



FACTORS AFFECTING
ICE CREAM PACKAGING

Thesis for the Degree of M. S.
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Donald Anton Seifert
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FACTORS AFFECTING ICE CREAM PACKAGING

By

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
REVIEW OF LITERATURE	3
Evidence of Moisture Loss in Packaged Foods . .	3
Cheese	3
Butter	5
Ice Cream	7
Meat	8
Various Frozen Foods	9
Moisture Loss Mechanisms	12
Initial Loss During Hardening	13
Total Volumes	13
Diffusion	14
Sorption With Subsequent Evaporation	15
Factors Affecting Evaporation in Packaged	
Products	16
Length of Storage	16
Temperature of Storage	17
Circulation of Air	19

	Page
State of Moisture	20
Humidity	21
Surface Coating on the Product	23
Vapor Pressure Differences	25
Packaging	26
Surface Area	26
Thickness of Packaging Material	27
Heat Transfer	28
Closure Seal	28
Packaging Material	29
Physical and Chemical Effects of Moisture Loss .	31
Flavor Deterioration	31
Surface Films	32
Shrinkage	32
PLAN OF EXPERIMENT	34
GENERAL PROCEDURES	36
Composition of the Mix	36
Mix Ingredients	36
Freezing and Packaging	37
Producing Shrinkage	38

	Page
Measurement of Moisture Loss	38
EXPERIMENTAL	40
Plastic Containers	40
Effect of Lids	43
Position of Paraffin	45
Saturation	49
Temperature	53
Peel Test	55
Shrinkage	56
Preliminary Moisture Determination	62
Moisture, Flavor, and Body and Texture	
Deterioration	67
DISCUSSION	74
SUMMARY AND CONCLUSIONS	81
LITERATURE CITED	83

LIST OF TABLES

TABLE	Page
I. Weight Changes in Various Ice Cream Packages Stored at Two Temperatures . . .	54
II. Amounts of Ice Cream Adhering to Various Containers	57
III. Preliminary Determination of Moisture Loss and Quality Deterioration	65
IV. Determination of Moisture Loss and Quality Deterioration (Mix 1)	70
V. Determination of Moisture Loss and Quality Deterioration (Mix 2)	71

LIST OF FIGURES

FIGURE	Page
1. Effect of rigid plastic containers on weight losses of ice cream at cab- inet temperature	41
2. Effect of container lids on weight losses of ice cream at cabinet temperature . . .	44
3. Effect of position of paraffining on weight losses of ice cream at cabinet temper- ature	47
4. Effect of saturation of carton on weight losses of ice cream at cabinet temperature	51
5. Comparison of air loss and moisture loss of ice cream in plastic coated containers	59
6. Positions of sampling	64

INTRODUCTION

Packaging was intended originally as a means of transporting food products from the producer to the consumer irrespective of the container's influence upon the quality of the product. Today we are conscious of the fact that packaging must maintain the fresh wholesome appearance of packaged foods during the normal interval that follows manufacture and precedes consumer consumption. With our present extended periods of storage, this problem of maintaining natural flavor and appearance has become more and more troublesome.

Evidence of moisture loss and flavor deterioration in packaged dairy products may be found in the literature; however, much of this information is restricted to butter and cheese. More recent investigations of a preliminary nature have shown that packaged ice cream will lose moisture during extended storage at cabinet temperatures. This fact coupled with a growing demand for single service containers necessitates additional research concerning the effectiveness of our ice cream cartons under practical storage conditions.

It is the purpose of this study to determine, if possible, where the moisture is being lost from the ice cream carton, and to outline some factors believed to influence the loss of moisture in packaged products. It is hoped that these findings may aid the ice cream manufacturer in combating this problem.

Since little information relative to moisture loss in ice cream has been reported in the literature, sources other than those concerning ice cream have been consulted for reference material. The literature of the frozen foods industry has provided the richest source of information on the factors responsible for the loss of moisture in packaged frozen products.

REVIEW OF LITERATURE

Evidence of Moisture Loss in Packaged Foods

Cheese

Investigations of weight loss in cheese during ripening and storage first appeared in the literature during the years 1897 to 1905. Van Slyke (1901) noted that unparaffined cheddar cheese lost 11.14 per cent of its total weight when placed in 60° F. storage for 15 months at a relative humidity of 75 to 80 per cent. It was also noted that cheeses containing the greatest percentage of moisture lost the most weight. Later investigations by Van Slyke et al. (1903) showed that larger cheeses lost less moisture per 100 pounds of cheese than did the smaller sizes of cheese. In all cases, higher storage temperatures resulted in a greater moisture loss.

Babcock et al. (1903) found that at a constant humidity, the amount of moisture lost from cheese would be greatest at higher storage temperatures, but this loss could be reduced by increasing the relative humidity of the storage room to 100 per cent.

In a study of the effect of salt migration on the moisture content of cheddar cheese, Hoecker and Hammer (1944) found that the cheese lost about seven per cent of its moisture in four months of ripening. The moisture content decreased sharply at the surface and center of the product during the first 15 days of pressing; then tapered off.

Paraffin coatings were used on experimental cheeses by Van Slyke et al. (1903) and Lane (1903) and it was found that after five months of storage, the non-paraffined cheese lost a greater percentage of moisture. These paraffin coatings had little effect on the flavor of the cheese. The effect of several coverings applied to cheddar cheese was studied by McCubbin and Reichart (1937). They observed that comparative moisture tests at five months of ripening revealed that parafilm-covered cheese contained about two per cent more moisture than cheese covered with paraffined cellophane. Also, cellophane-covered cheese contained three to four per cent more moisture than paraffined cheese.

In a review of the changes that have occurred in cheese curing and types of coverings for cheese, Reichart and Downs (1941) concluded that the greatest economy in retarding moisture

evaporation of cheese was obtained by combining paraffin coatings with curing at low temperatures. Templeton and Sommer (1937) in investigating wrappers for processed cheese noted that the wrapper must maintain the moisture within the cheese. However, certain wrapping materials caused flavor deterioration. This was evident particularly when the cheese was still hot at the time of contact with the wrapper, or when heat was needed to seal the wrapper.

Butter

The loss of weight in butter has been accorded a matter of serious consideration, since butter is sold on the basis of weight. Salted and unsalted drums of butter were stored by Washburn and Dahlberg (1917) at -15° F. for 284 days. The salted butter lost 2.70 per cent of its moisture whereas the unsalted butter lost 0.19 per cent. Guthrie (1917) stored 100 tubs of butter at 0° to -10° F. for 134 days and observed an average shrinkage of 0.29 per cent. Seventeen tubs showed an increase in weight from 0.5 to 27.5 ounces, while 83 tubs lost weight ranging from 0.5 to 15.5 ounces.

Hunziker and Hosman (1920) stored an unsalted pound print of butter at 75^o F. for a month and found that the moisture content of the interior of the print was six to thirteen times greater than that of the outside, which had lost moisture through evaporation.

The moisture loss of "leaky" butter was investigated by Dahlberg (1922), who found that butter made "leaky" lost 4.2 per cent in weight during six months storage at 45^o F., while its control lost only one per cent under the same storage conditions. Another study of "leaky" butter by Guthrie (1926) showed that underworked butter lost 3.54 per cent moisture during eight months of storage at 0^o to 5^o F., while the same butter "worked" ten more revolutions lost only 0.64 per cent in weight under the same storage conditions. Guthrie et al. (1936) observed shrinkage in twelve butter samples held 36 days at 50^o F. The losses ranged from 0.44 to 2.02 per cent, with the average loss being 1.14 per cent.

