A STUDY OF THE INFLUENCE OF WRAPPING MATERIAL AND METHOD
OF WRAPPING ON THE RATE OF FREEZING AND KEEPING
QUALITY OF FROZEN PORK SAUSAGE

by

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Alberta, Canada, 1947

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Husbandry

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1949

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INTRODUCTION

The preservation of foods by freezing has been practiced for centuries in arctic regions. But it is only within recent years that food preservation by this method has come into any degree of prominence in the temperate zones. As recently as the early twenties there was considerable prejudice against frozen foods, and not without due cause as there were characteristic flavors and aromas associated with the cold storage products of that time which were not conducive to acceptability.

No doubt the development of mechanical refrigeration has played an important part in the enormous growth of the frozen food industry during the past decade, but the application of these mechanical developments in the frozen food locker industry has been an important factor in changing the public attitude towards frozen foods.

The first attempts at preserving meat by freezing were discouraging because the resulting quality of the frozen product was deficient in quality and rather unsatisfactory. Too often the freezing of meat involved the placing of unwrapped steaks and roasts in a low temperature room without protection and leaving them there indefinitely. The resulting product was dry, unattractive, frequently rancid and in other cases had acquired additional off-flavors. The necessity for protection of the product was soon recognized and many types of wrapping and packaging materials were developed to meet the needs of the individual locker patron as well as the frozen food industry.

At the present time there is need for further information regarding the efficiency of these wrapping materials. Some additional problems of the industry, regarding which there still seems to be a difference of opinion, include style of wrapping, double wrapping versus single wrapping, rate of freezing and type of freezer. This study was undertaken for the purpose of procuring some additional information on these questions.

REVIEW OF LITERATURE

The first wrapping material to be used extensively in the frozen food industry was a vegetable parchment paraffin-coated on both sides. This paper was a great improvement over its predecessors, one of its most valuable characteristics being its wet strength.

Ordinary transparent cellophanes were used and had the additional advantage of transparency for display purposes. This paper proved inadequate because it was not moisture-vapor-proof and the sheets stuck to the product.

Compact cardboards containing few air spaces were extensively used for packaging and transporting quick-frozen fish. They proved satisfactory because of an asphalt layer in the center of the board which increased the moisture-vapor-proofness.

Glassine papers, paraffined on both sides were used successfully as a heat-sealed wrapping. This material had a relatively high resistance to the passage of moisture vapor, but lost its strength when wet and was therefore not suitable for use in direct contact with the product.

Moisture-vapor proof cellophane came onto the market about 1929 and was the closest approach to a completely moisture-vapor-proof wrapping material at that time. This paper was transparent and had a very high resistance to the passage of moisture vapor, did not stick to the frozen product and the material itself was water and grease proof.

Clarence Birdseye (1) was one of the first to undertake a concerted investigation of existing frozen food wrapping materials. He realized, among other factors, that desiccation was one of the chief causes of poor quality. Accordingly he set up an experiment to measure the moisture loss through various packaging materials. This was done by stretching and sealing samples of the wrapping materials over dishes of constant size and containing measured quantities of water. The interior of each dish was kept at a constant temperature and humidity. The results of this study are reproduced in Table 1. Moisture-vapor-proofness is measured in grams of water-vapor lost per square meter of surface per 24 hours at 38° C.

Table 1. Relative moisture-vapor-proofness of several wrapping materials.

Sample no.	Wrapping material	Moisture-vapor-proofness
1	Regular cellophane	1920
2	Parchment (waxed one side)	1350
3	Glassine (unwaxed)	1250
4	Parchment (unwaxed)	1130
5	White glassine (waxed both sides)	220
6	Brown waxed paper (waxed both sides)	100
7	Glassine (waxed both sides)	70
8	Kraft (waxed both sides)	42
9	Glassine (waxed both sides)	42
10	White waxed paper (waxed both sides)	17
11	Kraft (waxed both sides)	12
12	Moisture-vapor-proof cellophane	5

Recognizing the importance of desiccation in reducing the quality of frozen meat, Birdseye (1) attributes dehydration to the lack of efficient moisture-vapor-proof wrapping materials.

Griswold and Blakeslee (2), in studies at Michigan Agricultural Experiment Station, on the effect of different wrapping materials on the keeping qualities of fresh frozen pork chops, stated that the wrapping materials themselves had a marked effect on the moisture loss. Of the wrapping materials used #50 kraft permitted the greatest moisture loss, with a brown waxed whalehide next, followed by lard, and a lard and tallow mix. As with previous investigators, Griswold and Blakeslee reported that the moisture-vapor-proof cellophanes allowed the least moisture to escape.

In a study of the surface drying of frozen poultry, Cook

(3) accounted for the factors affecting the rate of drying. These include the storage temperature, relative humidity, movement of the surrounding atmosphere and the rate of movement of moisture from the interior of the package to the cooling surface. Moisture exists in the frozen product in the solid state, therefore its movement to the surface is slow. However, surface drying can still occur although the actual weight loss is small. In chilled or unfrozen products, the internal movement of moisture is greater, and a greater loss of weight with less actual surface drying is possible. Surface desiccation can be reduced only by minimizing the rate of evaporation from the surface. If this is the case, two paths of correction are open; one, increasing the relative humidity, and two, lowering the storage temperature. The vapor pressure of water and the moisture capacity of the air both decrease as the temperature is lowered. Therefore the rate of drying can be reduced by lowering the temperature, increasing the relative humidity, or by a combination of these.

Moran (4) placed the eutetic temperature of the liquids in muscle tissue in the region of -36° F. Since most products start to freeze around 32° F., then at temperatures between these extremes, the majority of the water is present as ice and will therefore have an equivalent vapor pressure of ice. Since frozen products have a vapor pressure equivalent to ice, a moisture-vapor-proof wrapping material should allow the air surrounding the product to rise to 100 percent relative humidity and thus prevent freezer burn. Relative humidities of 98 percent or higher seem to be necessary to reduce freezer burn to small proportions over a year's storage period at 7° C.

In 1935, a method for determining the moisture vapor transmission rate of different materials was described by Tressler and Evers (5). Twenty cubic centimeters of water were frozen in crystallizing dishes. The wrapping material being tested was sealed over the dish with a special sealing wax. The dishes were then placed in a constant temperature and humidity chamber at 5° F. and 50 percent relative humidity. The air in the dishes was allowed 48 hours to come to equilibrium with the air of the chamber before being weighed and the weights recorded. After this weighing the dishes were returned to the chamber for seven days before the second weights were recorded. The difference between the first and second weights, the average loss per dish per day, the average loss per paper and the loss per square meter were calculated.

Dubois and Tressler (6) cautioned against confusing waterproofness and moisture-vapor-proofness. A material may be waterproof but not moisture-vapor-proof. They observed further that the fat of meat wrapped in a material with a low moisture-vapor transmission rate does not become rancid as quickly as that packaged in a material with a high moisture-vapor transmission rate. They explain this on the basis that there exists a film of moisture on the surface of the meat which protects the fat from oxidation by the air. Meat stored in a material with a low moisture vapor transmission rate and a relatively high temperature such as 10° F. will likely absorb odors and flavors.

McCoy (7) reports a rating of frozen food wrapping materials. He includes in his list the following 12 factors to take into consideration when selecting a first rate wrapping material.

1. toxicity
2. odor
3. moisture-vapor transmission rate
4. heat sealing properties
5. ease of marking
6. ease of application
7 appearance
8. water-proof and grease-proof
9. strength before freezing
10. strength after freezing
11. percent loss through wrapper after 1 year storage
12. stripping qualities

According to McCoy (7), the problem with frozen products is to keep the moisture in the food. This involves the use of an adequate moisture-vapor-proof barrier and proper application. In general, the results obtained with the laminates in this study, were better than those with the heavy kraft papers. The importance of good contact was proved along with the fact that some materials require careful handling at low temperatures as they tend to shatter when cold.

Ziegler and Christian (8) report in a study on quality of frozen pork that the type of wrapping material was very important in maintaining quality in frozen meats after six months' storage. Aluminum foil proved superior to other types and the waxed papers were definitely not adequate for storage periods over six months.

