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THE EFFECT OF FAT AND MOISTURE
ON THE FREEZING OF BEEF

Thesis for the Degree of M. S.
MICHIGAN STATE COLLEGE
Hubert Quinton Tucker, Jr.
1953

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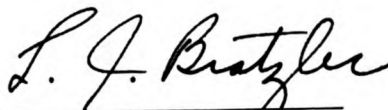
The Effect of Fat and
Moisture on the Freezing of Beef

presented by

Hubert Quinton Tucker, Jr.

has been accepted towards fulfillment
of the requirements for

M.S. degree in Animal Husbandry


Major professor

Date July 15, 1953

THE EFFECT OF FAT AND MOISTURE
ON THE FREEZING OF BEEF

By

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A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Animal Husbandry

1953

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T892

ACKNOWLEDGMENTS

The author wishes to express his most sincere thanks to Lyman J. Bratzler, Associate Professor of Animal Husbandry, for his patience and helpful guidance during the process of this study.

He is also deeply grateful to Dr. Erwin J. Benne, of the Agricultural Chemistry Department, and his associates, for their interest in the problem and advice in relation to the analytical determinations.

The timely suggestions of Professor D. E. Wiant, C. M. Hanson, and J. B. Cawood, of the Department of Agricultural Engineering, are most gratefully acknowledged; and the cooperation of the Department in providing facilities and equipment was much appreciated.

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INTRODUCTION

Temperature, its action and its control in the food industry, has been and is an ever increasing challenge to the food technologist. The methods of food preservation and merchandising are constantly changing in order to meet the increasing demands of the public. The comparatively recent popularity of frozen foods has created the problem of handling a much larger variety of foodstuffs. It is generally agreed that freezing alters food from its natural state to a lesser degree than any other method of preservation. However, there are still unsolved problems involving such factors, as deterioration, quality, physical appearance, and marketing. There is voluminous literature on the effect of temperature, storage, and all phases of processing on the quality of food products.

The literature relating to the thermal properties of meat and their effect on freezing is not as complete as it should be. It is realized that the thermodynamics of meat, as well as other foodstuffs, is a very complicated subject because of the influence of many variables. This study was undertaken in an attempt to illustrate and explain the effect of certain components of beef on its freezing rate.

REVIEW OF LITERATURE

The importance of temperature in the food industry was expressed by Baselt and Ball (1947) by basing the progress of civilization on the development of the food industry. The first line of resistance was conquered when man learned how to store food and make it available when needed. The temperature range that man must deal with is not wide when one considers the limits of -40° F. and $+500^{\circ}$ F. Seldom in the food industry does one get out of this range.

Structure and Composition

It was of interest to note the descriptions given by the many authors of the material with which they were dealing. These descriptions indicated from which phase of science the product was of interest to each worker.

Hiner (1950) described the structure of muscle as consisting of multinucleated elongated fibers, oval in cross section, surrounded by a sheath called the sarcolemma. Groups of these cells surrounded by connective tissue formed muscle bundles, and groups of bundles formed a muscle. The composition of muscle substance was a complex fluid, plus longitudinal running myofibrils with dark and light bands that gave the appearance of striations. The fat of meat was

dispersed in the connective tissue between the bundles of fibers. Muscle contained 60-75 percent water, most of which was in the fibers or within the sarcolemma.

Short and Staph (1951) stated that foods such as fruits, vegetables and meats were chemical and mechanical mixtures. These mixtures consisted of water, fat, sugars, salts and solids. Sugars, salts and other compounds were considered water soluble solids.

H. E. Staph (1951) summarized twenty years of work on the thermal properties of foods, and presented a complete definition of the materials with which he had been working. He broke foodstuffs into six components. Water was present in two forms - free and bound. The free water was contained within the cell and was readily removable by osmosis. Bound water was held by colloids as a part of a disperse phase. It was stabilized so that it could not be removed by pressure, and was not frozen at -20° C. A protein group consisted of proteins, complex amino acids, alkaloids, and other nitrogenous substances. The fat group consisted of glycerides, sterols, lecithins, and some amino acids were said to be present. The nitrogen-free extract group was composed of starches, gums, sugars and organic acids in the case of plant foods, and glycogen in the case of meats. Fiber was cell wall material consisting of cellulose, lignin, and pentosans, and was applicable only to plants. The mineral group consisted of potassium,

magnesium, calcium, phosphorous, chlorine, iron, sulfur and aluminum. A portion of this ash was considered soluble.

Hawk, Oser and Sumerson (1948) described the minerals present in muscle tissue as being present in the form of inorganic salts. The most predominating cation of muscle was potassium, followed by sodium, magnesium and calcium. The anions included chloride, phosphate, and traces of sulfate.

Preservation by Freezing

The literature seemed in agreement as to how freezing preserves foodstuffs, but varied as to which function of the process was most important.

Woodroof (1940) stated that preservation by freezing was based on the slowing of chemical, physical and biological activities, which practically stop when ice is formed in the tissues. The activity was reduced one-half for each eighteen degrees drop in temperature. Some enzymatic action may continue, however, at low temperatures.

Bartlett (1944), in his study on the latent heat of foodstuffs, stated that low temperature preservation was based on the retardation of microbial, enzymatic and chemical reactions.

Gortner, Erdman and Masterman (1948) went into some detail in explaining the effect of low temperatures on enzymatic and microbial activity.

Tressler and Evers (1943) quoted work that indicated that from 60 to 99 percent of the microorganisms on fruits and

vegetables were killed, and on meat and fish only 50 percent of the microorganisms were killed due to freezing. The activity of those not killed was of little consequence at low storage temperatures, but may be of concern after thawing. This work also stressed the effect of freezing on chemical and enzymatic actions.

Moran (1929) stated that controlling enzymes is probably one of the most important factors in the preservation of food-stuffs, except for lean meat, in which it is of a secondary nature. The control of enzyme activity is of importance in preserving animal fats.

The Freezing Process

Moran (1929) explained what happened when meat was subjected to freezing temperatures. He defined the composition and structure of muscle, and stated that the most active centers of crystallization were formed between the fibers, and the bulk of ice at normal temperatures was located between the fibers and between the bundles. This was explained by the fact that lymph bathed each individual fiber, and its solidification temperature was higher than that of the muscle substance; so crystallization started there first.

Hiner (1950) stated that muscle contained 60 to 75 percent water - most of it contained in the fibers. If this is true, Moran's reason for the formation of ice crystals between the bundles and fibers may not be adequate.

Woodroof (1940) described the movement of water in and out of cells during the freezing and thawing process, which may be a more logical explanation for Moran's observation.

The opinion of most workers was that the solidification of foods was dependent on the crystallization of the water present.

Winter (1952) wrote that during freezing there was a progressive separation of water in the form of ice crystals. The slower the process the fewer the number and larger the crystals. The more rapid the freezing the higher the number and smaller the crystals. The large crystals were located between the fibers and between the bundles, and the small crystals were evenly distributed throughout the tissue.

Richardson and Scherubel (1908) discussed the formation of ice crystals and their distribution.

Diehl (1932) presented one of the more purely scientific articles and discussed the freezing process from a physiological point of view. He stressed the part the composition of the frozen material had on the resultant product.

Much of the work was typified by that of Birdseye (1951) who tried to explain the action of freezing through its effect on the quality of the resulting product. He discussed quick freezing under two distinct theories - mechanical and physicochemical. Both theories were required to explain the beneficial results obtained from rapid freezing. The mechanical theory involved the location and size of crystals. The physicochemical theory evolved around the continuous freezing process where the

first crystals of pure water formed tended to concentrate the remaining salts and lower the point of solidification. This process was most important, mainly from 31°-25° F. If this range was traversed slowly, the resulting high concentration of salts would denature the protein, thus altering the final product.

Staph (1951) gave an interesting dissertation on the subject in which he said to visualize food as a simple mixture of pure water and a dry material. He assumed this mixture had some of the properties of a solution, and as concentration increased the fusion point of the water was depressed. When the temperature was reduced to just below 32° F., the mixture started to freeze. (Pure water would continue to freeze at 32° F.) Heat was eliminated and removed as the water froze, and as it froze the remaining mixture changed in concentration, resulting in less water, and a depression of the temperature of solidification. No more water would freeze until that point was reached. The temperature of the food lowered as heat was constantly removed. There was a continuous process of more water freezing and the freezing point being lowered. This continual depression of freezing point was where the process of freezing in foods differed from that of water.

Taylor (1930) made a critical review of the work presented in the literature. According to him, the theory of large crystals puncturing cell membranes and allowing juices to escape

did not hold true, because sausage and other lacerated materials did not yield large quantities of juice. In answer to the theory that rapid freezing caused fluid to freeze in cells and rupture them, due to expansion, he stated this was not necessarily true because of the great elasticity of animal tissue. The advance of freezing as a new preservative agent should conform to a knowledge of what really happens when food freezes.

Thermal Properties

The thermodynamics of foodstuffs is an important but very perplexing problem. If one could apply the laws of heat and heat transfer, which are based on homogeneous materials, as found in texts such as Faires (1950) or Brown and Marco (1951), the problem would be easily solved. One of the outstanding works in attempting to explain the thermal properties of foodstuff, and how such factors were involved in the freezing process, was that of Walter Stiles (1922). Since then, comparatively few researchers have attempted to establish constants for thermal properties of foods.

Woolrich (1930) demonstrated that the latent heat of foodstuff was closely related to its moisture content. Woolrich (1933) published conclusions from four years' work on the latent heat of foodstuffs:

1. Experiments indicate that the latent heat of fusion of fresh vegetables, fruits, meats and dairy products is directly proportional to the moisture content by weight.