In a study of the effect of aluminum foil as a butter wrapper, Ziemba (1947) observed that the moisture losses of the control samples were 2.25 per cent greater than in the foil-wrapped butter.

Ice Cream

It has been generally accepted in the ice cream industry that shrinkage of ice cream manifests itself as a loss of volume, but relatively few investigators have studied weight losses in ice cream. Smith (1935) was one of the first investigators to study changes in the weight of ice cream during storage. The conclusions reached were of a negative nature in that packaged ice cream did not materially change in weight over storage periods of 16 to 24 weeks. Of 520 packages stored at -6° F. in an automatically-controlled hardening room, only 21 varied greater than five grams from the initial weight. No change in weight occurred in 33 per cent of the 520 packages; 51 per cent lost weight; and 16 per cent gained weight.

No further research relative to ice cream and moisture losses could be found in the literature until Meiser (1950) reported weight changes in packaged ice cream at cabinet temperatures. An average loss in weight of 20 grams per pint was observed during 24 weeks of storage at 7° F. in untreated paper containers.

Meat

Pleuthner (1939) stated that a quarter of beef stored at 32° F. will lose weight at the rate of 0.60 per cent per day at a relative humidity of 75 per cent; 0.30 per cent per day at 85 per cent; and 0.12 per cent at 95 per cent. At 40° F. storage, a quarter of beef will lose weight at the rate of 0.76 per cent each day at a relative humidity of 75 per cent; 0.45 per cent at 85 per cent; and 0.15 per cent at 95 per cent.

Hiner and Hankins (1941) noted that moisture losses will occur in meat stored at temperatures above freezing, even when covered with a relatively vapor-proof wrapper. Beef aged 35 days at 34° F. in moisture-vapor-proof cellophane lost 4.58 per cent of its moisture.

Liver sausage wrapped in a polyethylene film, as observed by Lauber et al. (1949), lost only 0.2 per cent of its moisture during three weeks storage in a refrigerator. Normal storage of liver sausage for 10 to 14 days at 40° F., caused a loss in weight of 10 to 12 per cent.

Various Frozen Foods

The literature of the frozen foods industry contains many investigations concerning moisture loss in meats, vegetables, and other frozen foods. Brookbank (1949) stated that the loss in weight of unwrapped frozen meat can amount to 10 per cent or more over storage periods of six months. The loss of weight in chopped steak wrapped in regenerated cellulose and stored 292 days at 0° F. was 5.1 grams per pound, or 1.12 per cent, as reported by Grant (1944).

DuBois and Tressler (1939) stored meats for six months at -5° to -10° F. and a relative humidity of 40 per cent. Meats wrapped in waxed paper showed the following weight losses: beef lost 4.6 per cent; pork lost five per cent; veal lost six per cent; and lamb lost three per cent. The effect of fluctuating storage temperatures on ground beef during six months of storage was studied by Hustrulid et al. (1949). Beef wrapped in a good quality locker paper lost an average of 5.72 per cent moisture when the storage temperature fluctuated from 0° to -10° F. Beef wrapped in the same paper, but stored at a constant 0° F. lost an average of 1.82 per cent in weight.

In a study of surface drying of poultry, Cook (1939) found that severely dehydrated muscle contained only 50 to 55 per cent moisture, whereas normal tissue contained about 72 per cent moisture. Thus, severe dehydration caused a loss of about one-third of the moisture originally present in the muscle. DuBois (1942) observed that at 0° F. chickens lost not greater than 0.5 per cent moisture in a year in a moisture-vapor-proof package, while chickens in waxed locker paper lost five per cent or four ounces per five-pound bird. The moisture losses of deboned turkey steaks were investigated by Klose et al. (1950). The white meat wrapped in waxed paper lost 8.8 per cent of its original weight after six months at 0° F.; whereas, the dark meat lost 11.9 per cent under the same conditions.

Graul and Lowe (1947), in studying the effect of storage on frozen cakes and batters, found that the frozen cakes lost 2.08 per cent moisture at 0° F. and 0.63 per cent at -10° F. during storage of eight months. The moisture loss for frozen batters during the 8 months of storage was 1.00 per cent at 0° F. and 0.83 per cent at -10° F. It was stated that the cakes and batters were packaged in relatively moisture-

vapor-proof packages, otherwise the moisture loss would have approached the limits of the total moisture content of these foods.

An extensive study of the effects of packaging on moisture loss of frozen foods was made by Woodroof (1941). The following weight losses for frozen fruits and vegetables were observed after storage of one year in poor packages: String beans lost 22.1 per cent; peaches lost 12 per cent; youngberries lost 58 per cent; strawberries lost 60 per cent; and lima beans lost 11.1 per cent. Youngberries, when hermetically sealed in glass bottles and kept frozen for two years, lost 38 per cent of their moisture to the void within the container. This loss took the form of ice on the inner walls of the container.

Stone (1930) observed that unwrapped marshmallows lost 10 per cent in weight during storage of two weeks. Marshmallows wrapped in waxed paper and glassine lost 7 per cent and 3 per cent moisture, respectively, during the same storage period.

Woodroof (1941) found that the amount of desiccation depended not only on the type of package, but upon the kind

of product as well. Strawberries lost approximately six times as much in weight as did blueberries when the same conditions of freezing and storage were employed. Youngberries lost about half as much as peaches, but eight times as much as blueberries. Beef was found to lose about one-third as much as peaches with the same surface exposure, but less than any of the common vegetables tested.

Moisture Loss Mechanisms

The transpiration of moisture from packaged frozen foods is a complex problem, because of the existence of two separate systems. One system is the package, with its distinct properties of pressures and atmosphere, while the storage room is another system entailing a different atmosphere and pressures of its own. Carson (1938) attributed the driving pressure in the moisture loss mechanism to a difference in vapor pressure, determined by the humidity and temperature on each face of the package. The transpiration of moisture, he felt, occurred in the presence or absence of air pressure, disregarding the fact that the circulating air had the capacity to contain the moisture or not. Thus, as the air became

saturated, the moisture condensed on the package in the form of frost.

Initial Loss During Hardening

Greene (1944) has noted that serious dehydration is possible in low temperature rooms during the period when the food temperature is being brought into equilibrium with the room temperature. In order to freeze food, there must be temperature differences between the food to be frozen and the air which does the freezing. There is also a temperature difference between that of the refrigerating coils and the air. Pressure differences are produced by these temperature differences, and the moisture of the food under pressure will leave the food and pass into the surrounding atmosphere. Therefore, dehydration occurs as soon as the product is stored in the low temperature room, because of these temperature differences.

Total Volumes

Moisture migration may occur as a movement of total volumes through the porous walls of a package. In this type

of migration, the water vapor flows in the same manner as steam flows through a pipe. McDermott (1941) stated that an external force is required for this movement, and work is done in overcoming the external and internal frictional resistances involved.