Winter (9) reports work done on the comparative protection against dehydration of various wrapping materials. Without giving details of the experiment he reports that the confectioner's style of wrapping gives better protection against dehydration than the butcher. He also stated that where ordinary waxed papers are used the butcher wrap is preferred over the confectioners, and explains this by the additional layers of paper covering the product in the use of the butcher style. The pliability of a wrapping material is important because the effectiveness of a waxed paper is highly dependent upon the continuity of the wax coating. A wax coating that cracks at low temperatures is unsatisfactory as it breaks any seal the wax might have provided.

According to Sayles, Gortner and Volz (10), water moves from the frozen meat to the package walls, either by convection currents due to a difference in temperature between the air and a colder package wall, or because of an alternate rise and fall of temperature. During a fall in temperature the water holding capacity of the air is reduced and ice deposited on the coldest surface existing at that time. If the coldest surface happens to be the package wall, ice will be deposited there and if the coldest surface is the package contents, ice will be deposited on the contents.

The transfer of radiant heat is instantaneous, and therefore any surface exposed to this type of transfer changes its temperature before any adjacent surface not so exposed. The air temperature of the freezer rises because of the heat flow from the outside. As a result the package walls and the air within the package receive heat. When the air temperature inside the package rises it will absorb water from the food. Ultimately the cycling refrigerant will start to flow again and bring down the freezer temperature. The walls of the package facing the plate if unprotected by a radiant foil will radiate heat to the plate and their temperature will drop before any similar drop in temperature of other walls not similarly exposed to the cooling plate, but which must be cooled later by convection currents. Therefore moisture condenses on the package walls cooled first, because the package wall in turn cools the air in the package reducing the moisture holding capacity of that air.

In summary, Sayles, Gortner and Volz (10) suggest the following to eliminate what they term cavity ice formation:

1. eliminate radiant heat transfer by
    a. wrapping the food in a radiant foil
    b. preventing cycling of the plate temperatures
2. eliminate temperature fluctuations in the freezer
3. prevent temperature gradiants between the food stuffs and the package surfaces
4. maintain higher humidities; e.g., above 95 percent

McCoy (11) reported in 1947 on the relationship of water vapor, vapor pressure and moisture-vapor-proofness on the quality of frozen meats. Water in the form of ice will sublimate. It is this fact that makes moisture-vapor-proof packaging necessary. Water vapor exerts a definite pressure which varies with the temperature.

Moisture will flow from a condition of high vapor pressure (V.P.) to one of low vapor pressure. The following is an example:

Water 100° F. and 50 percent relative humidity = 66.50 lbs. V.P. per square inch (inside package)

Water 10° F. and 60 percent relative humidity = 0.71 lbs. V.P./sq.in. (inside freezer room)

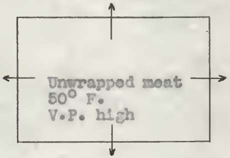
63.79 lbs. V.P./sq.in.

If this difference (63.79) remains between a piece of meat and the atmosphere in which it is frozen, moisture-vapor will be transferred from the meat to the surrounding atmosphere. Since this moisture cannot be replaced, it is lost from the meat and freezer burn or dehydration results.

The following illustrations explain the four principal conditions under which moisture is lost from frozen packaged meat or other food products.

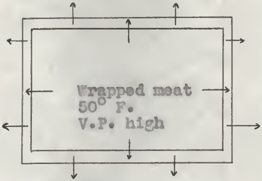
I Unprotected meat (no wrapping)

Air 0° F.
V.P. low



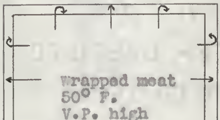
The vapor pressure differential causes a flow of moisture from the meat to the air. Internal moisture moves to the surface of the meat and is then absorbed by the air. Result: meat quickly dehydrates.

II Poor wrapper (poorly wrapped) Air 0° F. V.P. low



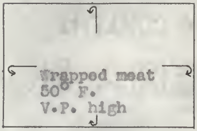
The wrapper although poor offers some resistance to passage of moisture vapor, but does not stop it. Moisture migrates from the inside of the meat to the surface air trapped between the wrapper and the meat, then continues through the wrapper and out into the freezer air. Result: rate of moisture loss retarded.

III Good wrapper (poorly applied) Air 0° F. V.P. low



Arrows represent the movement of the moisture from inside the meat to the air space and surface of the meat. Here, however, the wrapper is a good moisture vapor barrier and the moisture does not pass through, but condenses on the wrapper as cavity ice. Result: losses further retarded, but dehydration occurs.

IV Good wrapper (properly applied) Air 0° F. V.P. low



In this case the wrapper is in close contact with the surface of the meat. No air pockets exist. Arrows depict migration of moisture-vapor to surface of meat. Wrapper is a good barrier and the vapor cannot pass through, consequently moisture is retained in the meat. Result: no dehydration of the meat.

Moisture will flow from a point of high vapor pressure to a point of lower vapor pressure at a rate proportional to the differential between the two (12). Thus, moisture will flow more rapidly from 100 percent to 50 percent relative humidity than from 100 percent to 80 percent relative humidity.

The lower the temperature the smaller the deficit between 100 percent relative humidity and the actual relative humidity; therefore the less moisture which must pass off in order to make up the deficit. This in turn results in a lowered vapor pressure. Therefore the lower the temperature the lower the vapor pressure.

A minute film of air at 100 percent R.H. surrounds any piece of frozen meat that is wrapped in a moisture-vapor-proof material at room temperature. When first in the freezer the product gives off enough moisture to raise this film to 100 percent relative humidity. The following diagram illustrates the above.

Air film 0° F., 100 percent R.H., V.P. = 0.0185 lbs. /sq. in.

Air (Room) 0° F., 80 percent R.H., V.P.= 0.0148 lbs. /sq. in.

At 0° F., 100 percent R.H., the V.P. = 0.0185 lbs. /sq. in.

At 0° F., 80 percent R.H., the V.P. = 0.0148 lbs. / sq. in.

Vapor Pressure Differential = 0.0037 lbs. / sq. in.

Since water-vapor will move so as to equalize two different vapor pressures, the film of air will be continually giving up its moisture and thus reducing its relative humidity. The vapor pressure of the stored product is constant at a constant temperature, so as soon as the air film has its vapor pressure reduced sufficient moisture will leave the frozen meat to raise the relative humidity of the air film to 100 percent. Thus there is a continuous movement of water-vapor from the stored product to the air film and on to the room air. The rate of vapor movement is directly proportional to the degree of difference of vapor pressure between the air film and the room air (12).

With the foregoing facts as a background the effect of fluctuating temperatures on dehydration of frozen stored products may now be explained. Supposing a freezer is at -10° F., then for some reason the temperature is raised to 0° F. The outside surfaces of the stored product will warm up to the room temperature. When the refrigerant starts flowing again, the room temperature is again lowered to -10° F. However, the temperature of the product lags due to its specific heat. Until the temperature of the product equals the room temperature of -10° F., the vapor pressure of the warmed product will be higher than the vapor pressure of the room air. Thus, a movement of moisture from the product to the room air is set up. This movement of moisture vapor will continue until the vapor pressures are at equilibrium.

In 1944, Gordon (13) reported on the factors to consider before a good protective paper can be manufactured. The amount of lamination in thickness applied is an essential part of producing a good resistant paper. If one is working with a base paper which is absorbent, a substantial weight of the lamination is absorbed before resistance starts, and if measured with a micrometer it will be seen that regardless of the weight of the coating absorbed, little or no resistance results until a definite thickness begins to register. This is partly explained by the fact that the fibers themselves absorb the coating, leaving little on the surface, and the coating tends to flow away from the high areas leaving them bare.

As the coating starts to cover the surface of the fibers and fills the low areas to the level of the high areas, resistance to moisture vapor transmission starts to take place. Any thickness in coating above this point or lower will show sharp increases in resistance properties.

Tauber et al. (14) reported on a relatively recent type of wrapping material, the polyethylene resins. The polyethylene films are a polymerization product resulting from pressure heating of ethylene gas in the presence of a suitable catalyst. The resin formed is tough and waxy and melts at 221 to 248° F. The properties of low moisture-vapor transmission, high oxygen carbon dioxide and sulfur dioxide transmission, and flexibility at low temperatures make it highly suitable as a wrapping material for frozen foods.