2. The fusion points of food products are considerably depressed by the presence of salts, starches, fats and sugars.
3. Most foodstuffs have a freezing range, often extending from just below the freezing point of water to a temperature near 0° F.
4. The presence of any alcohol by breaking down starches or sugars lowers the fusion point.
5. The presence of fats, starches and mineral salts has no measurable effect on the value of the latent heat of fusion of foodstuffs examined.

Awbery and Griffiths (1933) published a paper on thermal properties of meat. They gave experimentally obtained values for thermal conductivity, thermal diffusivity, specific heat and density of lean beef.

Values in B.t.u. of the heat required to lower temperature of meat containing various percentages of water were demonstrated by the American Society of Refrigerating Engineers (1934-1936).

Short, Woolrich, and Bartlett (1942) came to the conclusion that, in a broad sense, the specific heat of foodstuff was proportional to the liquid content in the frozen region.

Bartlett (1944) produced a paper in which he stated: "Refrigeration is now a science and no longer an art." After making five assumptions, he proceeded to give formulae from which the following information might be obtained: (1) the percent of ice; (2) temperature rate of ice formation; (3) thermal capacity in partially frozen region; (4) quantity of heat removed in chilling.

Short (1944) experimentally produced values for specific heats of a number of foodstuffs.

Staph (1951) attempted to sum up the work done to that date and stated that the thermal characteristics of all foodstuffs seemed to follow the same general pattern regardless of the chemical properties or their amounts. He did, however, determine relative values of the thermal characteristics.

Short and Staph (1951) stated that the energy that must be removed from a particular foodstuff was the sum of the sensible energy removed from each constituent and the latent heat of fusion of water and fat. Fats may not undergo a change in the normal freezing and storage range; hence, only the heat of fusion of water which is frozen should be considered.

Since water plays such an important role in the thermal properties of foodstuffs, a more thorough understanding may be obtained of it in its several forms by reference to Dorsey (1940). The physics involved in the crystallization of water, thermal properties of water and ice were adequately discussed.

Rates of Freezing

In the freezing of foodstuffs, interest in freezing rates has centered around a single zone. This range has been called the "zone of maximum crystal formation", and the limitations of the zone, as well as the definition of the term "maximum", varied with the many writers.

Tressler and Evers (1943) gave the range as from 31° F. to 25° F.

Moran (1932) described this zone as being represented by a thermal arrest in a freezing curve of a substance. He measured the range from +5° C. to -5° C., and stated that these values were chosen because in this zone 82 percent of the water in muscle was crystallized.

Woodroof (1940) said that complete freezing was not obtained until temperatures of -60° F. to -80° F. were reached. He mentioned the zone of water crystallization as 30° F. to 0° F.

The American Society of Refrigerating Engineers (1934-1936) stated that about 75 percent of the freezing occurred between 31° F. and 23° F., and 100 percent when the temperature was -60° F. to -80° F.

Wiesman (1947) stated that the major portion, or 62 percent of the moisture, was frozen in the range from 32° F. to 25° F.

Birdseye (1951) said that a very large portion of the total water was changed in the temperature range from 31° F. to 25° F., and this range has become known as the "zone of maximum crystal formation". Most foods were frozen solid at 20° F., and most all free moisture was solidified at 0° F. but small quantities continued to freeze until -70° F. was reached. It was generally agreed that crystal size, and quality of the product was greatly influenced by the rapidity with which

the material froze through an average of the above-mentioned zones.

Winter (1952) summed up as to what rate of freezing was required to produce a quality product by stating: "As late as 1952 few people are in agreement as to what constitutes quick freezing. Probably the best definition is getting the product frozen before deterioration in quality sets in."

Factors Affecting Rates of Freezing

Stiles (1922) asserted that factors affecting the time of cooling may be grouped into two classes: internal factors depending on the nature of the cooled substance; and external factors depending on the properties of the external medium. The former is the thermal conductivity, specific heat, density, latent heat, specific surface and nature of the surface of the cooled body; the latter is the temperature, conductivity, specific heat, density and degree of agitation of the external medium. He determined the thermal conductivity for beef fat as .153 calories per meter, per hour, per degree Centigrade. He also obtained a value of .227 for muscle, and, in doing so, illustrated that there was no significant difference in conduction along or across the muscle fibers. The insulating quality of fat covering muscle was also demonstrated in his work.

Joslyn and Marsh (1930), by the use of various sugar solutions, showed that as the concentration of sugar increased the rate of temperature change increased.

Woolrich (1931) stated that heat of fusion was directly proportional to moisture content. Salt, starch, sugar and fats had no measurable effect on heat of fusion.

Birdseye (1951) remarked that the amount of water solidified at any given temperature is substantially the same whether the temperature drop is slow or fast.

Nicholas (1945) demonstrated the effect of several different methods of freezing on freezing rates. He also demonstrated the effect of size of package and number of layers of wrapping material had on the freezing rate of foodstuffs.

Finnegan (1941) produced a very interesting study on the effect of frozen mass formation on the freezing rate of foods. If a food was uniformly frozen, the point of final solidification would normally be located at the approximate center of the greatest vertical and horizontal cross sections. Each food has an optimum point of final solidification which will give the highest freezing rate at a given temperature regardless of the method. Some methods of handling during freezing change the point of final solidification and decrease the freezing rate.

Ramsbottom, Goeser and Strandine (1949) presented an excellent paper on the effect of different factors on the freezing rate of meats. They discussed the effect of air blast on freezing rate, as related to ice crystal size at varying depths in beef rounds. It was concluded that meats containing a high percentage of fat tissue froze more quickly than meats containing

very little fat tissue. The freezing rate of meat decreased with an increase in the insulating value of the package.

Ramsbottom (1951) stated that if there are air pockets between the package material and the meat, the rate of freezing at that location is delayed.

Table I(a) presents an accumulation of data that lead to certain conclusions that are given in "Results and Discussion".

TABLE I(a)
THERMAL PROPERTIES OF SELECTED MATERIALS

Material	Thermal Conductivity ¹	Total Emissivity ²
	$k = \text{Btu}/(\text{hr.})(\text{sq.ft.})$ (deg. F./in.)	
Aluminum	1475.00	.040
Aluminum foil	--	.087
Paper, thin	--	.924
Paper	1.00	--
Refractory materials		
Poor radiators	--	.67 - .75
Good radiators	--	.80 - .90
Water	3.50	.95
Beef - lean	3.87	--
Beef - fat	1.04	--
	$k = \text{Calories}/(\text{hr.})/$ ³ (meter)/(deg. C.)	
Pork fat	0.153	--
Beef fat	0.150	--
Muscle (along fibers)	0.227	--
Muscle (across fibers)	0.221	--

¹ Compiled from American Society of Refrigerating Engineers (1934-1936).

² Compiled from Brown and Marco (1951).

³ Compiled from Stiles (1922).

PURPOSE

The principal objective of this study was to investigate the freezing of beef as affected by several selected factors. This study was adapted to demonstrate the effect of the following factors on the freezing of beef:

1. Moisture content
2. Fat content
3. Distribution of fat
4. Selected wrapping materials

PROCEDURE

Preparation of Meat

The lean meat used in this work was obtained from cutter grade beef rounds. Cod fat from good and choice grade rounds was used as the fat portion. The lean and fat were cut uniformly into cubes about one inch square. Portions of each were weighed and mixed in the appropriate proportions to obtain the various percentages of fat in the samples used. All samples were first ground through a 3/8 inch plate and then through a 3/32 inch plate. The batches were then well mixed, wrapped in Dupont 450 MSAT #80 cellophane, and stored in a cooler. Approximately three pounds of meat were prepared for each percentage used. A one hundred gram sample of each batch was placed in a sealed jar and placed in frozen storage until it was used for moisture and fat determinations.

Forms

The volume of samples frozen was maintained as constant as possible through the use of plastic forms. Forms which had inside dimensions of six centimeters were constructed of Plexiglass, a methyl methacrylate type plastic, selected because of its thermoplastic and low heat conducting properties. Strips of this material 1/16 inch thick were patterned

so that by drilling $1/8$, $7/32$ and $5/8$ inch holes, approximately 54 percent of the surface area of the four sides of the cube was removed. A bottom was made by adhering strips $3/16$ inch wide at $3/16$ inch intervals across one end of the form. The top was not enclosed. Figure 1(a) shows the form as it was used.

Thermocouples

The conventional twisted type thermocouple was not considered adequate for this work because the exact point of temperature recording was difficult to determine. Butt-weld thermocouples were constructed under the guidance of members of the Department of Agricultural Engineering, Michigan State College. These thermocouples were constructed so they could be threaded through the meat samples and temperatures recorded at the geometric center of the cubes. The materials used in construction of these thermocouples were copper and constantan wire of Number 24 gauge. The temperatures were recorded on a 12 lead Brown Electronik Strip Chart Recorder. The constantan end of the butt-weld thermocouple was spliced permanently to the constantan lead from the recorder. The more rigid copper end was not spliced until it was threaded through the meat sample. This type thermocouple is shown in Figure 1(b).