Diffusion

Another type of migration, diffusion, may be involved in dehydration of frozen foods. McDermott (1941) has observed that an example of diffusion is the ability of perfume, when released in still air, to permeate the entire volume of a room. Diffusion requires no energy dissipation, for the energy lost by one molecule to another remains in the system, and the transfer of molecules requires only that the density of the vapor be greater in some region than in some other. In such a case, a greater number of molecules are traveling from the dense to the less dense region. Since diffusion through solids occurs almost imperceptibly at low temperatures, it must be conceded that diffusion through ice cream packages, if occurring at all, will travel the route of openings in the container wall.

Sorption With Subsequent Evaporation

Sorption, the phenomena of binding of moisture in solids, is another mechanism by which moisture may be transferred. McDermott (1941) has noted that sorption is associated with properties of solids, whereas movement of masses and movement by diffusion occur in the absence of solids or through the pores of solids.

In addition to water as a part of the chemical or physical composition, a solid may contain: adsorbed water, adhered to surfaces; absorbed water, within the pores; and water within capillaries, which is a combination of both. An adsorbed film is neither chemically bound nor "free" fluid. The film occupies a position midway between the two, just as it is neither a liquid nor a gas, since the film has a thickness of only one molecule.

Capillary water can be compared to the wetting of a wick, where the film is extended along the wick through adhesive forces. These forces advance the boundaries of the film while internal forces of adhesion and cohesion renew the molecules leading the advance. Absorbed water is held loosely

within the pores of a solid. An example of this is the water that can be expelled from a sponge by squeezing.

It appears feasible that an important mechanism of moisture loss through ice cream containers is the hygroscopic action of the package. The package becomes saturated with sorbed moisture and then releases this moisture to the surrounding atmosphere.

Factors Affecting Evaporation in Packaged Products

Length of Storage

Carson (1938) has observed that the amount of moisture passing through a membrane is directly proportional to the time of exposure. However, time is required (from a few minutes to several days, depending on the package material) for the sorption and evaporation of moisture to reach a steady state, so that the rate of transpiration becomes constant. Extending the length of storage from three months to six months was found by Klose et al. (1950) to increase moisture losses in frozen turkey steaks an average of 225 per cent.

A minimum period of exposure of 48 hours in the hardening room was recommended for ice cream by Ramsey et al.

(1947) in order to achieve maximum hardening. If this minimum storage period was not observed, moisture losses of the ice cream in retailers' cabinets was increased because of weakened resistance of the softer ice cream to the passage of moisture.

Temperature of Storage

The effect of storage temperature on moisture loss was studied by: Cook (1939), Dahle et al. (1947), Graul and Lowe (1947), Iverson (1947), Kohler (1939), McCubbin and Reichart (1937), Oswin (1948), Ramsey et al. (1947), and Van Slyke et al. (1903). These investigators observed that the rate of evaporation will generally decrease as the temperature is lowered. Both the vapor pressure of water and the moisture-holding capacity of the air will decrease as the temperature is lowered. Rabak (1947) observed that peas, frozen in paperboard with heat-sealed liners, lost twice as much moisture at 15° F. than at 0° F. during 20 months of storage with reasonably constant humidity.

A widely fluctuating temperature, according to Woodroof (1941), was the biggest single cause of desiccation of frozen

products. In another study, Woodroof (1941) contended that moisture passed from the food into the air within the container when the temperature rose unless the container was completely filled and evacuated of air. When the temperature dropped, the moisture was deposited on the inner surface of the container as frost. Thus, more moisture left the product with each change in temperature. The mechanics of this release and refreezing of moisture outside the product is believed to be irreversible. Carson (1938) stated that the effect of a rise in temperature was to primarily increase the driving pressure, thus increasing the permeability to moisture. However, it is cautioned that some workers have reported greater increases than would be expected. When the system is not isothermal, McDermott (1941) noted, the transfer of moisture by diffusion and sorption may operate either in the same or in opposite directions.

Hustrulid et al. (1949) observed that moisture losses in ground beef during storage of six months were more than three times greater for a fluctuating storage temperature of 0° to -10° F. than they were for a constant 0° F. In addition to increased dehydration, Finnegan (1939) found that fluctuating

temperatures produced oxidation, structural damage, and re-adjustment of water in the product due to thawing and re-crystallization. It was found that relatively small fluctuations above 0° F. will cause much more damage than large ones at -20° F.

Circulation of Air

Differences in temperature were observed by Woodroof (1941) to cause air currents, with the warmest air rising to be re-cooled by the coils, and thereby, giving up moisture to the coils. This air again contacting the product will be less than saturated, and will tend to absorb moisture. On rising to the coils, the cycle is completed. Thus, the slowly-moving air will constantly drain moisture from the product and deposit it on the refrigerating coils. Woodroof and Rabak (1949) noted that the movement of low-humidity air across the package surface will accelerate oxidation and the loss of flavor in addition to increasing moisture loss.

It was found by Cook (1939) that air appeared to exert a solvent action, particularly at low temperatures, thus retaining a quantity of water vapor more closely related to the

vapor pressure of supercooled water than to that of ice. Greene (1944) theorized that if the circulating air had no further capacity for containing moisture, vapor pressure differences, if present, caused the moisture to leave the food and condense on the product. Ramsey (1946) has noted that undue circulation of air in the hardening room increased the shrinkage of ice cream in paper containers.

State of Moisture

The work of Leighton (1927) and others indicated that ice cream is never completely frozen. In such a case, it seems possible that an ice cream package at -10° F. (a common storage temperature) may contain moisture in the form of liquid, solid, and vapor. It has been noted by McDermott (1941) that adsorbed moisture is neither to be considered as a liquid nor a gas, because of the monomolecular nature of the film. Carson (1938) observed that certain materials, such as paper, will absorb and transmit moisture more rapidly if one face of the package is in contact with water, than if the paper is in contact with the saturated vapor from water. For materials such as rubber, behavior in contact with moisture will

not differ, irregardless if it is in contact with the liquid or the vapor state.

Humidity

The free air within the frozen food container was observed by Rabak (1947) to approach 100 per cent relative humidity, while the atmosphere of the low temperature room was usually far below saturation. Thus, a vapor pressure difference was produced which caused the migration of water vapor. Cook (1939) found that frozen poultry stored at humidities less than 95 per cent was unsatisfactory, as the product was seriously affected by desiccation in from two to three months. Humidities from 98 to 100 per cent maintained the product satisfactorily for 83 weeks.

Greene (1944) investigated the vapor pressure differences between frozen foods and the freezer room air under different conditions of relative humidity and temperature. This study indicated that changes in the relative humidity of the storage space exerted greater influence on moisture losses than did comparative changes in the temperature of storage. The work of Pleuthner (1939) with storage of beef at 32° to

40° F. also indicated the importance of relative humidity. It was found that within the range of 31° to 42° F. the effect of temperature changes was slight (about 25 per cent) when compared with that caused by a change in relative humidity from 75 to 95 per cent.

One theory of moisture transmission advanced by Carson (1938) was that each side of the package membrane absorbed moisture according to the relative humidity on each side, and an equilibrium of transpiration was then obtained. Thus, a very high relative humidity on one face will upset the relationship between the vapor pressure and the rate of transpiration of moisture. McDermott (1941) noted that the total sorbed moisture within the package material was not generally a linear function of the relative humidity, but increased rapidly after a relative humidity of 80 per cent had been reached. This increase was believed to be due to the accumulation of interstitial or absorbed water, which was much less at lower relative humidities.