In 1946, Dearing (15) published an article on the future of the frozen food industry and how it depends upon proper packaging. The question of what was actually needed in an ideal frozen food wrap was investigated. The factors arrived at as being necessary properties of an ideal frozen food wrapping material were as follows:

1. complete protection against dehydration
2. complete protection against bacteria within the container
3. complete protection against discoloration and weakening of the material caused by "leakage" from the product
4. ease of handling
5. ease of marking or identification
6. tensile strength to withstand rough handling

7. costs must be within range of economical application
8. the material must possess a certain amount of eye appeal

METHODS AND PROCEDURE

This study was undertaken to secure further information on available wrapping materials. The study covers a 12 month storage period using pork sausage.

The sausage was made from regular pork shoulders and additional trimmings which were sorted so as to obtain a ratio of 25 percent fat and 75 percent lean and seasoned with one pound of salt, two ounces of sage and two ounces of pepper for every 50 pounds of meat. The seasoning was thoroughly mixed with the trimmings and ground twice through a 3/8 inch plate then once through a 3/16 inch plate. The sausage was then packed on a platter and allowed to chill for 24 hours.

Fifteen lots, each consisting of three samples were placed under observation. Each sample weighed 453 grams. All packages were weighed every 28 days and weight loss used as a measure of the protection offered by the different wrapping materials. The lots were arranged so as to measure the degree of protection resulting from single and double wrapping and between the confectioner's and butcher's style of wrapping. In wrapping, care was taken to obtain maximum contact between the wrapping material and the sausage. The exclusion of air pockets and subsequent ice crystal deposits within the package eliminated the dehydrating effect as explained by McCoy (12). The packages were frozen in a blast freezer at -10° F. After freezing they were placed in a steel locker and stored at 0° F. for 12 months. The designation of these lots is presented in Table 2.

The second part of this study was designed to measure the influence of different wrapping materials and method of wrapping upon the rate of freezing. The same wrapping materials were used as tested in the first part with the exception of No-Air-Wrap. This part of the study was carried out in two series. In Series I, four pound packages of pork sausage were used. The sausage was similar to that described in the first part of the study. Six different wrapping materials were used in Series I and eight in Series II. Temperature observations were made by means of a potentiometer connected to 10 thermocouples. The terminal of the thermocouple was inserted into the center of the sample in order to give the internal temperature of the sausage. Hourly readings were made over a period of 12 hours. In this study, a lot consisted of two samples which were frozen simultaneously. The distribution of the lots of Series I is presented in Table 3 and of Series II in Table 4.

Table 2. Designation of lots used in Experiment I.

Wrapping material	Single or double wrap	Methods of wrapping: Confectioner's	Butcher's
Unwrapped	Lot I		
No-Air-Wrap	single	Lot II	
Aluminum Foil	single	Lot III	
Aluminum Laminate	single	Lot IV	Lot IVA
Kraft Paper	single	Lot V	Lot VA
Kraft Paper	double	Lot VI	Lot VIA
K. V. P. 666	single	Lot VII	Lot VIIA
Cellophane and Stockinette	single	Lot VIII	Lot VIIIA
Glassine Laminate	single	Lot IX	Lot IXA

Table 3. Distribution of lots used in Series I.*

Lot no.	Wrapping material	Method of freezing	Style of wrapping	Single or double wrap	Samples per lot
I	Aluminum Foil 0.0015	blast	confectioner's	single	2
II	Aluminum Laminate	blast	butcher's confectioner's	single	2
III	Kraft Paper	plate	confectioner's	single double	2
IV	Kraft Paper	plate	butcher's	single double	2
V	K. V. P. 666	blast	confectioner's	single double	2
VI	K. V. P. 666	blast	butcher's	single double	2
VII	Cellophane + Stockinette	plate	confectioner's	single double	2
VIII	Cellophane + Stockinette	plate	butcher's	single double	2
IX	Tite	plate	butcher's confectioner's	single	2

* Four pound packages used in this study.

Table 4. Distribution of lots used in Series II.*

Lot no.	Wrapping material	Method of freezing	Style of wrapping	Samples per lot
I	Aluminum Foil 0.0015	blast	confectioner's	2
II	Purity Double Wound	blast	confectioner's	2
III	Shellmar	blast	confectioner's	2
IV	Mead	blast	confectioner's	2
V	Polyethylene Resin	blast	confectioner's	2
VI	Kraft	blast	confectioner's	2
VII	Waxed Kraft	blast	confectioner's	2
VIII	Minerva	blast	confectioner's	2
IA	Aluminum Foil 0.0015	plate	confectioner's	2
IIA	Purity	plate	confectioner's	2
IIIA	Shellmar	plate	confectioner's	2
IVA	Mead	plate	confectioner's	2
VA	Polyethylene Resin	plate	confectioner's	2
VIA	Kraft	plate	confectioner's	2
VIIA	Waxed Kraft	plate	confectioner's	2
VIIIA	Minerva	plate	confectioner's	2

* Two pound packages used in this study.

OBSERVATIONS AND DISCUSSION

The weight losses for all lots are presented in Table 5 on a percentage basis. The figures are averages of three samples up to and including the seventh period (196 days); thereafter they are the average of only two samples. At the seventh weigh date one sample of each lot was opened for observation.

Total weight loss offers a means of grouping or classifying these wrapping materials. Group I consists of those materials which lost less than 0.5 percent during 12 months' storage period and includes: Aluminum Foil, Aluminum Laminate and Cellophane with a Stockinette covering. Group II includes the improved wax paper, Glassine Laminated paper or those which lost between 0.5 and 2.5 percent in a 12 month storage period. Group III includes wax paper and Kraft paper where the loss was between 6 percent and 10 percent for the entire storage period.

It is considered that Group I with a loss of less than 0.5 percent in a 12 month storage period offers adequate protection for normal storage. In the case of Group II the weight loss was less than 0.5 percent during the first 6 months which might be interpreted as meaning that these papers offer adequate protection for a short storage period not to exceed 6 or an absolute maximum of 9 months. The papers in Group III permitted a weight loss in excess of 1 percent after a 3 month storage period, following which the rate of loss increased rapidly indicating that these papers should not be used for a storage period exceeding 3 to 4 months. The sausage frozen without wrapping lost 0.75 percent during the freezing period and the loss continued at a rapid rate during the entire storage period. The average weight loss of these groups is presented in Fig. 1.

When the samples were opened for inspection, which included color, freezer burn or dehydration, and odor after 6 months' storage, the observations indicated that the materials in Group I, which permitted a loss of less than 0.5 percent, provided the greatest degree of protection against freezer burn and preserved the original pink color of the sausage. The aroma of the sausage was sweet indicating protection against oxidation. The Group II materials permitting a weight loss of 0.5 to 2.5 percent showed considerable freezer burn and some oxidation as indicated by aroma while Group III materials showed excessive freezer burn, complete discoloration of the sausage and a distinctly unsweet aroma. The sausage stored with no protection was excessively dehydrated, having a dry white appearance throughout, as well as on the surface.

A comparison of butcher's and confectioner's styles of wrapping was made with four different wrapping materials and is presented graphically in Fig. 2. This graph shows uniformly small differences indicating that under practical conditions any difference in protection resulting from the method of wrapping is too small to be significant, provided the wrap is properly applied.

For a number of years during the development of improved wrapping materials, many individuals advocated double wrapping as a means of reducing dehydration. A comparison of single and double wrapping was made using ordinary Kraft paper and wax paper. The results are presented in Fig. 3. After a 12 month period there was little difference in moisture loss between the single and double wrap. Double wrapping offered little additional protection, in so far as moisture loss is concerned. The additional wrapper may have provided mechanical protection, such as is necessary with cellophane, but does not appreciably retard moisture loss.

Some enthusiastic salesmen have used faster freezing as a sales point for their product. This claim does not seem to be borne out by the data acquired in this study. In the first series, six wrapping materials were used and applied in different manners including confectioner's single wrap, confectioner's double, butcher's single wrap and butcher's double wrap. The freezing curves for the comparison are presented in Figs. 4, 5, 6, 7, and 8. Part of these were frozen in the blast freezer and part in the plate freezer. While the freezing curves presented are not all parallel, the differences may be considered minor, and in closer relation to the freezing temperature than to the material used in packaging.

Table 5. Percentage weight loss over a 12 month storage period (Av. 3 samples).