Freezer

A Revco ten cubic foot chest type frozen food storage unit was used in this study. This unit was manufactured by

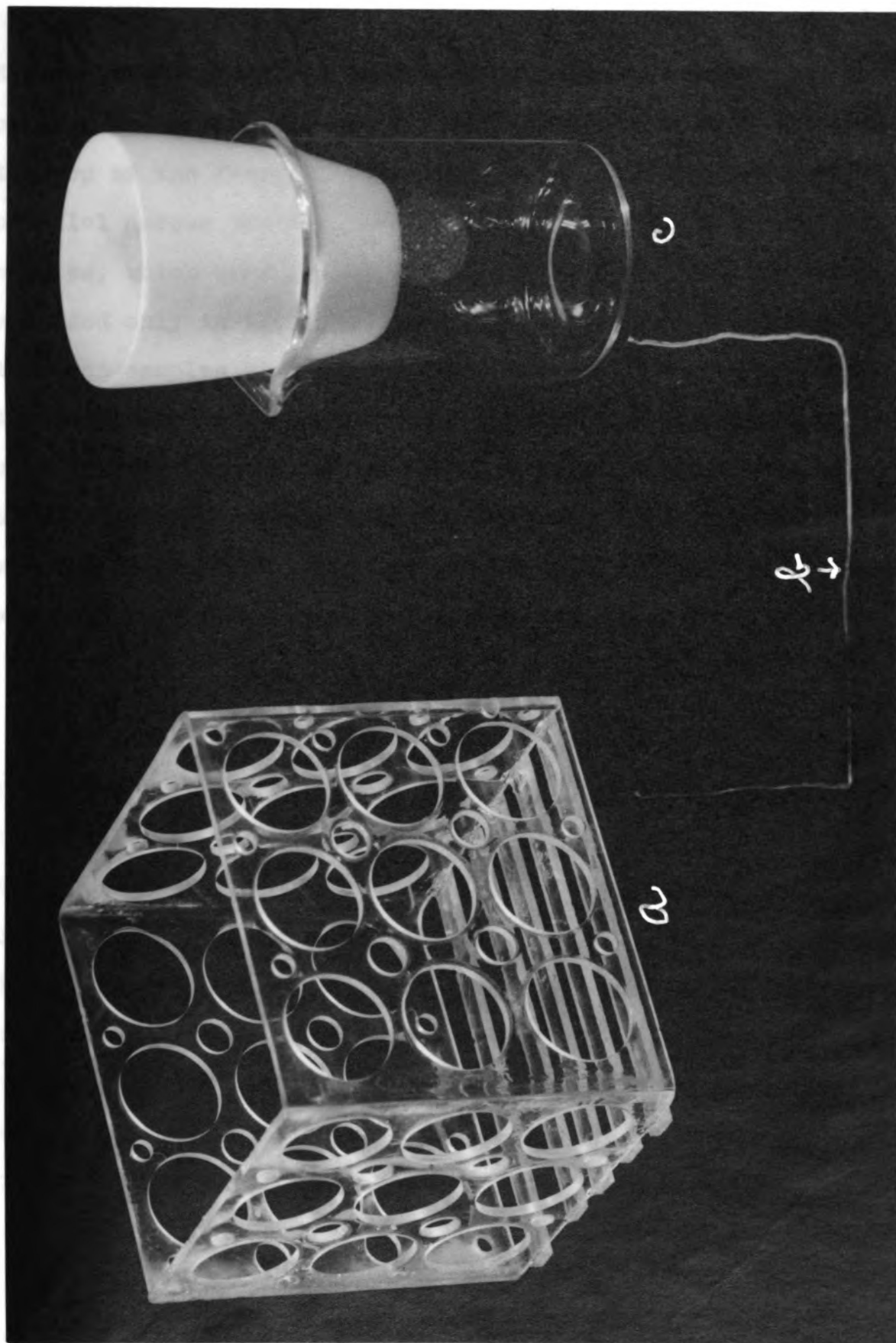


Figure 1. Equipment. (a) plastic form; (b) Butt-weld thermocouple; (c) Gooch crucible and 30 ml. beaker.

Revco, Incorporated, of Dearborn, Michigan. A small fan displacing 200 cubic feet of air per minute was secured close to the top of the freezer. The blast from the fan was directed parallel across the top, so a direct stream did not hit the samples, which were in the bottom of the freezer. The fan was used only in the first part of the work involving the thirteen samples of different fat content. Freezer temperatures averaged -10° F., plus and minus three degrees. The unit cycled through a range of six degrees every twenty minutes. No fan was present in the work on fat coverings and wrapping materials. The temperature at the same adjustment averaged approximately -14° F., plus and minus three degrees.

Trials

Meat samples of the various fat contents were frozen in groups of three. Each group consisted of a lean sample and two samples of varying fat content. The meat was packed in the Plexiglass forms, as uniformly as possible, and weights of samples and forms recorded. Thermocouples were positioned in the center of the forms, which were placed in the freezer as shown in Figure 2. Two paper cartons containing two hundred and fifty milliliters of distilled water were frozen and placed between each outside sample and the wall of the box. This reduced the effect of direct radiation from the

side of the freezer to outside samples. Each sample was placed on the top of an overturned petri dish.

The frozen samples were removed, allowed to thaw, the thermocouples removed, and the meat emptied from the forms. A second and third run was conducted using samples from the original batch of meat. The only difference was that each sample was in a different position in the freezer each time, as indicated in Figure 2. An average of the three runs for each percent of fat was used to lessen any variation that position in the freezer would have on the freezing time.

Fat Coverings

In determining the effect of fat covering, fat was molded in the forms so that a one centimeter cube of space was left in the center. This space was packed with ground lean beef and topped with fat. The finished product was a six centimeter cube of fat with the one centimeter cube of lean in its center. Two samples were prepared in this manner. A third sample was prepared by mixing fat and lean in the same proportions as in the first two. Thermocouples were inserted; the filled forms were placed in the freezer in the same manner as previously described. The samples, after freezing, were thawed and frozen again at different positions in the freezer.

Another trial consisted of fashioning a one-half centimeter layer of fat, as uniformly as possible, on the sides of the form. Lean was packed in, and then a layer of fat one-half

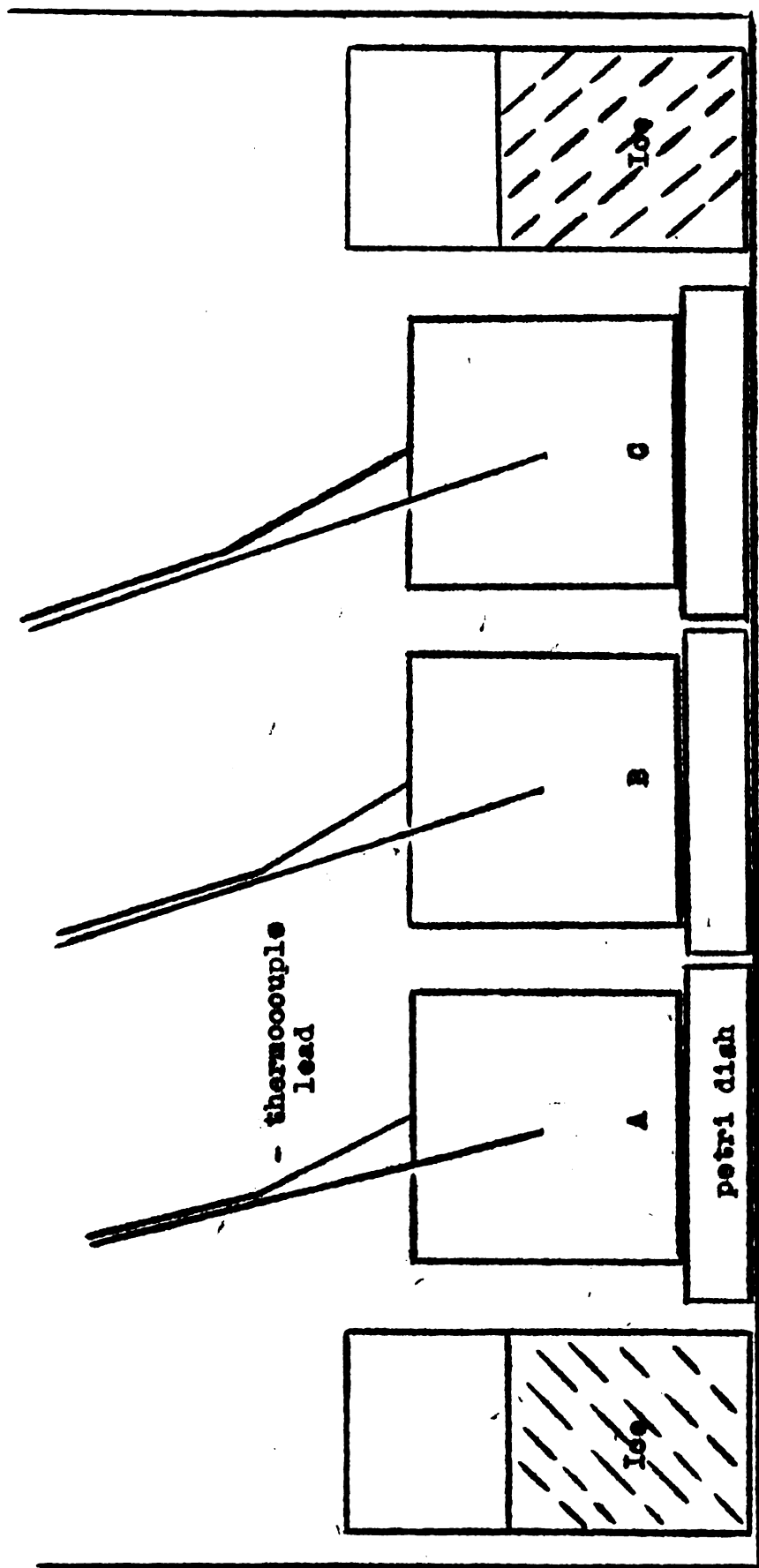


Figure 2. The arrangement of samples in the freezer. In the second run, the samples were rearranged C, A, B, and in the third run B, C, A.

centimeter thick was placed on top. The finished sample was a six centimeter cube - the outside one-half centimeter was fat and the remaining portion ground lean beef. A second form was filled with a mixture of fat and lean in the same proportions by weight as in the first sample. A third form contained all lean ground beef. A thermocouple was inserted in the center of each sample and the samples placed in the freezer, as previously described.