Babcock et al. (1903) found greater moisture losses in cheese stored in boxes at higher temperatures than in cheese stored in boxes at lower temperatures. The relative humidity

of the boxes was measured, and it was found that in boxes of cheese stored at 35° to 40° F., the air was saturated. At the higher temperatures, the relative humidity of the boxes was low enough to allow the evaporation of moisture from the cheese. Cheese stored for 15 months at 75 to 80 per cent relative humidity was found by Van Slyke (1901) to lose 11 per cent moisture, while cheese stored in a saturated atmosphere in a bell jar for 15 months gained two per cent in weight.

Surface Coating on the Product

Since the efficiency of any package is to a great extent dependent upon the tightness of the seal, it is natural to conclude that an ideal food covering would consist of an uninterrupted film of protective material applied as a dip coating directly to the product. A film having the required chemical and physical characteristics correctly applied, supplies a protection that approaches the efficiency of a hermetically-sealed metal or glass container. Dip coating of cheese with paraffin has long been practiced with quite satisfactory results, but this practice has not entirely eliminated moisture losses. Another type of surface coating is the glazing of fish by dipping

the frozen fish into a cold water solution for an instant. This leaves a thin coating of ice on the fish which almost eliminates desiccation.

Rabak (1947) has described capably the natural protective coatings of fruits, seeds, and nuts. The covering of such fruits as apples and pears consists of a thin coating of moisture-resistant waxes. This coating retards vapor losses, but permits respiration. The peanut is an example of Nature's "double wrap," while the cocoanut is Nature's hermetically-sealed container. Woodroof (1941) and Greene (1944) have observed that the amount of desiccation of frozen foods is influenced by the exterior skin or shell of some products. Very quick freezing of foods, especially when in contact with dry ice, will produce an icy crust on the surface of the food. This crust will retard moisture losses by acting as an insulation for the interior of the product. Woodroof (1941) noted that the duration of this protection was short, with the most protection being given during the first five days of storage and steadily diminishing for 40 to 60 days.

Vapor Pressure Differences

The driving force behind the transpiration of moisture in packaged frozen foods has been generally attributed by authorities to the differences in vapor pressure that exist between the interior and exterior of the package. In outlining formulae for the calculation of permeability of packaging materials, Oswin (1948) stated that the rate of moisture-vapor transmission was proportional to the vapor pressure difference across the material. Carson (1938) admitted this to be true generally, but cautioned that important exceptions have been observed, and that the vapor pressure within the container cannot always be determined. The difference in vapor pressure is determined by the temperature and the humidity on each face of the membrane.

Greene (1944) listed the vapor pressure differences for some of the common storage temperatures and humidities. It was noted that a large temporary difference existed during freezing of the food, while that experienced during storage of the frozen food was much smaller. In comparing the effects of these vapor-pressure differences, it must be remembered

that exposure time is relatively short during the time when the food temperature is being brought down to room temperature.

Packaging

The importance of the package in retarding moisture loss of frozen foods should not be overlooked. It appears that a few of the least permeable packaging materials afford such a degree of protection that the adverse effects of fluctuating storage temperatures and low humidity are almost negligible. Penn (1945) has advocated that in evaluating a package, 75 per cent of the score should be based on the protective qualities of the package. The other 25 per cent should be based on the sales appeal of the package.

Surface Area

A cylindrical container with tapered sides, termed nestyle, is widely-used in the ice cream industry. Meiser (1950) observed that tall nestyle packages were more resistant to moisture transfer than were squat nestyles. Since both containers were constructed of the same weight paper, it appeared that

the greater surface area of the squat nestyle may explain its inferiority.

Thickness of Packaging Material

Carson (1938) observed that there is some uncertainty as to how permeability to moisture varies with the thickness of the package material. For a consumer standard, the thickness should be of less concern than the over-all permeability. McDermott (1941) noted that one investigator found resistance to low velocity air to be more influenced by density than thickness, while others have observed resistance to water vapor transfer to be non-linear with thickness. It was found by Meiser (1950) that thickness may account for the greater resistance of cylindrical containers to water-vapor transfer, when compared to nestyle containers. The unfilled nestyles averaged 25 grams in weight, while unfilled cylindrical containers averaged 33 grams.

The effect of double wrappers on moisture loss of frozen foods was investigated by Rabak and Stark (1946). It was found that double wrappers increased the resistance of waxed paper to vapor transfer fivefold, while that of cellophane

was increased threefold. Possibly, the second overwrap results in partial resealing of the porous areas of the first overwrap by transferring coating from one sheet to the other during heat-sealing.

Heat Transfer

No mention of the effect of heat transfer of packaging materials on water-vapor transmission could be found in the literature. However, Stone (1930) claimed that waxed glassine exhibited superior heat-insulating properties. Two cartons of ice cream were allowed to stand for 45 minutes at 80° F. The control carton, upon inspection, contained "mushy" ice cream; while a carton wrapped in glassine and heat sealed, "contained a firm, solid brick with only traces of melting at the corners." A carton with superior resistance to heat transfer may be also more resistant to water-vapor transfer, if for no other reason than its protection against fluctuations in storage temperature.

Closure Seal

The ice cream industry has almost ignored the importance of a "water-vapor proof" closure seal; while the frozen

foods industry, in its few years of development, was quick to recognize the effect of a poor seal. Rabak (1947) has noted that an imperfect seal will defeat the utility of the most efficient water-vapor resistant material. The poor seal was believed by Woodroof and Rabak (1949) to be the point of greatest loss of water vapor. These investigators recommended that the seal should be as good as the package, while Shaffer (1945) observed that no package is better than its seal. Poor seals permit leakage before and after freezing.

Packaging Material

The following list by Woodroof and Rabak (1949) contains some of the types of packaging materials that have been found satisfactory for frozen foods:

- waxed papers
- moisture and water-resistant cellophanes
- laminated materials
- rubber and rubber derivatives
- aluminum foil
- coated paperboard
- dip coating
- tin, aluminum, and glass

This list is being constantly supplemented with new materials. Many of these materials may be useful to the ice cream industry.

The literature is rich in data of the water-vapor transmission rates of materials used for packaging of frozen foods; Brookbank (1949), Carson (1938), Dahle et al. (1947), DuBois (1942), DuBois and Tressler (1939), Grant (1944), Levy (1931), and Woodroof and DuPree (1942). Evaluation of the results has been difficult because of the variety of conditions under which the tests have been conducted. Carson (1938) has standardized the results of 28 investigators into common units of measurement.

Among the variations noted in the 28 tests were:

- a. The test period varied from two to 2,000 hours.
- b. The temperature of the test varied from 7° to 113° F.
- c. The area tested varied from 0.02 to 50 square inches.
- d. Vapor pressure differences varied from zero to 72 mm. Hg.
- e. The results were reported in 20 different units.

The majority of tests have been conducted at temperatures above freezing. Brookbank (1949) believed this to be unsound since results reported at 100° F. may be entirely different at 0° F. The paper industry is aware of this disparity, and research is being conducted to prepare a standardized test for determining the permeability of packaging materials at sub-zero temperatures.