Lot no.	Wrapping material	Wrap	Style wrap	28 day storage periods 1	2	3	4	5	6	7	8	9	10	11	12
I	Unwrapped			1.32	1.69	3.53	4.63	5.23	6.84	7.72	8.25	9.49	11.0	12.3	15.6
II	No-Air-Wrap	wax	dip	+0.33	+0.33	+0.39	+0.17	+0.17	+0.33	+0.33	+0.33	+0.33	-0.11	-0.11	-0.11
III	Aluminum Foil 0.0015	sing	conf	0.0	0.0	0.0	0.0	0.0	-0.11	-0.11	0.0	C.0	-0.02	0.0	0.0
IV	Aluminum Laminate	sing	conf	+0.13	+0.07	+0.13	+0.13	-0.13	+0.11	+0.22	+0.22	+0.22	0.0	+0.22	+0.22
V	Kraft Paper	sing	conf	1.03	2.00	1.92	2.80	3.46	4.45	5.56	6.84	7.21	8.32	8.98	10.8
VI	Kraft Paper	doub	conf	0.75	1.10	1.28	1.78	2.17	2.95	4.17	4.95	6.26	7.15	7.59	8.91
VII	K.V.P. 666	sing	conf	0.07	0.07	0.0	0.28	0.44	0.84	0.95	1.17	1.39	1.39	1.39	2.05
VIII	Stockinette + Cellophane	sing	conf	0.29	0.13	0.07	0.07	0.02	0.15	0.04	0.26	0.37	0.59	0.59	0.38
IX	Glassine Laminate	sing	conf	0.04	0.04	0.04	0.04	0.11	0.28	0.28	0.28	0.39	0.61	0.61	0.61
IVA	Aluminum Laminate	sing	butch	+0.02	+0.38	+0.16	-0.07	-0.07	-0.19	-0.19	-0.09	-0.31	-0.20	-0.19	-0.19
VA	Kraft Paper	sing	butch	0.99	1.52	1.96	2.37	2.70	3.42	4.63	5.40	5.73	2.17	7.33	9.82
VIA	Kraft Paper	doub	butch	1.03	1.10	1.63	2.07	2.44	3.68	4.28	4.79	5.88	6.99	7.43	8.53
VIIA	K.V.P. 666	sing	butch	0.04	0.04	0.04	0.11	0.26	0.62	0.62	0.83	0.95	0.83	1.28	1.50
VIIIA	Cello + St.	sing	butch	0.39	0.31	0.24	0.18	0.17	0.04	0.04	0.38	0.26	0.26	0.26	0.48
IXA	Glass.Lam.	sing	butch	0.13	0.02	0.02	0.04	0.08	0.19	0.19	0.19	0.19	0.75	0.75	0.95

\# Positive trends of Lots II and IV nonsignificant, therefore due to weighing error. All weights were read to the nearest gram.

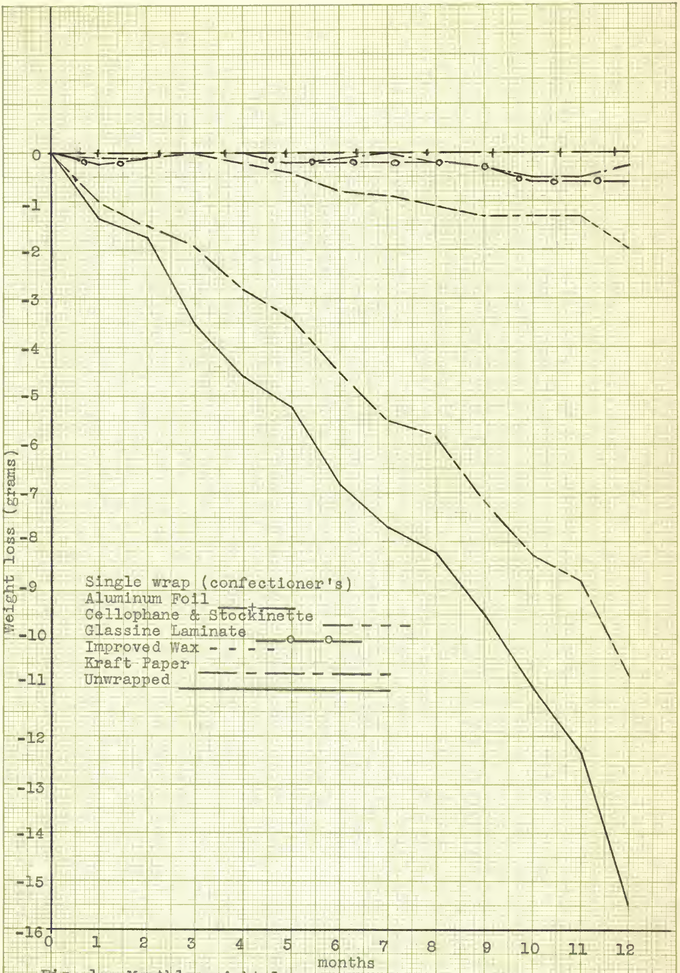


Fig. 1. Monthly weight loss.

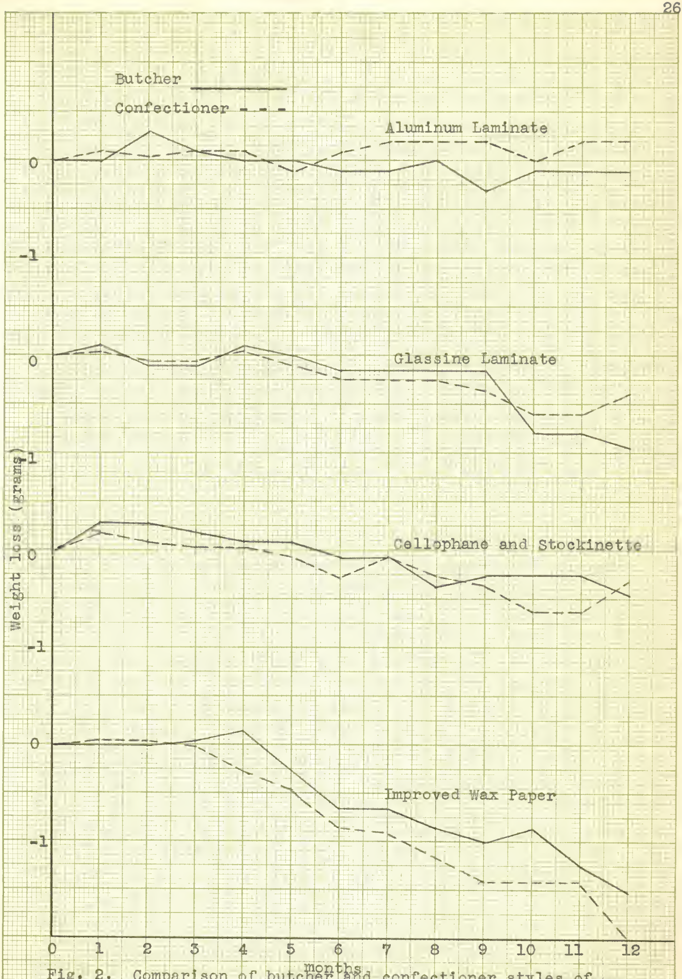


Fig. 2. Comparison of butcher and confectioner styles of wrapping.

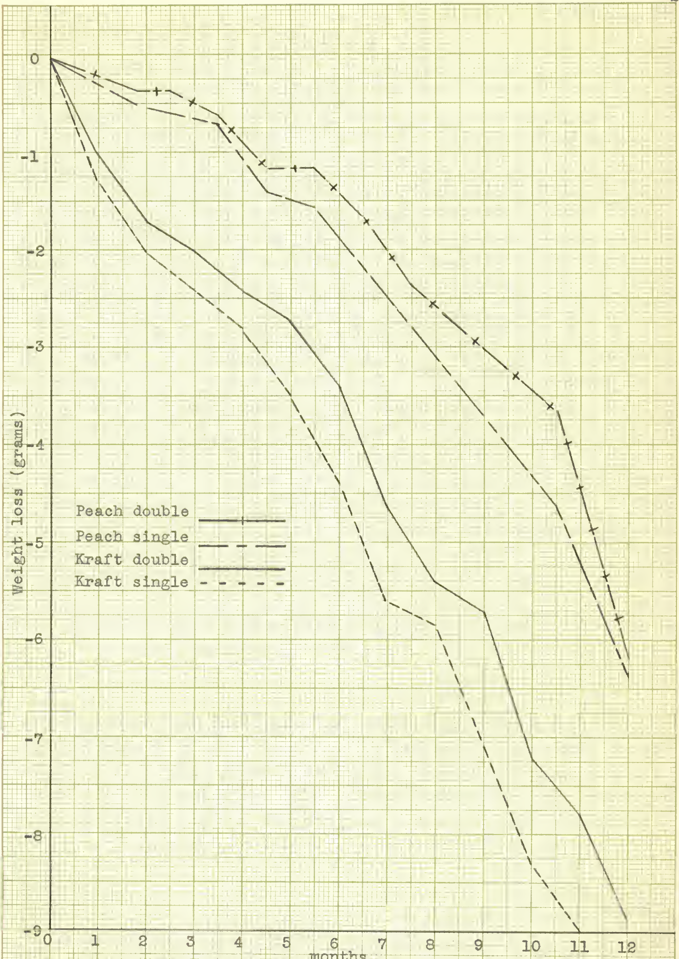


Fig. 3. Comparison of single and double wrapping.