Wrapping Materials

Three forms were packed with lean ground beef from the same batch. The samples were wrapped in various wrapping materials (6 x 12½ inches), using the confectioners' or drug-store wrap. Thirty pound Kraft brown wrapping paper, Dupont 450 MSAT #87 cellophane, and aluminum foil of .015 inch thickness were used, respectively, on the three samples. Thermocouples were positioned and the samples placed in the freezer as before. As in the previous work, these samples were thawed and frozen again in different positions to check the results.

A similar trial was made using forms of lean ground beef and wrapping materials of the same dimensions. In this trial one sample was wrapped in a single layer of aluminum foil; another had two layers of cellophane. A third sample was wrapped in one layer of cellophane and two layers of thirty pound Kraft brown wrapping paper. The thermocouples were inserted and the samples frozen as before.

Chemical Analysis

Water and fat determinations were made, in duplicate, as outlined in "Official Methods of Analysis of the Association of Agricultural Chemists" (1950), with a modification suggested by Dr. Erwin Benne (1952) of the Agricultural Chemistry Department, Michigan State College. This method enabled the use of a single sample for both fat and moisture determinations. Asbestos padded crucibles were placed in thirty milliliter tall type beakers (Figure 1(c)), the samples added to the crucible and a cotton pad placed on top. After drying for twenty-four hours in a 75° C. vacuum oven, the samples were weighed. Moisture was determined by difference. The dried samples in the crucibles were removed from the beakers and ether extraction made by the Bailey Walker Method. The beakers served the purpose of collecting any fat that filtered through or crept over the crucible during the drying process for the water determination. The fat was removed from the beakers with ether, and each beaker matched with its respective crucible after the extraction for drying and weighing. The difference in weight represented the ether extract, or fat portion of the sample.

RESULTS AND DISCUSSION

Table I shows that the fat content varied from 3.3 percent to 90.8 percent, and the moisture ranged from 72.5 percent to 6.7 percent in thirteen lean beef, lean beef and fat mixture, and beef fat samples. The extreme values represented the variation found between lean beef and beef fat. Intermediate values were the results of mixing the two components. Figure 3 illustrates that there was a very significant inverse relationship between fat and moisture composition of all samples.

Water content of meat was closely correlated with the protein-ash portion, as illustrated in Figure 4. These observations were used in explaining certain results obtained.

The time, in minutes, required for the various samples to traverse the range in temperature from 35° F. to 10° F. are given in Table I. Relationship between these values and fat and moisture content are presented in Figures 5 and 6.

Freezing rate depends basically on two principles: How much heat is present and how rapidly it can be removed. There are many factors, such as temperature, cooling medium, air velocity, atmospheric pressure, composition of the substance, and others involved in both of these principles.

TABLE I
COMPOSITION AND FREEZING TIME OF THIRTEEN SAMPLES

Sample	Percent Fat	Percent Moisture	Time* A 35°-10°F.	Time B 32°-24°F.	$\frac{\text{Time B}}{\text{Time A}}$ (%)
A	3.3	72.5	118	91	77
B	5.1	71.1	115	86	75
C	6.0	71.7	113	83	73
D	7.6	71.6	111	83	75
E	7.8	66.7	114	87	76
F	21.7	58.2	109	80	73
G	27.0	54.5	103	75	73
H	36.0	47.2	98	72	73
I	48.6	38.9	87	64	74
K	60.1	30.0	82	58	71
L	70.8	22.4	79	45	57
M	90.8	6.7	62	19	31

*Time, in minutes, average of three runs.

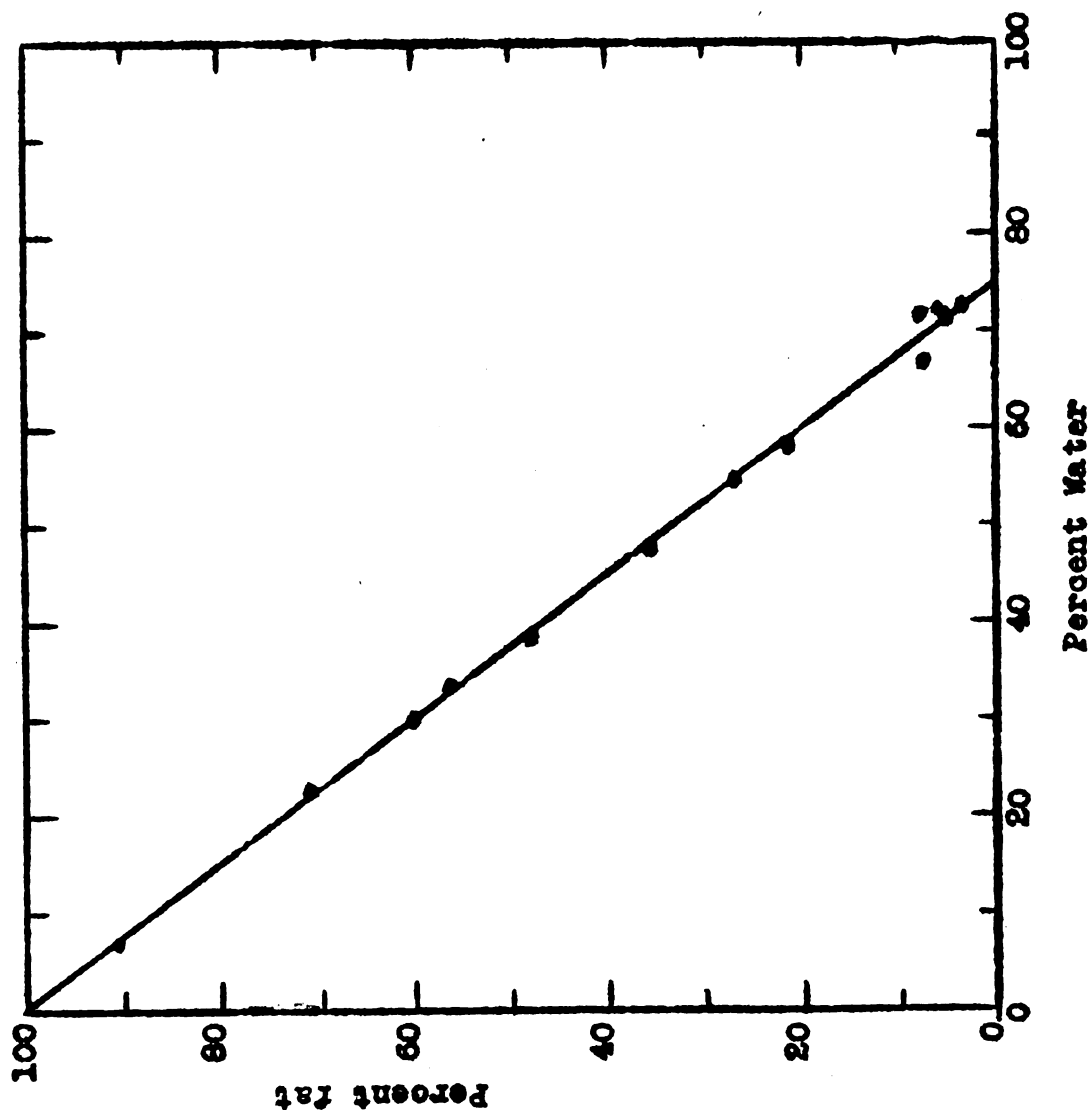


Figure 3. Relationship of fat to moisture content of 13 samples of beef.