Physical and Chemical Effects of Moisture Loss

Flavor Deterioration

Vanilla ice cream of high quality was found by Schricker (1935) to show the effects of age within four weeks from date of manufacture under normal conditions of storage. Chocolate ice cream developed "off-flavors" within four to six weeks, and strawberry within two weeks. Arbuckle (1949) observed that ordinary ice cream packages must be supplemented with additional wrappers of protective materials if subjected to zero temperatures of storage for six weeks or longer. It was recommended that dairy products at low temperatures should be stored separately to eliminate absorption of flavors. Smith (1935) stored ice cream samples at a constant -6° F., and noted flavor changes in vanilla ice cream at 86 to 100 days of storage. Strawberry ice cream turned slightly stale at 72 to 107 days, with a disagreeable stale flavor noted at 114 days. Chocolate and maple walnut ice creams kept well and retained their flavors for three to four months.

A number of frozen food investigators have studied "freezer burn," a local dehydration of frozen food tissue.

Brookbank (1949) observed that air pockets between the food and the wrapper are focal points for this dehydration. The wrapper was colder than the meat, causing vapor to condense on the wrapper around the air pocket. Cook (1939) and Rabak (1947) have attested to the flavor changes caused by "freezer burn."

Surface Films

Smith (1935) noted that of 520 ice cream samples stored at a constant -6° F., all showed a tough, rubbery film on the surface after 107 to 114 days of storage. Meiser (1950) found a tough, leathery film of approximately 1 millimeter in depth in ice cream samples stored at 7° F. for eight weeks. In this case, it seemed reasonable to attribute this surface film to the dehydration of the surface.

Shrinkage

Kohler (1939) observed that two types of ice cream shrinkage exist. When refrigeration is applied severely to ice cream, a meniscus-like type of shrinkage will occur, causing the center of the ice cream to be depressed. Another

type of shrinkage results in the ice cream receding from the wall of the container and sinking to a lower level. This latter type shrinkage may be produced by severe pressure changes, or, as shown by Meiser (1950), may result from severe desiccation of the product. Dehydration of this magnitude resulted in a loss in weight as well as a loss in total volume of the packaged ice cream. Whether two types of shrinkage actually exist is still a debatable question that can only be answered by further experimentation.

PLAN OF EXPERIMENT

From the foregoing discussion, it is evident that frozen foods will lose weight during storage. This loss of weight is believed to be due to evaporation of moisture from the product. Those known factors influencing the rate and degree of desiccation have been discussed previously in the review of literature. There is some evidence that packaged ice cream will also lose weight through evaporation during storage, as shown by Meiser (1950).

Since investigators in the frozen foods industry have found certain factors to influence moisture loss, it is the purpose of this study to determine, if possible, the effect of some of these factors on moisture losses in packaged ice cream. In other words, what part of the product is losing moisture, and how does this loss affect that part?

Because ice cream is subjected to many varied procedures of packaging and storage, it is evident that the scope of this study must be limited to the facilities available on a laboratory scale. With this viewpoint in mind, the following experiments were performed:

1. Plastic Containers. Ability of rigid plastic containers to retard weight losses in packaged ice cream.
2. Container Lids. Ability of container lids to retard weight losses in ice cream packaged in untreated cylindrical paper containers.
3. Position of Paraffin. Ability of the lateral and horizontal surfaces to retard weight losses in paper cartons.
4. Saturation. Ability or inability of saturated paper to retard weight losses in untreated paper containers.
5. Storage Temperature. Ability of sub-zero temperatures to retard weight losses in varied ice cream cartons.
6. Peel Test. Ability of varied ice cream cartons to resist adhesion of the ice cream to the container surface.
7. Shrinkage. Ability of plastic-coated containers to resist shrinkage as measured by volume loss and weight loss.
8. Surface Retention of Moisture. Ability of lateral and horizontal surfaces of varied ice cream containers to resist desiccation and flavor deterioration.

GENERAL PROCEDURES

The following procedures were followed generally throughout the experiments. In cases where the procedures listed below were modified, the modifications will be described under their proper headings throughout the remainder of the study.

Composition of the Mix

Mixes testing approximately 12 per cent butterfat, 11 per cent milk solids not fat, 15 per cent sugar, and 0.5 per cent gelatin of 150 Bloom strength were obtained from the Michigan State College Creamery.

Mix Ingredients

Frozen cream and whole milk supplied the butterfat for the mixes used in the experiments. Additional milk-solids-not-fat were supplied by fresh skim-milk and roller-process skim-milk powder. Sucrose and sweetose were the sweetening agents used, while the stabilizer consisted of gelatin with an added whipping aid. The mixes were pasteurized at 155° F. for 30 minutes; then homogenized in two stages with 2,000 pounds

pressure on the first stage and 500 pounds pressure on the second stage. Following homogenization, the mixes were cooled on a surface cooler and stored in a holding vat at 33° F. for 24 hours prior to freezing.

Freezing and Packaging

The mixes were frozen in a Vogt continuous freezer (200 gallons per hour capacity), or in a 40 quart Cherry-Burrell direct expansion batch freezer. The samples were taken directly from the Vogt freezer, when the desired overrun (90 per cent) was reached, and placed immediately in the hardening room. The batch-frozen ice cream was packed by hand into pint containers and immediately placed in the hardening room. The first and last portions drawn from the batch freezer were not used in the experiments, and the hand-packaging was done as quickly as possible in a cold storage room to eliminate errors caused by softening of the ice cream. All samples were hardened at -9° F. $\pm 1^{\circ}$, then transferred to a closed electric cabinet at a temperature of 7° F. $\pm 1^{\circ}$.

Producing Shrinkage

In all cases except one, shrinkage was produced in a natural manner by allowing extended storage of the ice cream at cabinet temperatures. In one experiment, shrinkage was obtained using a modification of Hankinson's (1942) vacuum induction method. The frozen ice cream was exposed to a vacuum of 20 inches for four hours. The vacuum was then released and the samples were returned to the storage cabinet for seven days before being investigated for shrinkage. It has not been conclusively shown that shrinkage produced by vacuum treatment is identical to that which occurs in spontaneous shrinkage.

Measurement of Moisture Loss

In all except the last two experiments, moisture loss was determined by weighing techniques. The containers were weighed on a triple-beam, stainless steel balance having a sensitivity of 0.1 gram. Weighings were made of the unfilled containers and of the filled containers after hardening. At intervals of one week the containers were removed from the

cabinet and re-weighed rapidly. The lids of the samples remained in place during the entire storage period.

In the last two experiments moisture loss was determined by analysis of the ice cream for total solids; since, theoretically, the loss of moisture should be proportional to the increase in total solids of the ice cream during storage. The Mojonnier method as outlined in Mojonnier and Troy (1925) was used for the total solids analysis of the ice cream samples.

EXPERIMENTAL

Plastic Containers

Brookbank (1949), Carson (1938), DuBois and Tressler (1939), Stone (1930), Woodroof and DuPree (1942), and Woodroof and Rabak (1949) have presented evidence in the literature to show the efficiency of plastic materials in retarding moisture loss when used as package coatings or as wrappers. However, no attempt was made to utilize containers manufactured of solid plastic which are now being used quite widely by the cheese industry. To determine the ability of rigid plastic containers to retard moisture loss in packaged ice cream, the following experiment was conducted.