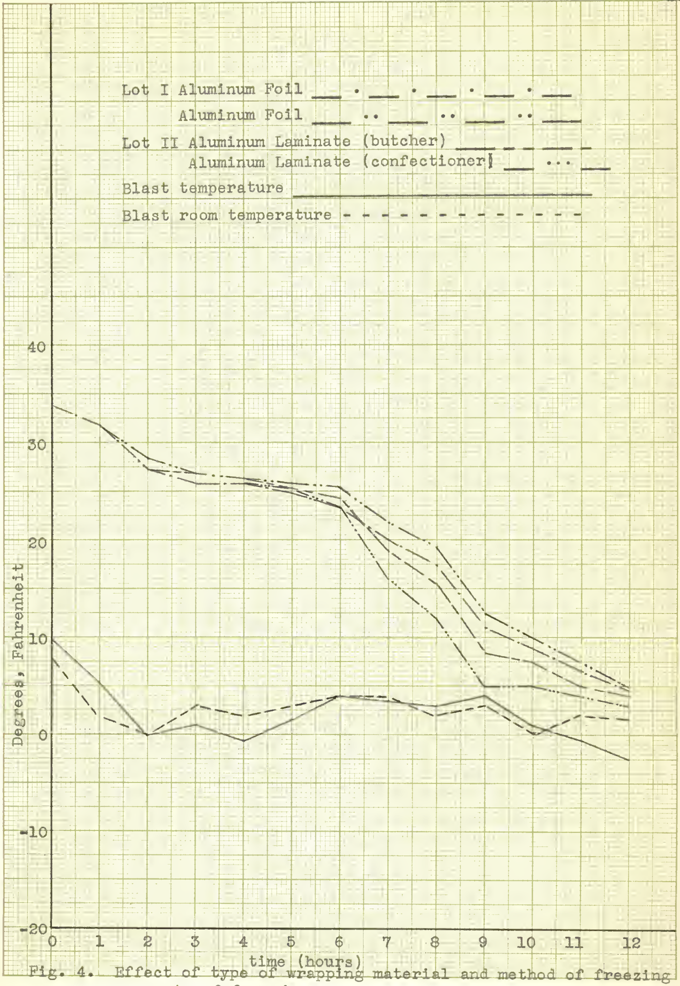


Fig. 4. Effect of type of wrapping material and method of freezing on rate of freezing.

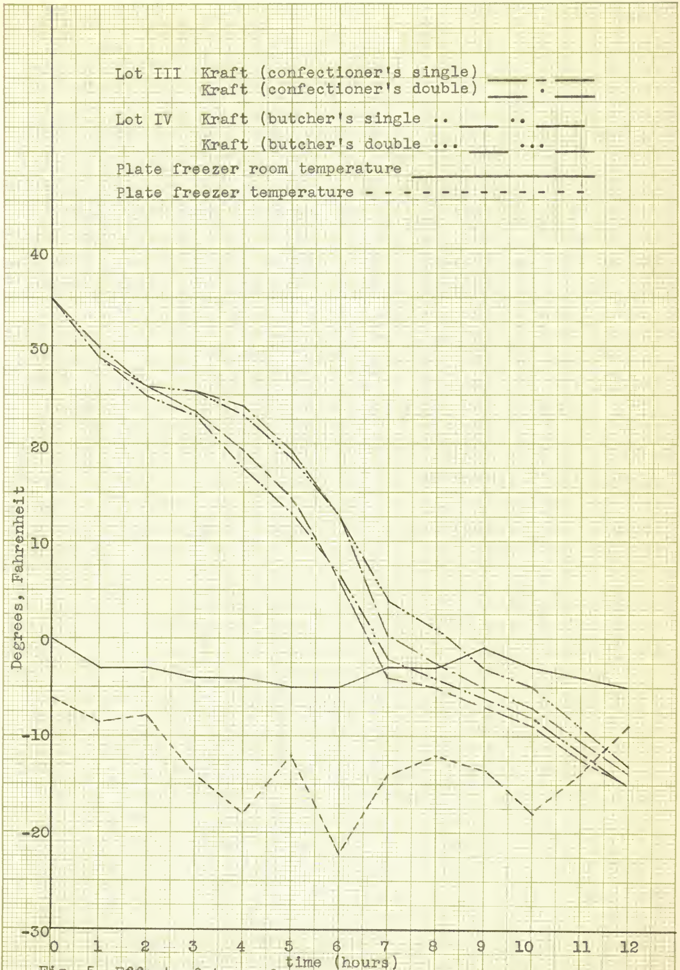


Fig. 5. Effect of type of wrapping material and method of freezing on rate of freezing.

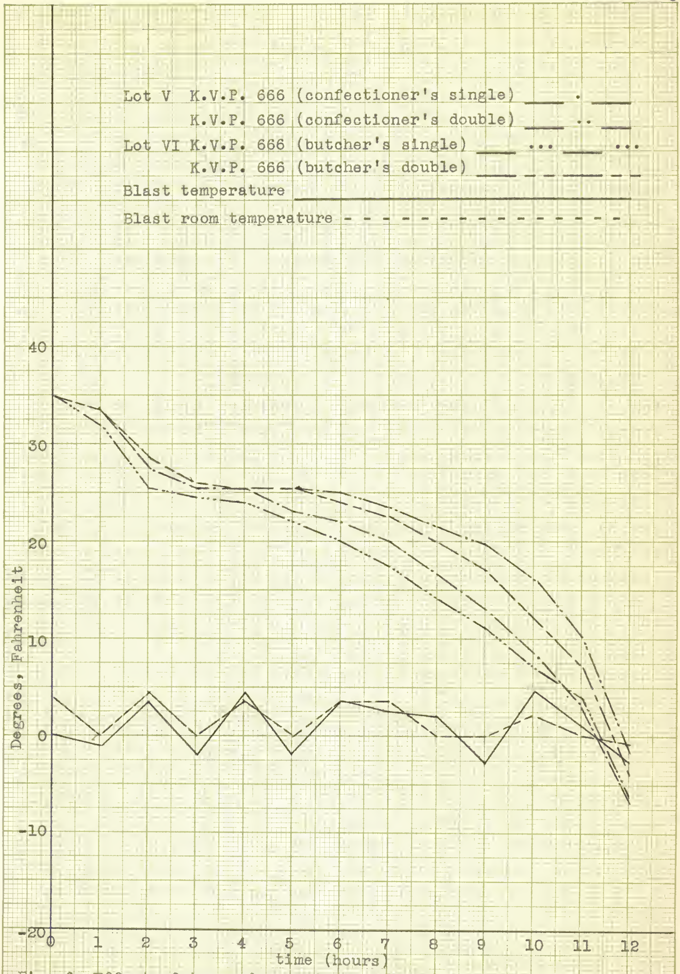


Fig. 6. Effect of type of wrapping material and method of freezing on rate of freezing.