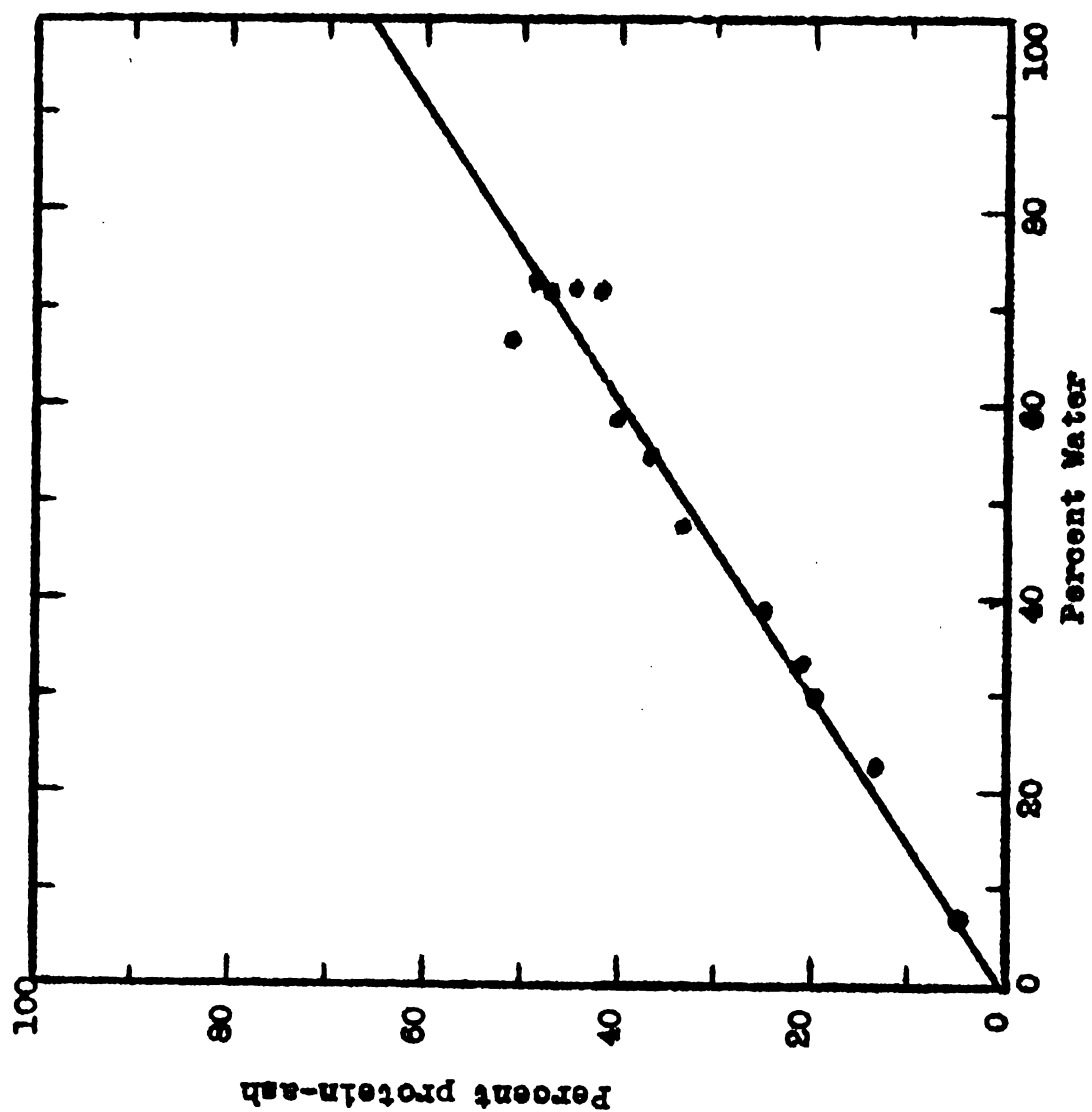


Figure 4. Relationship of Moisture content to protein-ash content of 13 samples of beef.

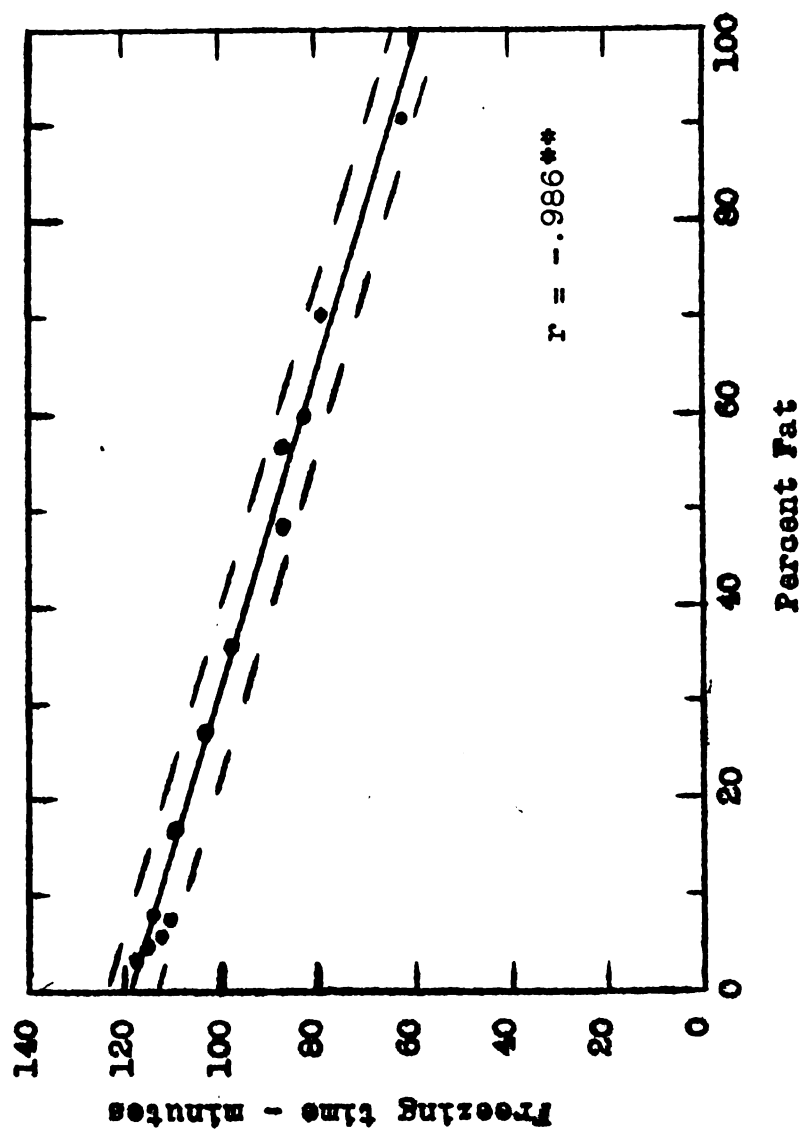


Figure 5. Correlation of percent fat in 13 beef samples with time to freeze from 35° F. to 10° F.

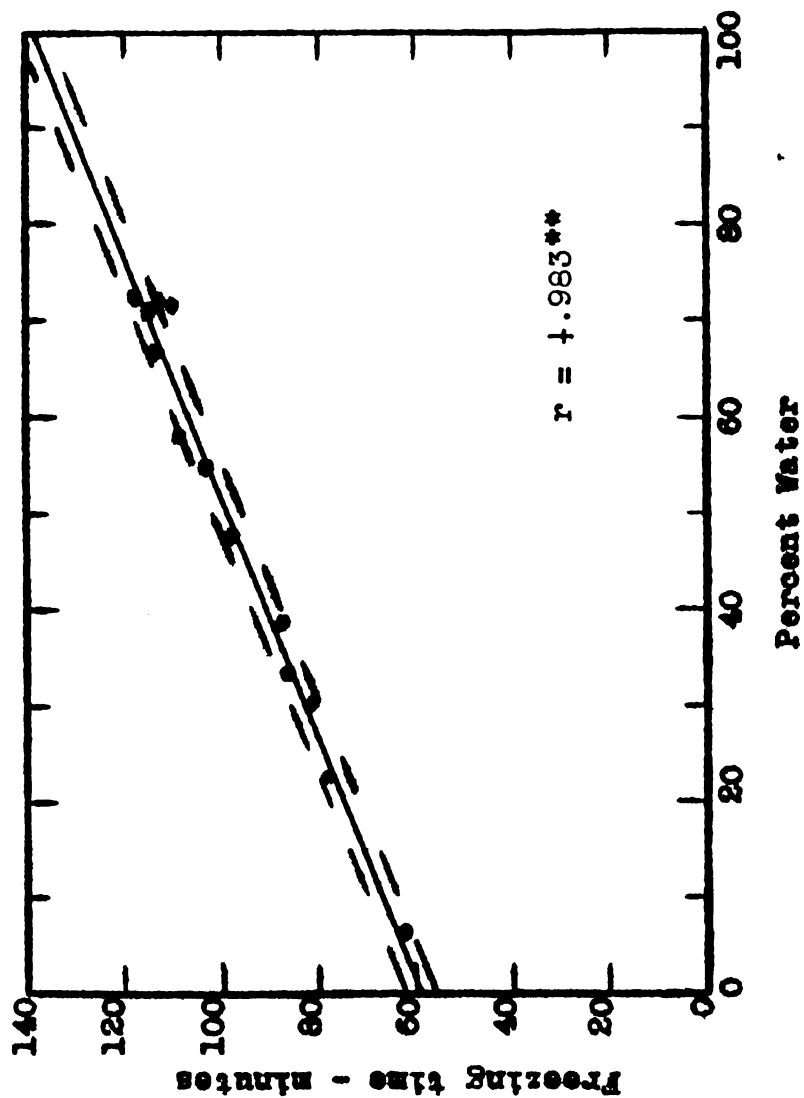


Figure 6. Correlation of percent water in 13 beef samples with time required to freeze from 35° F. to 10° F.

An attempt was made to consider the factors that were characteristic of the individual specimens, such as specific heat, thermal conductivity, freezing point, and latent heat of fusion.

Specific heat of meat, or of any foodstuff, as described in the review of literature, is a difficult value to obtain because of the many variables that can affect it. It has been established, however, that the specific heat of foodstuffs is closely associated with their water content.

Very little data were found on thermal conductivity coefficients for meat. Enough were found to establish the fact that lean meat is a more efficient conductor of heat than beef fat.

Moisture content may be said to play an important part in the thermal conductivity of foodstuffs, since water is one of the best conductors of heat in the class of non-metallic liquids. There are many values for the freezing point of meat and for all practical purposes these values, or ranges, are sufficient.