The containers were filled directly from the continuous freezer and stored for eight weeks in the ice cream cabinet. At weekly intervals, the samples were weighed and returned to the cabinet. The results are illustrated in Figure 1; each point plotted was the average of triplicate determinations. The containers used are listed below:

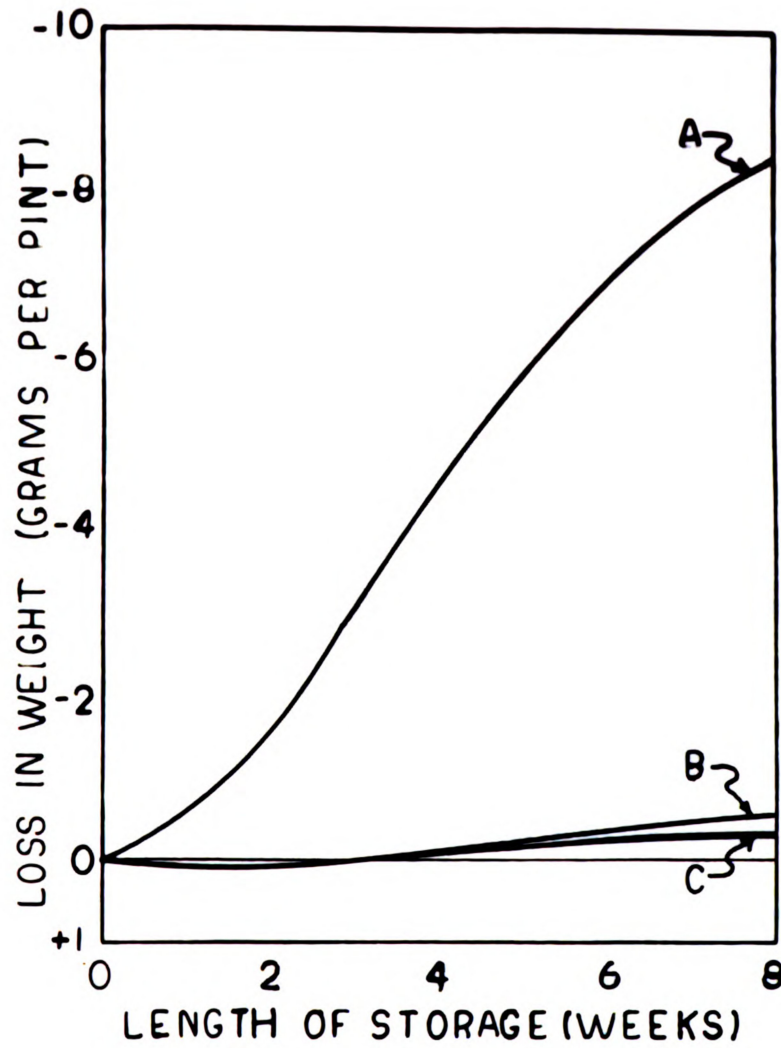


Figure 1. Effect of rigid plastic containers on weight losses of ice cream at cabinet temperature. A - Untreated cylindrical. B - Cylindrical plastic. C - Rectangular plastic.

Container A - Untreated control (cylindrical paper carton).

Container B - Cylindrical container of heavy weight plastic (screw-type lid).

Container C - Square container of heavy weight plastic (insert-type lid).

Both plastic containers were vastly superior to the untreated paper carton. The square plastic container lost slightly less moisture than the round plastic container, possibly because the insert lid provided a tighter closure than the screw-type lid. The weight loss of the plastic containers was so slight, however, that the small difference between the two must be considered insignificant. Because plastic is not hygroscopic or porous, it is reasonable to assume that the moisture loss did not occur through the known processes discussed previously, but occurred at the junction of the lid with the container proper.

At the present time, plastic containers of this style are not practical for packaging of ice cream because of their cost; however, we cannot disregard future use of this type of package. Lighter-weight plastics in the form of package coatings and bags may be satisfactory for ice cream merchandizing.

Effect of Lids

In the early stages of the ice cream industry, it was a common practice not to use lids on metal containers of ice cream. In most cases, a single sheet of thin parchment was the only covering afforded the surface of the product. The importance of closures has been mentioned previously in this study. Rabak (1947), Shaffer (1945), Woodroof and Rabak (1949) are in general agreement that a package is no better than its closure seal, thus the following experiment was planned to determine the degree of protection offered by the lids of ice cream containers.

Six cylindrical containers (untreated) were filled with ice cream and stored for eight weeks at cabinet temperatures. The lids were removed from three of the cartons after hardening, while on the other three cartons the lids remained in place during the entire period of storage. At weekly intervals the six cartons were weighed, and the results recorded in Figure 2. Curve A represents the average of containers with the lids removed, while Curve B represents the average of the containers whose lids remained in place during the study.

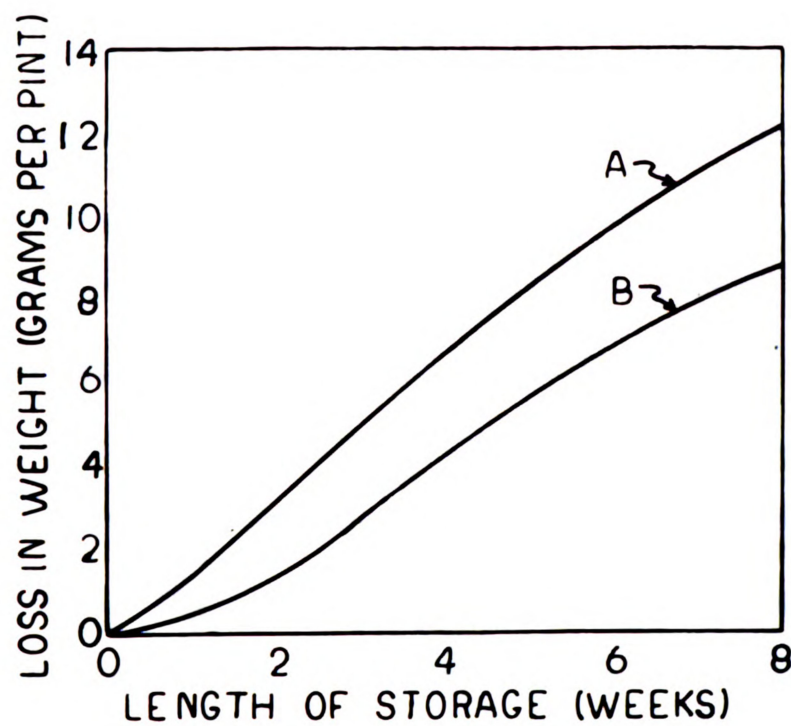


Figure 2. Effect of container lids on weight losses of ice cream at cabinet temperature. A - Lids removed. B - Lids in place.

The results show that after eight weeks of storage, the containers with lids removed lost an average of 12.4 grams, while the average loss of the containers with lids in place was 8.8 grams. This indicates that the closures of the containers offered some protection. Although the amount of protection may appear small when the weight losses are compared, it must be remembered that a minute decrease in moisture content may produce pronounced changes on the macroscopic surface layers. The frozen foods industry who thoroughly investigated this problem of closures concluded that heat-sealing is an indispensable operation in frozen food packaging. Ice cream does not react favorably to heat-sealing, but perhaps other means may be found to eliminate this avenue of escape. Further studies relative to the importance of proper closures appear on subsequent pages.

