all Lots is presented in Table 5. An analysis of Tables 2, 3, and 4 indicates that as the quantity of storage was increased the kilowatt-hour consumption remained reasonably constant. It required approximately 0.05 kilowatt-hours per hour to maintain the Boxes at 0 degrees F. while empty. The addition of 40 to 180 pounds of frozen meat increased the kilowatt-hour consumption of 0.06 per hour, or an average increase of 0.01 kilowatt-hour per hour. Box A was the most efficient of the three boxes in freezing Lots 3 and 4 from a power consumption standpoint. Box A required 0.11 and 0.12 kilowatt-hours per hour to freeze 40 and 60 pounds respectively as shown in Table 2. The kilowatt-hour per hour requirement by Box B to freeze Lots 3 and 4 was 0.16 and 0.19, respectively, and appears in Table 3. Similar requirements for Box C for the same Lots appear in Table 4, and are 0.15 and 0.18 kilowatt-hours, respectively, for the freezing of Lots 3 and 4.

The amount of electricity used in a 24 hour period per cubic foot of space decreased as the size of the freezer increased, as is indicated in Table 5. Box B, 11.1 cubic feet of storage space, required 0.40 kilowatt-hours to freeze and 0.16 kilowatt-hours to store. Box C, 8 cubic feet of storage space, required 0.51 kilowatt-hours to freeze and 0.22 kilowatt-hours to store. This decrease in power consumption as the size of the box increased is in agreement with the findings of Erwin (22), Masterman (23), and Donalley (24).

Table 2. Power consumption. Box A, 8 cu. ft. storage space.

Lot no.	Temperature control set	K.W.H. per hr	K.W.H. per 24 hr	K.W.H. per cu. ft. per 24 hr.
Lot no. 1				
To cool to 0° F.	maximum	.14	3.36	.42
To maintain 0° F.	½ maximum	.04	.96	.12
Lot no. 2				
To freeze to 0° F.	½ maximum	.05	1.20	.15
To store at 0° F.	½ maximum	.05	1.20	.15
Lot no. 3				
To freeze to 0° F.	maximum	.11	2.64	.33
To store at 0° F.	½ maximum	.06	1.44	.18
Lot no. 4				
To freeze to 0° F.	maximum	.12	2.88	.36
To store at 0° F.	½ maximum	.06	1.44	.18
Average all lots				
To freeze to 0° F.		.09	2.24	.28
To store at 0° F.		.05	1.36	.17

Table 3. Power consumption. Box B, 11.1 cu. ft. storage space

Lot no.	Temperature control set	K.W.H. per hr	K.W.H. per 24 hr	K.W.H. per cu. ft. per 24 hr.
Lot no. 1				
To cool to 0° F.	maximum	.30	7.20	.65
To maintain 0° F.	½ maximum	.07	1.68	.15
Lot no. 2				
To freeze to 0° F.	½ maximum	.12	2.88	.26
To store to 0° F.	½ maximum	.07	1.68	.15
Lot no. 3				
To freeze to 0° F.	maximum	.16	3.84	.34
To store at 0° F.	½ maximum	.08	1.92	.17
Lot no. 4				
To freeze to 0° F.	maximum	.19	4.56	.41
To store at 0° F.	½ maximum	.08	1.92	.17
Lot no. 5				
To freeze to 0° F.	maximum	.20	4.80	.60
To store at 0° F.	½ maximum	.08	1.92	.17
Average all lots				
To freeze to 0° F.		.16	4.02	.40
To store at 0° F.		.07	1.86	.16

Table 4. Power consumption. Box C, 8 cu. ft. storage space.