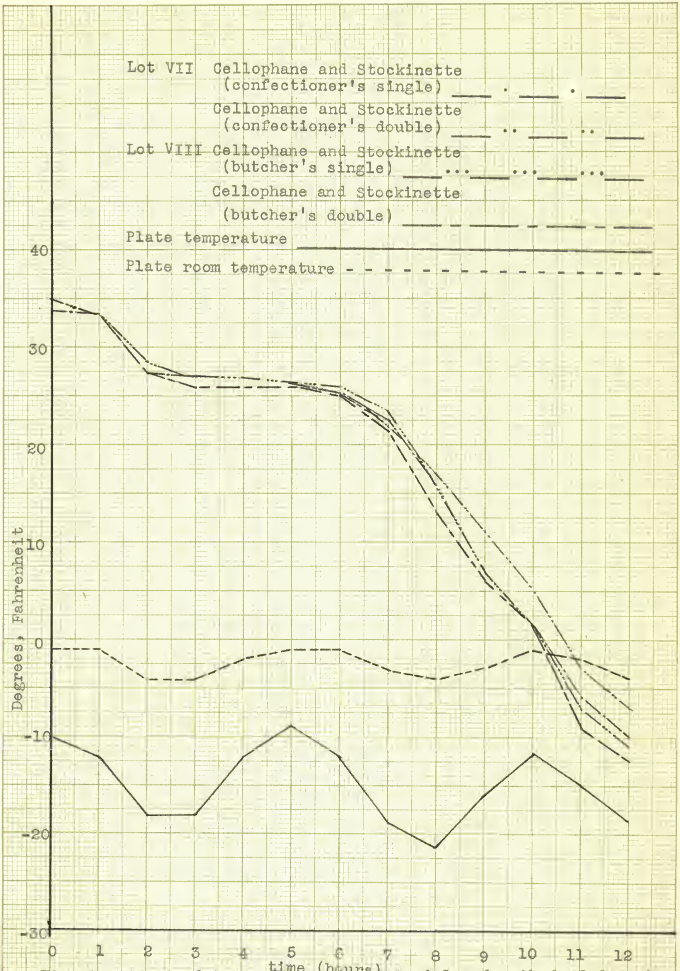


Fig. 7. Effect of type of wrapping material and method of freezing on rate of freezing.

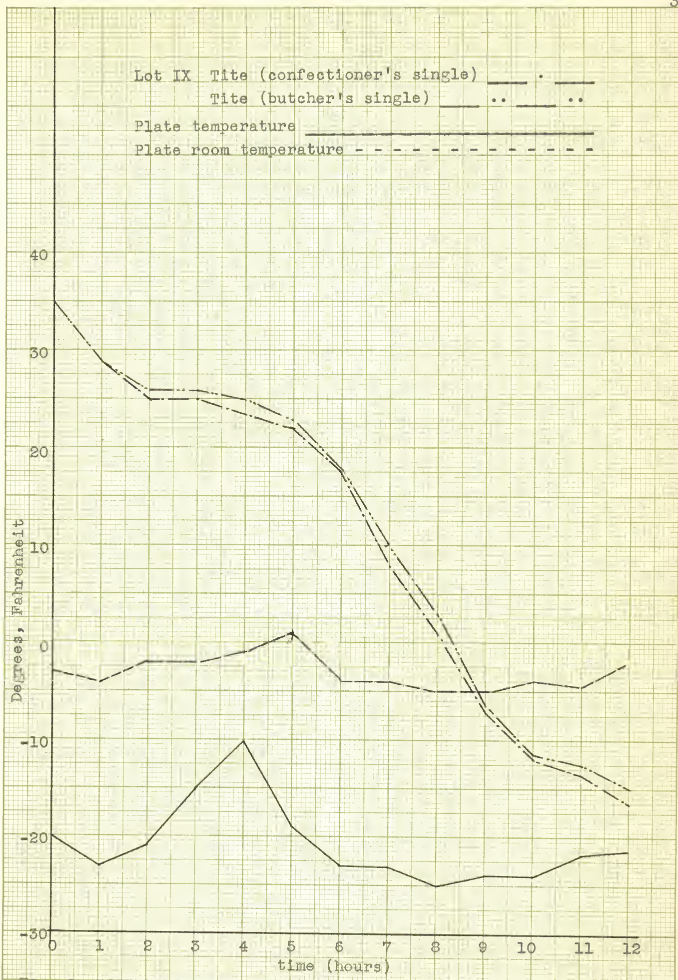


Fig. 8. Effect of type of wrapping material and method of freezing on rate of freezing.

The original temperature of the sausage when placed in the freezer was 35° F. In all cases it required two hours to bring the internal temperature of the sausage down to the freezing point. This was termed the chilling time. It required three to four hours before crystallization was completed and the temperature again descended. This was termed the freezing time or period of crystallization. The only exception to this pattern was in the case of kraft paper where the period of crystallization was less well defined.

The second series was run at a later date and included eight different wrapping materials. These wrapping materials were run in duplicate in both the blast freezer and plate freezer simultaneously. All packages were single wrapped, confectioner's style. It was unfortunate that it was impossible to control the freezer temperatures, and thereby eliminate that variable. The data are presented graphically in Figs. 9, 10, 11, 12, 13, 14, 15, and 16. The rates of freezing show very little variation between the packages frozen at the same time. Table 6 summarizes these curves giving the average freezing temperature, and period of time required to bring the two pound packages to the freezing point and the length of time required to complete the freezing process. As might be expected, the lower the temperature the shorter the period of crystallization. The aluminum foil and Purity Brand wrapped samples had the shortest freezing periods but the freezer temperatures were at the same time the lowest (-20° F.). The

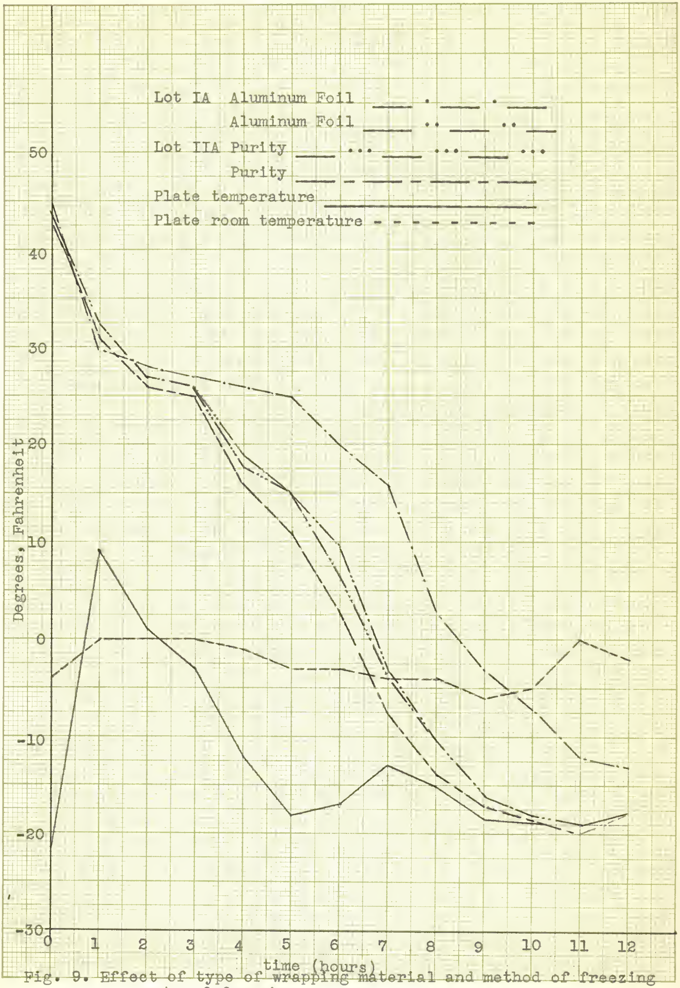


Fig. 9. Effect of type of wrapping material and method of freezing on rate of freezing.