A freezing point of meat indicates only that temperature at which the crystallization of the water present begins, and therefore indicates that removal of the greater portion of the heat load has begun. Actually, the term "freezing point of a foodstuff" is a misnomer, because it

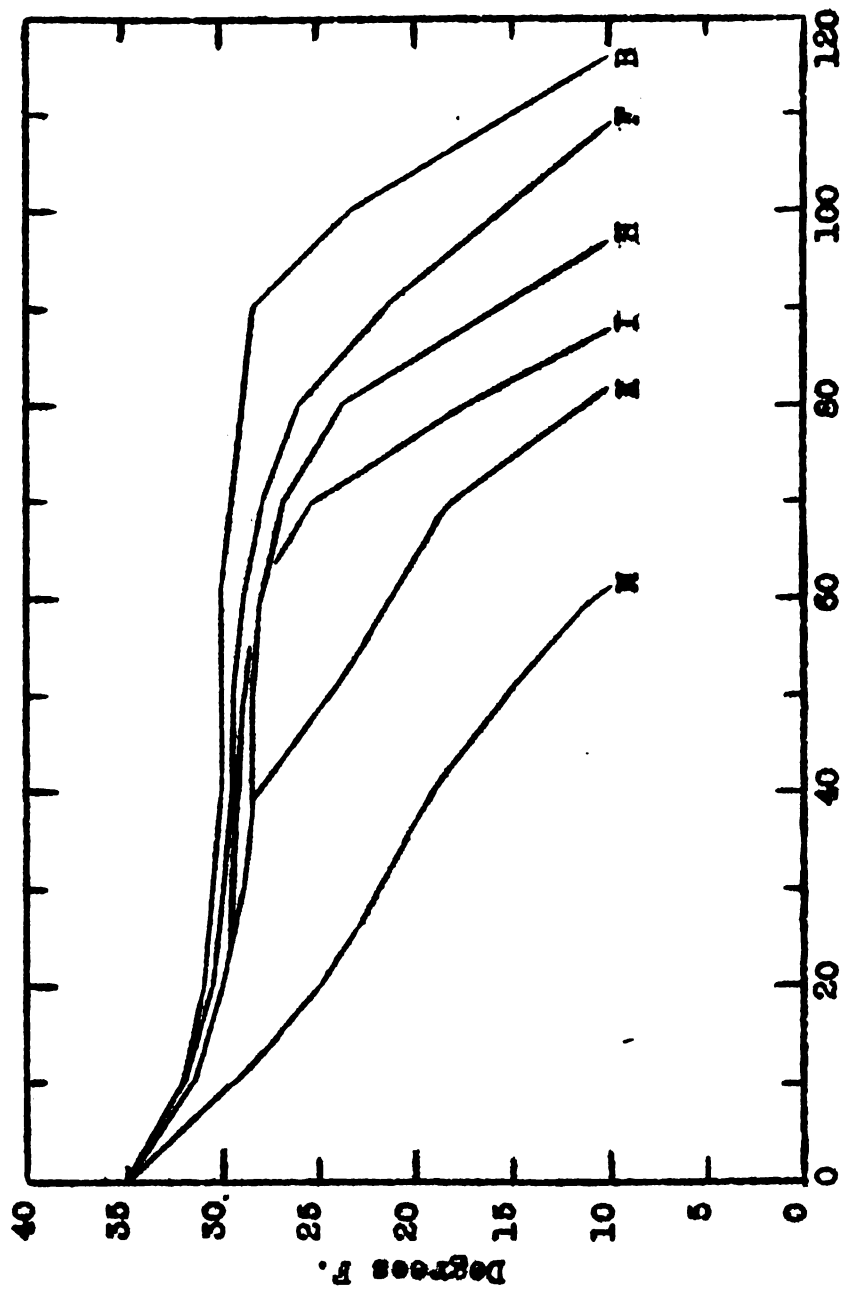
indicates only the beginning of a phase. A much better expression would be "freezing zone", which would include the range within which a greater percentage of the water was solidified. There were several ranges for this zone given in the literature.

The "latent heat of fusion" is another term that can only be used loosely when applied to foods. The definition states that it is the amount of heat required to change the state of a unit of substance without a change in temperature. The change of state in meat starts at about 31.5° F., and continues through the temperature scale until 100 percent solidification is reached at about -60° F. to -80° F., according to Woodroof (1940). Water is the most important constituent of meat to change state, and it requires approximately one B.t.u. to lower the temperature of one pound water one degree in the range above its freezing point. However, 144 B.t.u.'s are required to lower it one degree through the freezing point. These facts will help explain the distribution of the load of heat as the freezing curves in Figure 7 show them. The leveling of the curves through the region from 32° F. to 24° F. represented increased heat removal due to the change of state of the water. As mentioned in the review of literature, the first crystals to form represent a decrease in water and consequently an increase in salt and colloid concentration of the remaining fluid which, in turn, lowers its point of solidification. This concentration of

the remaining fluid and lowering of the freezing point is mainly of significance through the zone of maximum crystallization. Moran (1932) and Wiesman (1947) have calculated that between 60 and 80 percent of the water present is solidified in this range.

A variation in the curve of a single sample indicated a change in the amount of heat being removed. Curves of six of the samples are shown in Figure 7. Table I also gives the percent of the total time that each sample spent in the zone from 32° F. to 24° F. Approximately 75 percent of the total time was spent in the range that water was changing state. The comparison of water and fat content to time required to drop the temperature one degree in three ranges is contained in Table II. It can be concluded from these data that the thermal properties of water played the largest role in the thermodynamic properties of meat; therefore, water is the most important single factor affecting the freezing rate of beef.

Fat exerts its action on freezing rate in an indirect manner by being inversely correlated with the moisture content. Fat may also exert a marked direct effect on rate of freezing if it is layered over a surface of lean. The results of Part I of this phase of the study are presented in Figure 8. The duplicated samples of a cubic centimeter of lean, surrounded by 2½ centimeters of fat, followed almost identical freezing curves. These samples required a considerably longer period



Freezing Period - Minutes

Figure 7. Freezing curves for six samples of beef with varying water and fat contents.

Sample	Fat %	Water %
B	5.1	71.1
F	21.7	58.2
H	36.0	47.2
I	48.6	38.9
K	60.1	30.0
N	90.8	6.7

TABLE II
ANALYSIS OF FREEZING CURVES

Sample	Percent Fat	Percent Moisture	Minutes Required to Lower ¹ Temperature 1° F.		
			Temperature Ranges		
			35°-10°	32°-24°	35°-32° & 24°-10°
A	3.3	72.5	4.7	11.4	1.6
B	5.1	71.1	4.6	10.7	1.7
C	6.0	71.7	4.5	10.4	1.8
D	7.6	71.6	4.4	10.4	1.6
E	7.8	66.7	4.6	10.9	1.6
F	21.7	58.2	4.4	10.0	1.7
G	27.0	54.5	4.1	9.4	1.6
H	36.0	47.2	3.9	9.0	1.5
I	48.6	38.9	3.5	8.0	1.3
J	56.2	33.3	3.5	7.0	1.8
K	60.1	30.0	3.3	7.2	1.4
L	70.8	22.4	3.2	5.6	2.0
M	90.8	6.7	2.5	2.4	2.5

¹ These values were obtained by dividing time required to traverse the range by the number of degrees in the range.

and the characteristics of the curves varied greatly from the mixed sample containing the same amount of water, fat, and other constituents. The variation between curves was due to difference in the rate of heat removal. A variation in distribution of fat and lean was the only significant difference in the samples. Table III, Part I, illustrates the composition and its distribution of the samples used. The lean meat contained about 57 percent of the total moisture in the sample and this was concentrated in the center, which meant that a greater percentage of the heat load had to travel a greater distance through the slower conducting fat. In the mixed sample, the lean, and consequently the heat load, was distributed uniformly throughout the sample. This indicated that a greater portion of the heat had to travel a shorter distance, and it could travel at a somewhat faster rate by taking the path of least resistance over connecting particles of lean.

Figure 9 represents the similar trial in which one cube contained lean, surrounded by a one-half centimeter layer of fat; another, a mixture of fat and lean in the same proportions; and a third contained all lean. The paths of these curves were very similar, the main difference being the amount of time spent in the zone 32° F. to 24° F. As in the preceding trial, the heat load was more concentrated in the fat covered sample, and most of the heat load had to travel through the slower conducting medium. The mixed sample had a higher