Lot no.	Temperature control set	K.W.H. per hr	K.W.H. per 24 hr	K.W.H. per cu. ft. per 24 hr.
Lot no. 1				
To cool to 0° F.	maximum	.22	5.82	.72
To maintain 0° F.	½ maximum	.07	1.68	.21
Lot no. 2				
To freeze to 0° F.	maximum	.16	3.84	.48
To store at 0° F.	½ maximum	.07	1.68	.21
Lot no. 3				
To freeze to 0° F.	maximum	.15	3.60	.45
To store at 0° F.	½ maximum	.07	1.68	.21
Lot no. 4				
To freeze to 0° F.	maximum	.18	4.32	.54
To store at 0° F.	½ maximum	.09	2.16	.27
Lot no. 5				
To freeze to 0° F.	maximum	.19	4.56	.57
To store at 0° F.	½ maximum	.07	1.68	.21
Average all lots				
To freeze to 0° F.		.17	4.08	.51
To store at 0° F.		.07	1.80	.22

Table 5. Power consumption. Average, all lots and all boxes.

Box	K.W.H. per hr	K.W.H. per 24 hr	K.W.H. per cu. ft. per 24 hr.
Box A, 8 cubic feet			
To freeze	.09	2.24	.28
To store	.05	1.36	.17
Box B, 11.1 cubic feet			
To freeze	.16	4.02	.40
To store	.07	1.86	.16
Box C, 8 cubic feet			
To freeze	.17	4.08	.51
To store	.07	1.80	.22

SUMMARY

1. Home freezer units similar to B and C used in this study may be expected to sharp freeze approximately 100 pounds of meat. Boxes similar to A can be expected to sharp freeze approximately 50 pounds of meat.

2. Meat, in amounts up to 120 pounds, that has been chilled for 24 hours at a temperature of 34 to 36 degrees F., will commence freezing in approximately 2 hours after being loaded into the home freezer unit.

3. Quick freezing was not accomplished by any of the three boxes while freezing 40, 60, or 120 pounds of meat.

4. The approximate freezing rate per cubic foot of storage space for Boxes A, B, and C was 6, 9, and 12 pounds, respectively.

5. Maximum temperature control setting is necessary if sharp freezing is to be expected.

6. By increasing the temperature control setting from one-half maximum to maximum at the beginning of the freezing operation, the freezing time will be decreased approximately 45 percent.

7. Packages placed in the home freezer to freeze will be frozen in the following order: (1) against the walls or coils, (2) deep into the cabinet, (3) near the top of the cabinet. Foods placed in a home unit for freezing should be placed as deep as possible into the box to insure sharp freezing.

8. A space to be used as a freezing area should be reserved at one end of the home freezer, unless a separate freezing compartment is provided for.

9. There is a marked difference in the efficiency of operation of units manufactured by different companies. Therefore, it is necessary for the owner of a home freezer unit to make some observations which will enable him to operate the box more efficiently. Suggested observations are: (1) temperature control setting required to maintain 0 degrees F. during storage, (2) maximum freezing load per 24 hour period. This can be accomplished by inserting a thermometer into the center of a package located on top of the arrangement of packages to be frozen. If the temperature of this package is lowered to 0 degrees F. in 24 hours or less, it can be assumed that the total load is sharp frozen.

10 The kilowatt-hours required to maintain an empty cabinet at 0 degrees F. is essentially the same as that required to store and maintain from 40 to 180 pounds of meat at 0 degrees F.

11. The electricity required for storage and maintenance is approximately 0.07 kilowatt-hours per hour; for freezing it is approximately 0.14 kilowatt-hours per hour.

12. The temperature fluctuation of the stored meat resulting from the addition of 40 to 120 pounds of warm meat to be frozen, was not sufficient to materially effect the quality of the frozen meat.

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BIBLIOGRAPHY

(1) Annual Report of the Board of Regents of the Smithsonian Institute. 1902-1903. p. 621

(2) Ramsbottom, J. M., P. A. Goeser, and E. J. Strandine. Factors affecting the freezing rates of meats. Refrig. Engg. 57:1188-1191. December, 1949.

(3) Beaven, F. C. Quick freezing. Refrig. Jour. 1:114-115. August, 1947.

(4) Moran, T. Rapid freezing. Critical rate of cooling. Soc. Chem. Indus. Jour. 51:16T. 1932.

(5) Poole, G. Recent progress in quick freezing. Refrig. Engg. 29:69. 1935.

(6) Koreneff, B. C. Technical aspects of quick freezing. Refrig. Jour. 1:118-119.