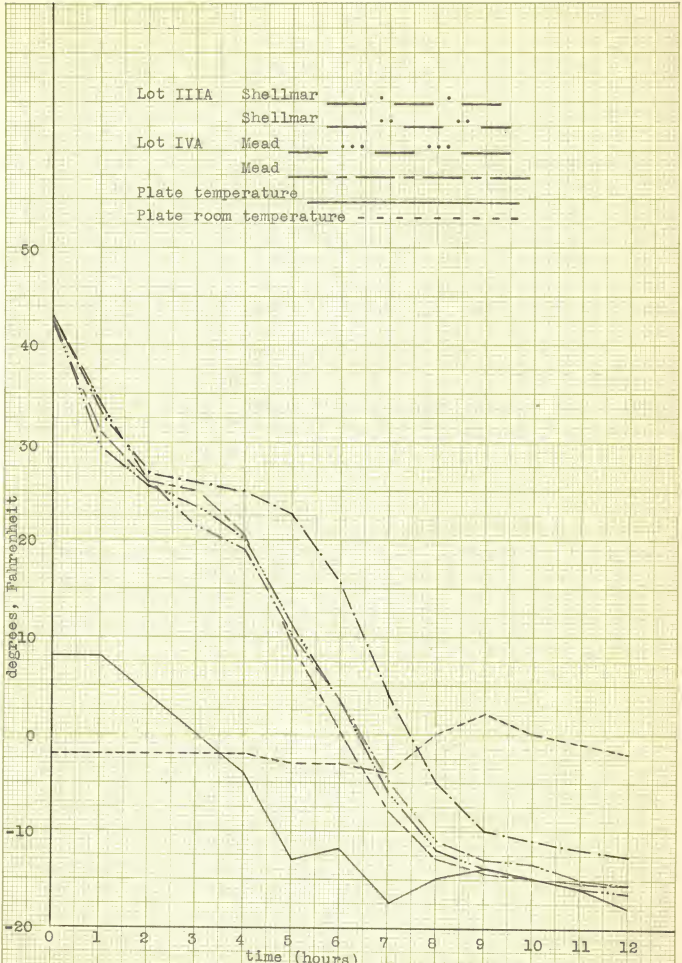


Fig. 10. Effect of type of wrapping material and method of freezing on rate of freezing.

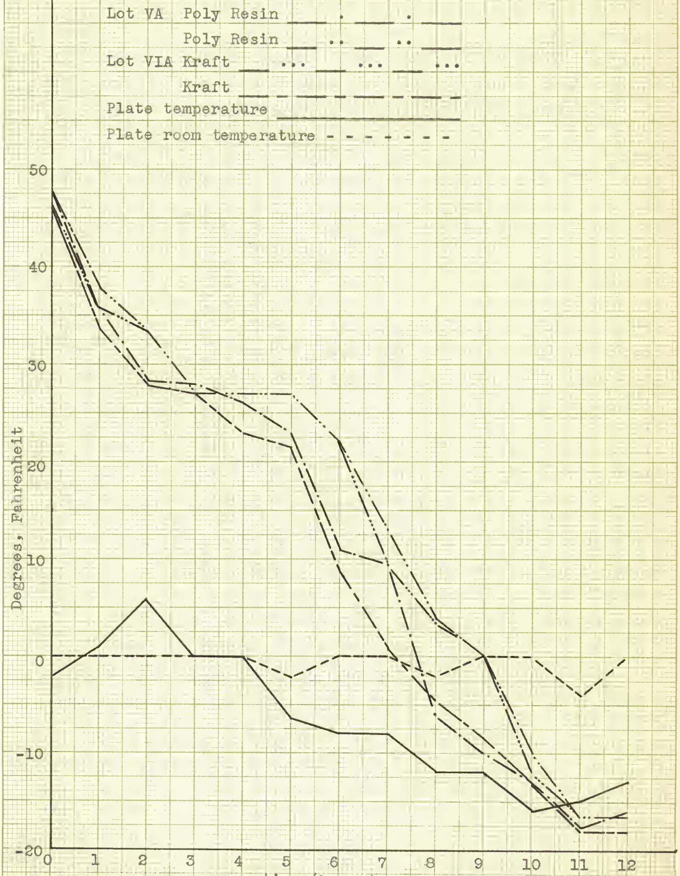


Fig. 11. Effect of type of wrapping material and method of freezing on rate of freezing.

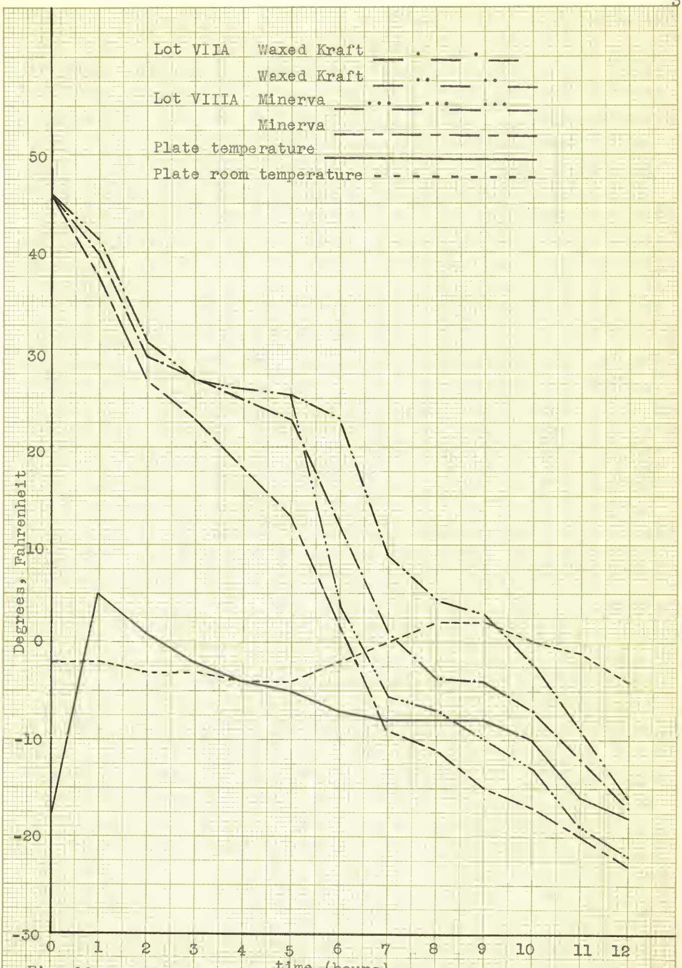


Fig. 12. Effect of type of wrapping material and method of freezing on rate of freezing.

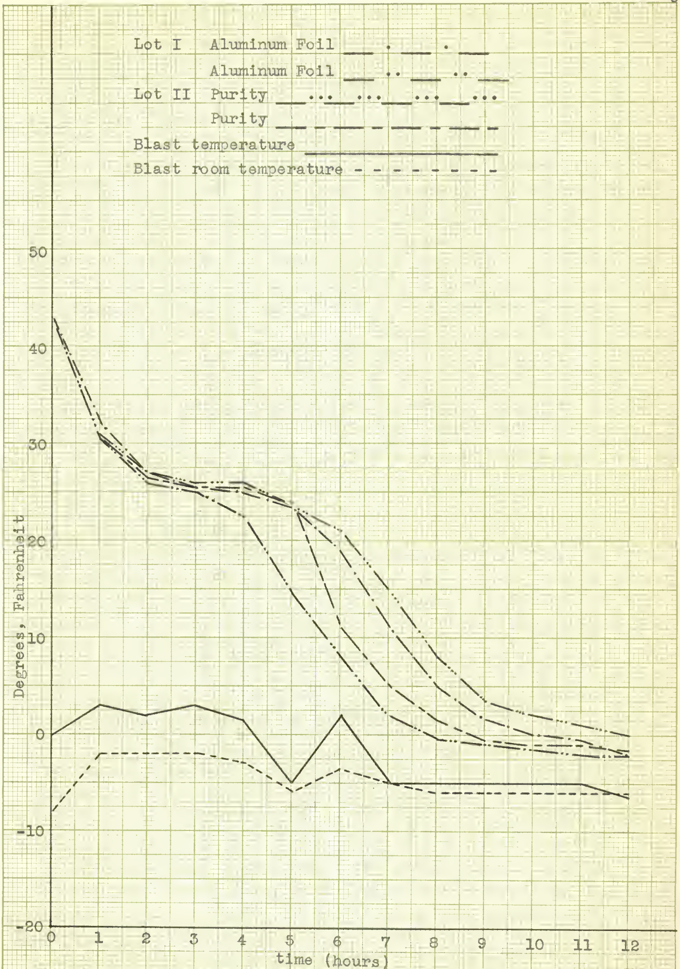


Fig. 13. Effect of type of wrapping material and method of freezing on rate of freezing.