Position of Paraffin

The previous experiments indicated that ice cream will lose weight when stored in untreated paper containers. Dahle et al. (1947) and Meiser (1950) have investigated the effect of paraffin coatings of containers on shrinkage of ice cream. These

investigators paraffined the containers on the interior and exterior to determine at which position paraffin offered the greatest resistance to shrinkage.

The procedures of Dahle et al. (1947) and Meiser (1950) were modified in the following experiment in that partial areas of the container were paraffined to determine where the weight was being lost. Cylindrical paper cartons were coated with paraffin at different positions on the outside of the containers by dipping the cartons in melted wax. The cartons were then filled with ice cream and stored for eight weeks at cabinet temperatures. Following weighings at weekly intervals, the results were plotted in Figure 3. Triplicate samples were made of each treatment listed below:

Carton	Treatment
A	Untreated control
B	Paraffined on bottom
C	Paraffined on top
D	Paraffined on top and bottom
E	Paraffined on side
F	Paraffined on top, bottom, and side

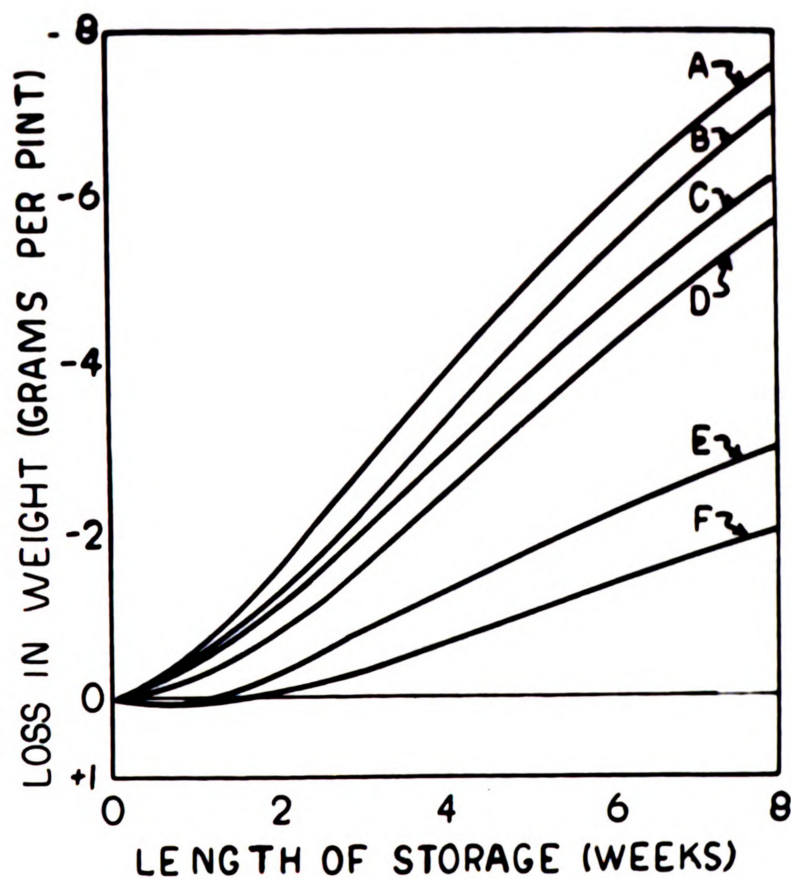


Figure 3. Effect of position of paraffining on weight losses of ice cream at cabinet temperature. A - Unparaffined. B - Paraffined bottom. C - Paraffined top. D - Paraffined top and bottom. E - Paraffined side. F - Completely paraffined.

Visual inspection of Figure 3 indicates that the most moisture was lost through the side of the container. However, when the weight losses of the top, side, and bottom of a package were divided by their respective surface areas, one found the loss in grams per square inch to be greater for the horizontal surface.

In calculating the loss per unit area, it must be assumed that B subtracted from A would give the loss through the bottom. Similarly, C and E subtracted from A would give the losses through the top and side, respectively. Then, if these losses were divided by the areas of the parts, the loss in grams per unit area could be found for each component. Using this method, the following losses were found:

Area Studied	Loss in Grams per Square Inch
Top	0.149
Side	0.129
Bottom	0.065

The greater loss at the top of the container was possibly due to a greater volume and circulation of air at this

point. Since packages were stored adjacent to each other, as is common in the dealer's cabinet, the sides were protected from air currents by the proximity of neighboring packages, while the tops were unobstructed.

Another explanation may be that the temperature in the cabinet was higher at the top of the container, causing more moisture to be lost. This same reasoning may account in part for the smaller losses at the bottom, where the temperature should be lower since the warmer air will rise. Also, the bottom was protected quite efficiently from the circulating air by a lip which extended downward from the side of the carton for a short distance. This lip, which is intended primarily to strengthen the carton, formed a small chamber that trapped air around the bottom and acted as an insulating agent.

Saturation

Carson (1938) and McDermott (1941) observed that hygroscopic properties of packaging materials facilitate the passage of moisture. Paper containers were believed by Meiser (1950) to absorb moisture from the ice cream. He maintained that

paper once saturated accelerated a bleeding of moisture from the product to the less dense atmosphere.

With the above thoughts in mind, an experiment was devised to determine the effect of saturation of the package prior to filling. Cylindrical containers of different treatment were saturated by allowing them to absorb moisture in the ice cream cabinet for seven days prior to filling with ice cream. Unsaturated containers of similar treatment were also filled with ice cream and stored with the filled saturated containers in an ice cream cabinet. All packages were weighed at intervals of one week. The results are shown in Figure 4. The containers used in the experiment are listed below. Each determination was made in triplicate.

Sample	Treatment
A	Saturated cylindrical (untreated)
B	Unsaturated cylindrical (untreated)
C	Saturated cylindrical (glassine-lined)
D	Saturated cylindrical (paraffined)
E	Unsaturated cylindrical (paraffined)
F	Unsaturated cylindrical (glassine-lined)