(7) Steel, L. M. Sharp freezing. Refrig. Jour. 1:326, 328, 331. January, 1948.

(8) Constable, P. C. Quick freezing; survey of methods and applications. Refrig. Jour. 1:338, 340, 342, 344, 346, 347. January, 1948.

(9) Pearson, A. M., and J. I. Miller. The influence of rate of freezing and length of freezer-storage upon the quality of beef of known origin. Jour. Animal Sci. 8:614. November, 1949.

(10) Ferris, J. P., and R. B. Taylor. Immersion quick freezing. Ice and Refrig. 97:177-180. 1939.

(11) Woodroof, J. G. Comparing methods of freezing fruits and vegetables. Refrig. Engg. 37:9-12. 1939.

(12) Pennington, M. E. Fifty years of refrigeration in our industry. Ice and Refrig. 101:45-48. 1941.

(13) Woolrich, W. R.
The romance and engineering of food preservation. Science. 99:107. 1944.

(14) Tressler, D. K.
Chemical problems of the quick-freezing industry. Indus. Engg. Chem. 24:682. 1932.

(15) Reiman, W., R. Hockman, D. C. McCoy, and G. A. Hayner.
A study of beef aging in relation to freezing. Refrig. Jour. 1:236. November, 1947.

(16) Brady, D., P. Frei, and C. Hickman.
Effect of freezing rate on quality of broiled steaks. Food Res. 8:388-393. 1942.

(17) Lee, F. A., R. F. Brooks, A. M. Pearson, J. I. Miller and F. Volz. Effect of freezing rate on meat appearance, palatability, and vitamin content of beef. Food Res. 15 (1):8-15. 1950.

(18) Smorodintsev, I. A.
Chemical changes in the preservation and defrosting of frozen meat. Chem. Abstracts. 38:6410. 1944.

(19) Woodroof, J. G.
Preserving foods by freezing. Geo. Agr. Expt. Sta. Bul. 233. June, 1944.

(20) Masterman, Nancy K.
Using the home freezer. New York Agr. Col. (Cornell) Ext. Bul. 658. November, 1944.

(21) Greene, Dorothy S., and V. E. Sater.
Food storage capacity in home freezers. Refrig. Engg. 57:1084-1086.

(22) Erwin, R. L.
Farm and home freezers. Ohio Farm and Home Research. 33:116-121. July-August, 1948.

(23) Masterman, Nancy K.
Freezer study shows low cost of operation. New York State Agr. Expt. Sta. Farm Research. 15:15. October, 1949.

(24) Lund, C. E.
Technical phases of home freezer development. Refrig. Engg. 51:513-520. June, 1946.

(25) Donnalley, J. R. Jr.
Preformance characteristics of commercial home freezers. Cornell University Engg. Expt. Sta. Bul. 34. December, 1944.

(26) Shrewsburg, C. L., L. W. Horne, W. Q. Braun, R. Jordan, O. Milligan, C. M. Vestal, and N. E. Weitkamp.
Chemical, histological, and palatability changes in pork during freezing and storage in the frozen state. Purdue Agr. Expt. Sta. Bul. 472. 1942.

(27) Hustrulid, A., and J. D. Winter.
Effect of fluctuating storage temperatures on frozen fruits and vegetables. Agr. Engg. 24:416. 1943.

(28) Gortner, W. A., F. Fenton, F. E. Volz, and E. Gleim.
Effect of fluctuating storage temperatures on quality of frozen foods. Indus. and Engg. Chem. 40:1423-1426. 1948.

(29) Larson, S. L., J. A. Mixon, and E. C. Stokes.
Marketing frozen foods - facilities and methods. U. S. Department of Agriculture, Production and Marketing Administration, Marketing Facilities Branch. Washington: Government Printing Office, June, 1949.

(30) Ramsbottom, J. M. and G. H. Koonz.
Freezing temperature as related to drip of frozen-defrosted beef. Food Res. 4:425-431. 1939.

(31) Watt, D. B., and D. L. Mackintosh.
The influence of wrapping material on the keeping quality of fresh frozen pork sausage. Kans. Acad. Sci. Trans. 53:75-90. 1950.