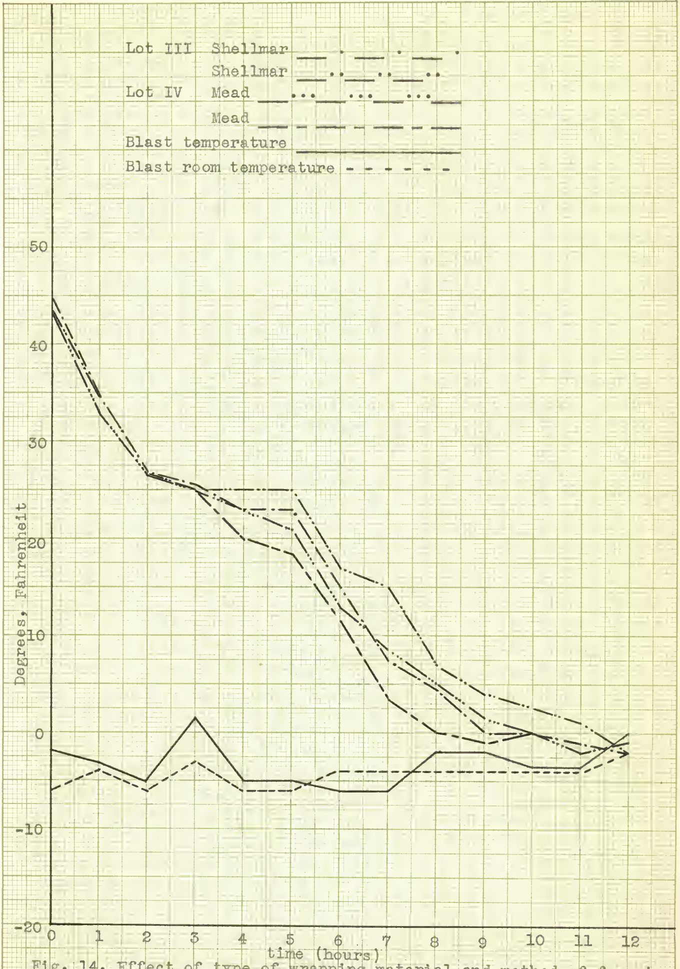


Fig. 14. Effect of type of wrapping material and method of freezing on rate of freezing.

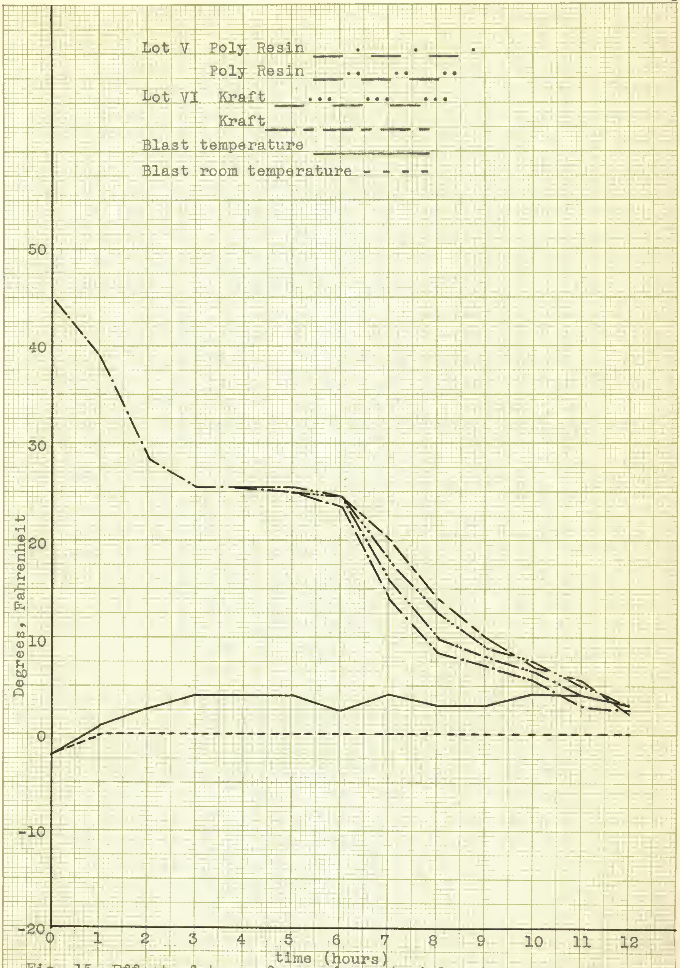


Fig. 15. Effect of type of wrapping material and method of freezing on rate of freezing.

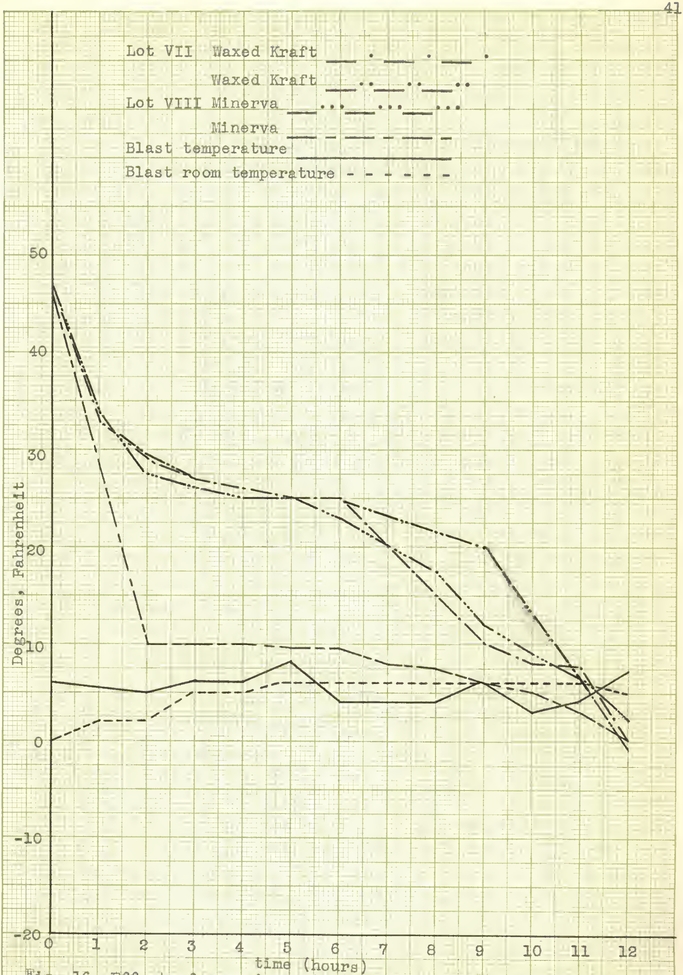


Fig. 16. Effect of wrapping material and method of freezing on rate of freezing.

Table 6. Average freezing temperatures and periods for samples in Experiment II.

Wrapping materials	Plate Freezer			Blast Freezer		
	Freezing temp.	Chilling time	Freezing time	Freezing temp.	Chilling time	Freezing time
Aluminum Foil 0.0015 Purity Brand	-20° F.	2	1	0° F.	2	3
Shellmar Mead	-10° F.	2	2	-4° F.	2	3
Polyethylene Resin Kraft	- 5° F.	2	3	+4° F.	2	4
Waxed Kraft Minerva	- 5° F.	2	3	+5° F.	2	4

longer freezing time of the polyethylene resin and kraft wrapped samples may likewise be attributed to higher freezer temperatures.

SUMMARY OF CONCLUSIONS

The following conclusions seem justified from this study.

1. Weight loss can be used as a convenient index of the protective qualities of wrapping materials.

2. Among the wrapping materials studied, No-Air-Wrap, Aluminum Foil, Aluminum Laminate, and Cellophane with Stockinette afforded a maximum protection against dehydration.

3. Improved wax paper and glassine laminated paper provided adequate protection against dehydration for six to nine months' storage at 0° F.

4. Ordinary wax and kraft papers should be used only when the better materials are not available and then the storage period should not exceed three months.

5. The method of classifying wrapping materials suggested by Winter appears to be satisfactory under practical storage conditions covering a 12 month period.

6. The confectioner's style of wrapping offers no advantage over the butcher style, insofar as dehydration is concerned if the wrapping material is properly applied.

7. Double wrapping offers little increased protection from dehydration over single wrapping.

8. All freezing curves are characterized by a sharp drop in internal temperature to the freezing point designated as "chilling", followed by a "plateau" designated as the period of crystallization.

9. The chilling period is almost constant for the same size package regardless of wrapping material, method of wrapping, or whether a single or double wrap was used.

10. The period of crystallization or freezing varies according to the freezing temperature but the wrapping material appears to have little or no influence upon this period.

ACKNOWLEDGMENTS

Indebtedness is acknowledged to Prof. D. L. Mackintosh, Professor In Charge of Meat Investigations at this Station, for planning and supervising this study; and to Dr. H. C. Fryer, Department of Mathematics, for his statistical assistance.

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