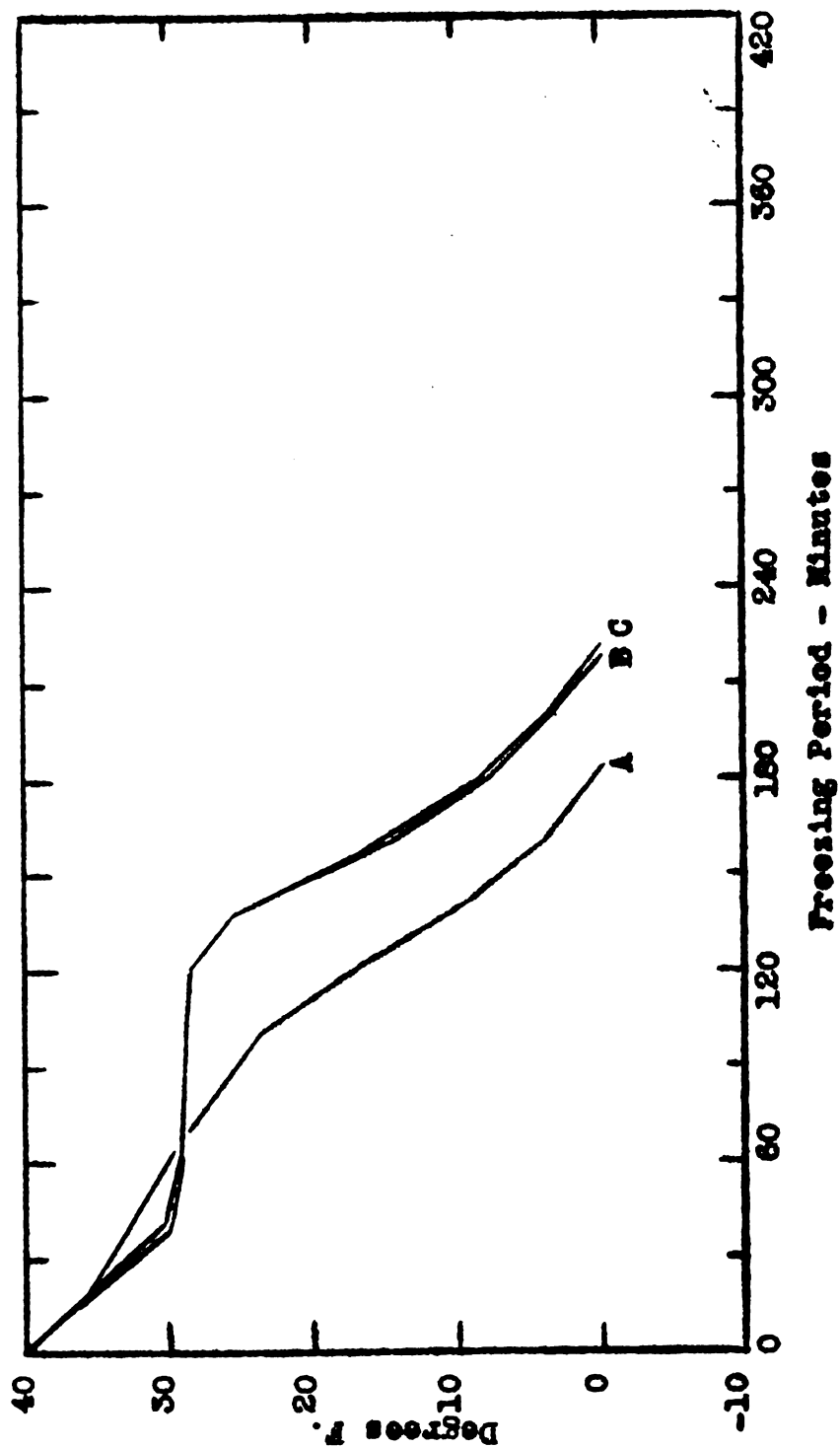


Figure 8. Freezing curves for Part I of the fat covering study.

A - Mixture
B - Fat covered
C - Fat covered

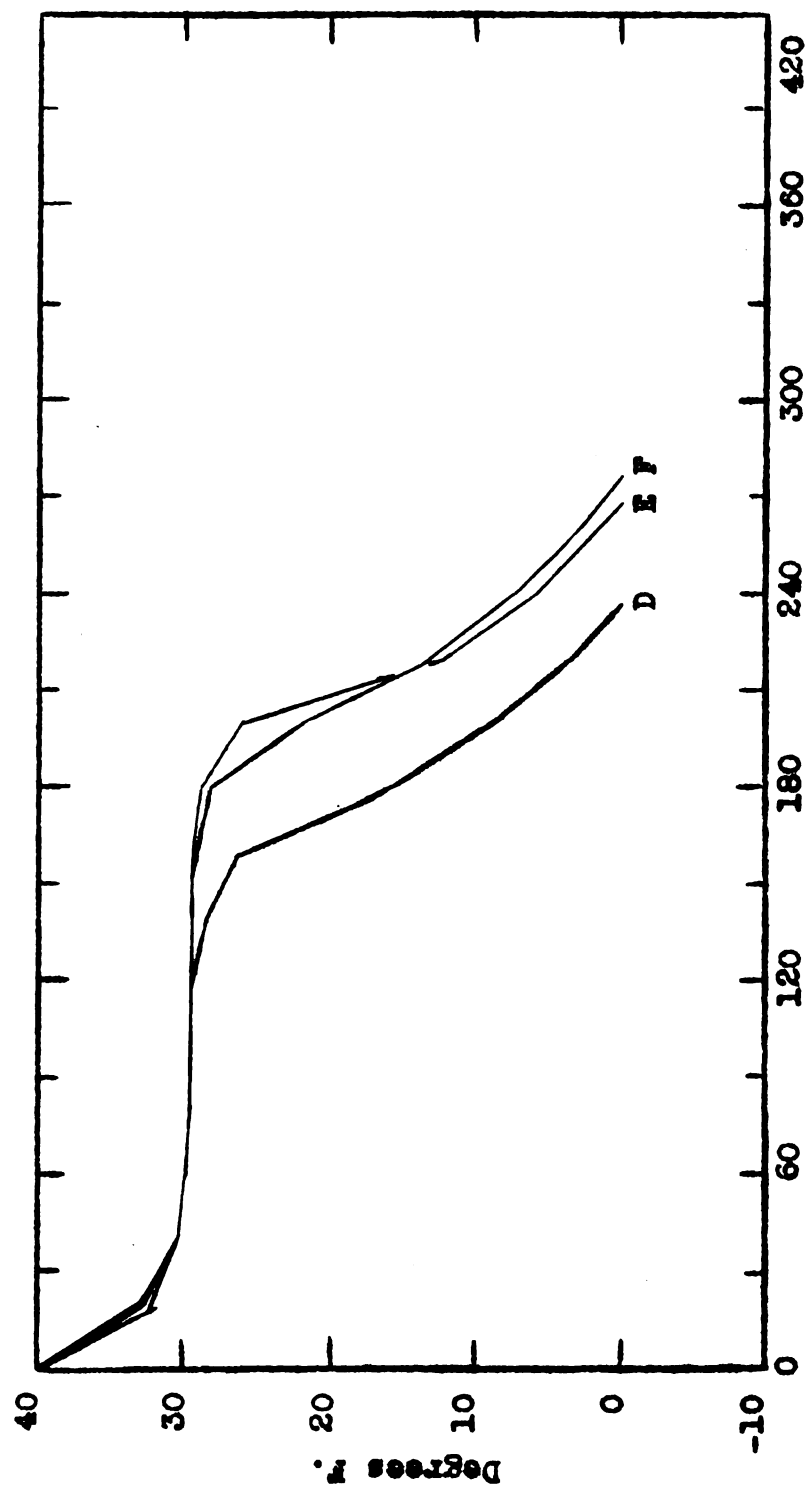
TABLE III
COMPARATIVE COMPOSITION, WEIGHT
AND FREEZING TIME OF FAT COVERED SAMPLES

Part I
(One Cm. Cube of Lean Covered with $2\frac{1}{2}$ Cm. Fat
(Samples A & B))

Sample	Weight (grams)	Moisture	Fat	Time in Minutes	
				40°-0°F.	32°-24°F.
Sample A: Mixture	220	17.6%(38.7 gms)	77.0%	183	54
Sample B	220	---	---	219	111
Lean	31	71.3%(22.1 gms)	6.4%	--	--
Fat	189	9.0%(17.0 gms)	88.1%	--	--
Sample C	220	---	---	222	113
Lean	31	71.3%(22.1 gms)	6.4%	--	--
Fat	189	9.0%(17.0 gms)	88.1%	--	--

Part II
(Five Cm. Cube of Lean Covered with $\frac{1}{2}$ Cm. Fat
(Sample C))

Sample	Weight (grams)	Moisture	Fat	Time in Minutes	
				40°-0°F.	32°-24°F.
Sample D: Mixture	226	46.9%(106.0 gms)	38.1%	236	141
Sample E: All lean	246	71.7%(176.4 gms)	7.9%	262	176
Sample F	226	---	---	274	141
Lean	126	71.7%(90.3 gms)	7.9%	--	--
Fat	100	9.5% (9.5 gms)	87.4%	--	--



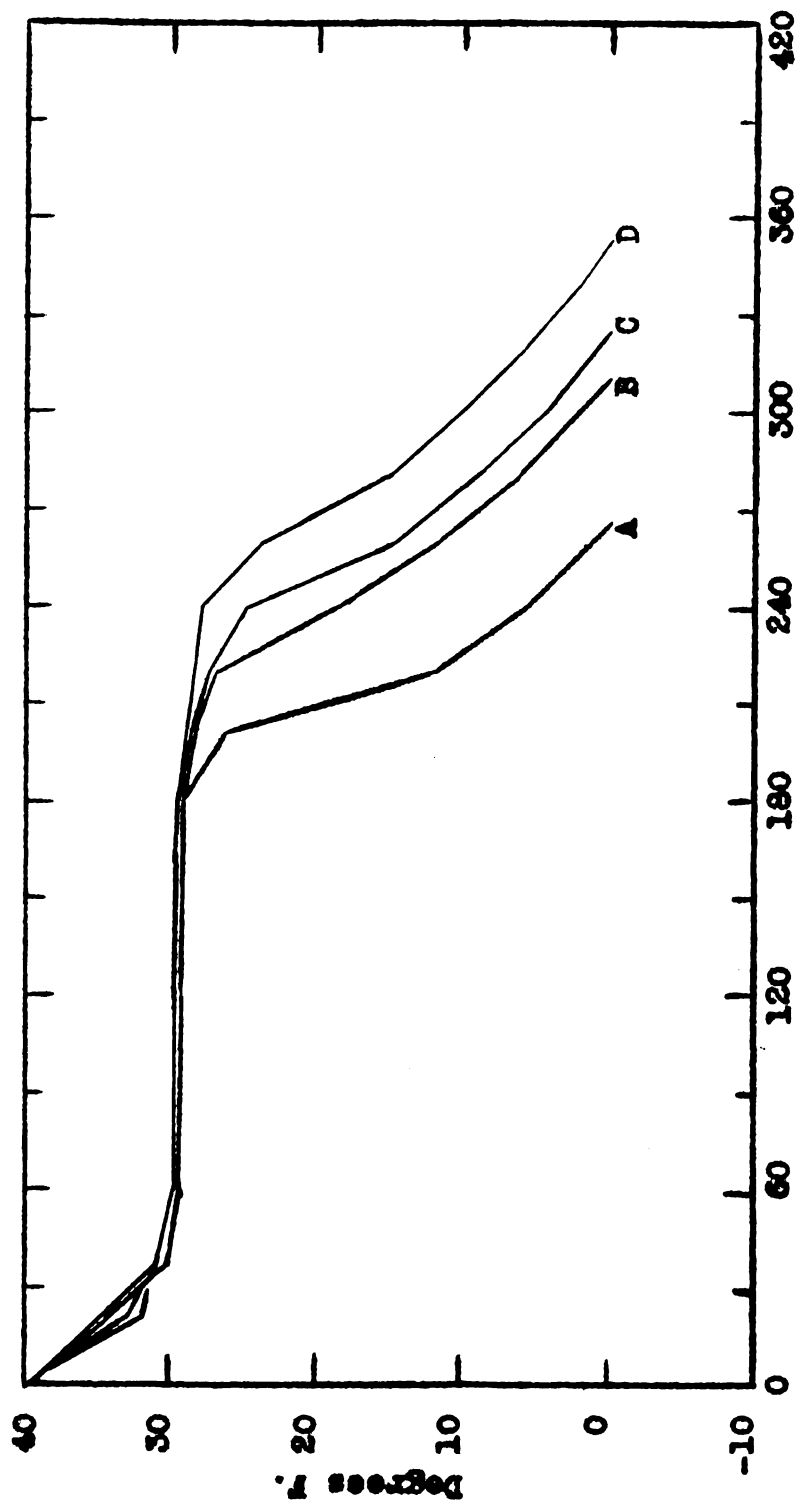
Freezing Period - Minutes

Figure 9. Freezing curves for Part II of the fat covering study.

D - Mixture
E - All lean
F - Fat covered

percentage of its load traveling a slightly shorter distance but also taking the path through the faster conductor. The difference in ability to conduct heat may also have caused the all lean sample, which spent more time in the crystallization zone, to travel at a faster rate than the covered sample after leaving that zone. There was no concrete proof found in the literature, but study has indicated that part of the difference in heat loss through fat and lean may be due to their differences in efficiency of surface radiation - lean being a more efficient radiator than fat.

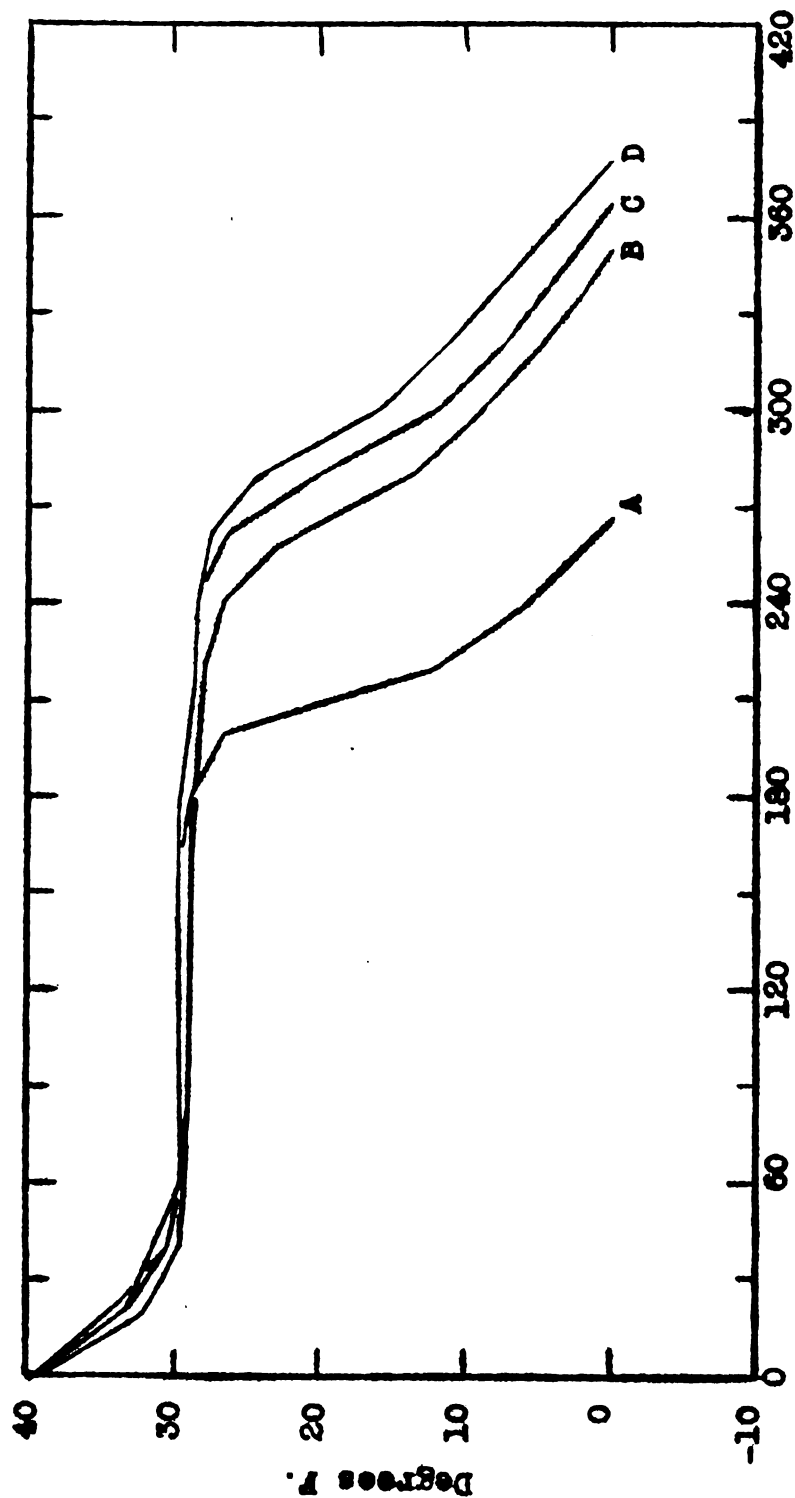
A comparison of three commonly-used wrapping materials as to their affect on freezing rate is shown in Figure 10. The main means of transfer were by radiation and convection since the samples were located in the freezer in such a manner that conduction accounted for a negligible portion of the heat transfer. Assuming that still air is a poor conductor of heat, a good portion was probably transmitted from the sample by means of radiation. No work was cited that gave thermal conductivity values of these wrapping materials, but from a study of the qualities of insulating and conducting materials in critical tables, the conclusion was drawn that, from the basis of thermal conductivity, brown paper was the best insulator, followed in order by cellophane and aluminum foil. Good qualities of radiation are associated with dark color and rough surface and the poorer radiators are polished, light colored metal surfaces.



Freezing Period - Minutes

Figure 10. Freezing curves of the single wrap samples.

- A - Unwrapped sample
- B - Kraft 30 lb. brown paper
- C - Cellophane MBAT #87
- D - Aluminum foil .015 in.



Freezing Period - Minutes

Figure 11. Freezing curves of the multiple wrap samples.

- A - Unwrapped sample
- B - Aluminum foil .015 in. (1 layer)
- C - Cellophane MSAT #87 (2 layers)
- D - Cellophane MSAT #87 (1 layer plus 2 layers of 30 lb. brown paper)

These materials would then be classed in reverse according to their radiating efficiency. The results in Figure 10 indicate that radiation qualities of the wrapping material had more effect on freezing rates than the factor of conductivity in this study.

The multiple wrap trial, where a sample with two layers of cellophane, and another with one layer of cellophane and two layers of brown paper were compared to a single layer of aluminum foil, is plotted in Figure 11. These results may be explained partially on the insulating quality of trapped air, as well as that of the materials. The aluminum foil wrap had trapped between it and the meat a single layer of air; the double wrap cellophane had one between it and the meat, and another between the first and second layers; and the cellophane-brown paper wrap had three layers of trapped air. These layers of air, plus the insulating qualities of the materials themselves, were sufficient to offset the effect of radiation indicated in the preceding trial. A summary of the data in these two trials is presented in Table IV.

TABLE IV
SUMMARY OF WRAPPING MATERIAL DATA

Sample ¹	Time in Minutes		
	40°-0°F.	35°-10°F.	32°-24°F.
Single wrap trial:			
Aluminum foil .015 in.....	355	288	239
Cellophane MSAT #87.....	328	264	216
Kraft 30 lb. brown paper..	312	251	205
Multiple wrap trial:			
Aluminum foil .015 in. ...	344	282	233
Cellophane MSAT #87 (2 layers)	362	292	239
Cellophane MSAT #87 (1 layer plus 2 layers brown paper)	378	310	250
Unwrapped sample ²	267	215	176

¹All samples of ground lean beef in the single and multiple wrap trials weighed 240 grams and contained 64.1 percent water and 16.2 percent fat.

²This lean beef sample weighed 246 grams and contained 71.7 percent water and 7.9 percent fat. It was run in a separate trial but under the same conditions.

SUMMARY

1. There was an inverse relationship found between the fat and moisture content of the meat samples used in this study.

2. There was a positive relationship between the portion of the meat, not fat and not moisture, and the moisture content.

3. There was a positive correlation between the water content of beef and the freezing time in the ranges studied.

4. Fat distributed throughout the meat sample inversely affected the freezing time.

5. External fat layers decreased the freezing rate of beef.

6. Common wrapping materials decreased the freezing rate of beef. Of the materials used, aluminum foil, cellophane, and brown wrapping paper decreased the freezing rate, in the order named, under the conditions of this study.

7. Multiple wrappings decreased the freezing rate of beef.

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