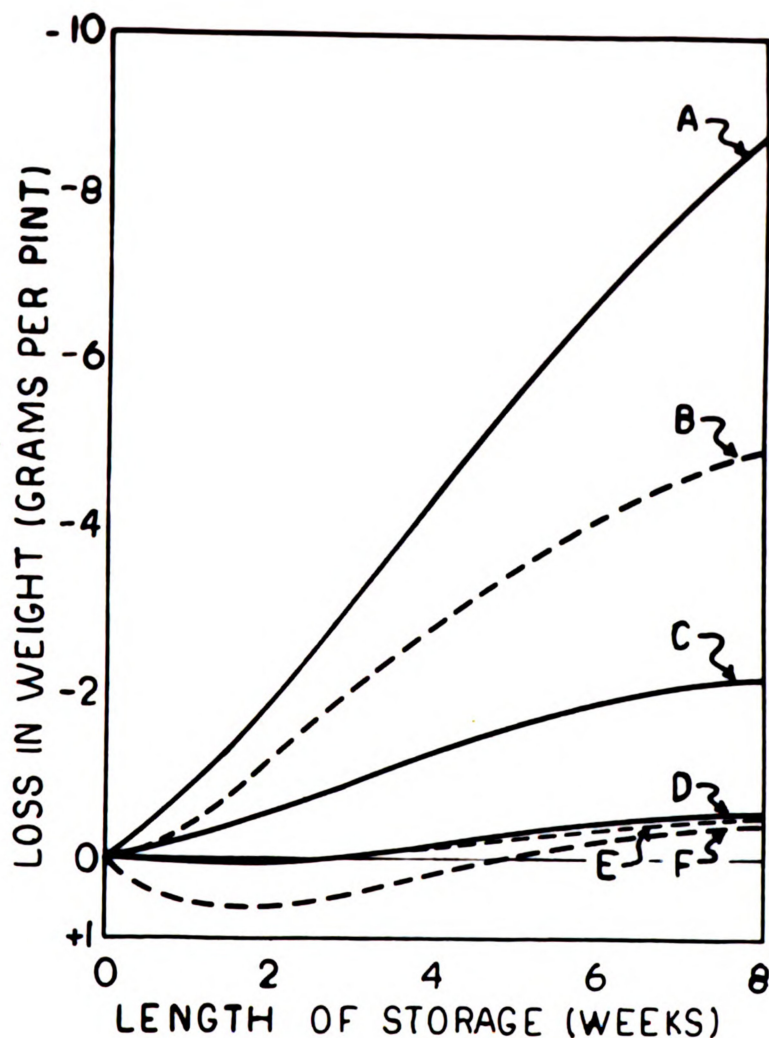


Figure 4. Effect of saturation of carton on weight losses of ice cream at cabinet temperature. A - Saturated (untreated). B - Unsaturated (untreated). C - Saturated (glassine-lined). D - Saturated (paraffined). E - Unsaturated (paraffined). F - Unsaturated (glassine-lined).

In all cases, saturation of the paperboard prior to packaging facilitated moisture transfer from the container to the cabinet air. Saturation had the least effect in the case of paraffined containers, since the paraffin coating reduced the number of pores by filling the interstices between the fibers. The small amount of saturation shown in the paraffined containers probably occurred through capillary action in the longer unhydrated fibers, as paraffin does not always seal the ends of these fibers.

It is not known why the saturated glassine-lined container differed so widely from its unsaturated counterpart in the amount of moisture lost. This may have been due to a loosening of the glassine layer from the container proper, a factor previously reported by Hicks (1950) as influencing moisture loss.

Meiser (1950) observed that a fairly uniform rate of moisture loss will be reached after the paper becomes saturated. In the studies conducted here, an almost steady loss of moisture was shown for the saturated containers, whereas the unsaturated containers lagged for about ten days before

a steady rate was reached. Possibly, this lag period parallels the time required for saturation.

Temperature

Moisture losses in frozen foods will generally decrease as the temperature of storage is lowered, as observed by a number of investigators, Cook (1939), Dahle et al. (1947), Graul and Lowe (1947), Iverson (1947), Kohler (1939), McCubbin and Reichart (1937), Oswin (1948), and Van Slyke et al. (1903). Low storage temperatures for ice cream have been recommended by Ramsey et al. (1946), (1947), but no evidence could be found in the literature as to the effect of low temperature storage on moisture loss in ice cream.

An experiment was designed to provide information on weight loss of ice cream when stored in various packages at two temperatures. The ice cream was filled directly from the continuous freezer into various containers, with triplicate samples of each package being stored at 7⁰ F. in an ice cream cabinet and at -10⁰ F. in a sub-zero unit. Weighings were made prior to storage and after four weeks of storage. The packages used and their changes in weight are listed in Table I.

TABLE I
WEIGHT CHANGES IN VARIOUS ICE CREAM PACKAGES
STORED AT TWO TEMPERATURES

Container	Average Change in Weight (grams)	
	-10° F.	7° F.
Untreated cylindrical	- 3.70	- 6.42
Glassine cylindrical	- 0.25	+ 0.05
Untreated tub	- 6.30	- 4.42
Paraffined tub	+ 0.22	+ 0.52
Untreated pail	- 9.47	- 4.85
Paraffined pail	- 1.72	- 0.87
Paraffined square	- 3.75	- 0.25
Untreated nestyle	- 7.32	- 3.75
Vinylite nestyle	- 1.20	+ 0.85
Paraffined nestyle	- 0.05	+ 0.60
Pliofilm bag	- 0.35	- 0.15
Cellophane bag	-12.36	- 9.25

Of all the packages included in this study, only one sample (untreated cylindrical container) lost more moisture at the higher storage temperature. This is contrary to results reported previously for such frozen foods as meats, vegetables, and fruits. Communication with certain ice cream manufacturers who are using these low temperature units has indicated experiences similar to that recorded here. Although no conclusions can be drawn from this experiment due to its conflicting nature, it does point out the need for an isobaric study relative to ice cream storage at different temperatures. An experiment of this nature, however, is too costly and time-consuming to be included in this thesis.

Peel Test

One criticism of untreated containers obtained from ice cream manufacturers is that ice cream, upon continued storage, has a tendency to cling to the surface of the package, thus making dispensing an arduous procedure. No reference to this criticism could be found in the literature, thus the following experiment was designed to obtain this information.

Containers of ice cream similar to those used in the previous experiment were examined following storage of four weeks in an ice cream cabinet and sub-zero unit. The protective package surrounding the ice cream was carefully stripped off while the ice cream remained firm. The amount of ice cream adhering to the package was observed and the results recorded in Table II.

It was found that containers allowing the greatest degree of moisture loss also retained the greatest deposit of ice cream on the peeled container. Deposits of this nature are very objectionable to the consumer. The adhesive deposit retained on the wall of the untreated containers was severely dehydrated and possessed a pronounced stale flavor. The ice cream clinging to the surface of the treated packages had a flavor not unlike the ice cream contained in the rest of the package.

Shrinkage

Shrinkage of ice cream manifests itself as a loss of volume, in which the ice cream pulls away from the walls of the container and, in some cases, sinks to a lower level. Dahle et al. (1947) has presented evidence showing treated

TABLE II
AMOUNTS OF ICE CREAM ADHERING
TO VARIOUS CONTAINERS

Container	Amount of Deposit
Untreated cylindrical	+++
Glassine cylindrical	+
Untreated tub	+++
Paraffined tub	++
Untreated pail	+++
Paraffined pail	+
Paraffined square	+
Untreated nestyle	+++
Vinylite nestyle	+
Paraffined nestyle	+
Pliofilm bag	+
Cellophane bag	++++

paper containers to be resistant to shrinkage. Previous experiments have shown treated containers to be resistant to moisture loss of packaged ice cream. Therefore, a comparison of the air transmission and water transmission rates of various packages under identical storage conditions should be a criteria upon which packaging materials are selected.

To test this theory, nine nestle containers obtained from a commercial manufacturer and coated with varying weights of plastic material were filled with ice cream and stored for four weeks at 7° F. in an ice cream cabinet. At the end of this storage period, the containers were weighed to determine the moisture loss.

Similar containers filled with ice cream were subjected to vacuum treatment for four hours; then stored in the same ice cream cabinet for seven days. At the end of this storage period, the vacuum-induced shrinkage was measured by filling the void between the ice cream and the container with cold water from a burette.

The values appearing in Figure 5 are the averages of triplicate samples of each container. The moisture loss is expressed as milligrams of moisture lost from each 100 grams

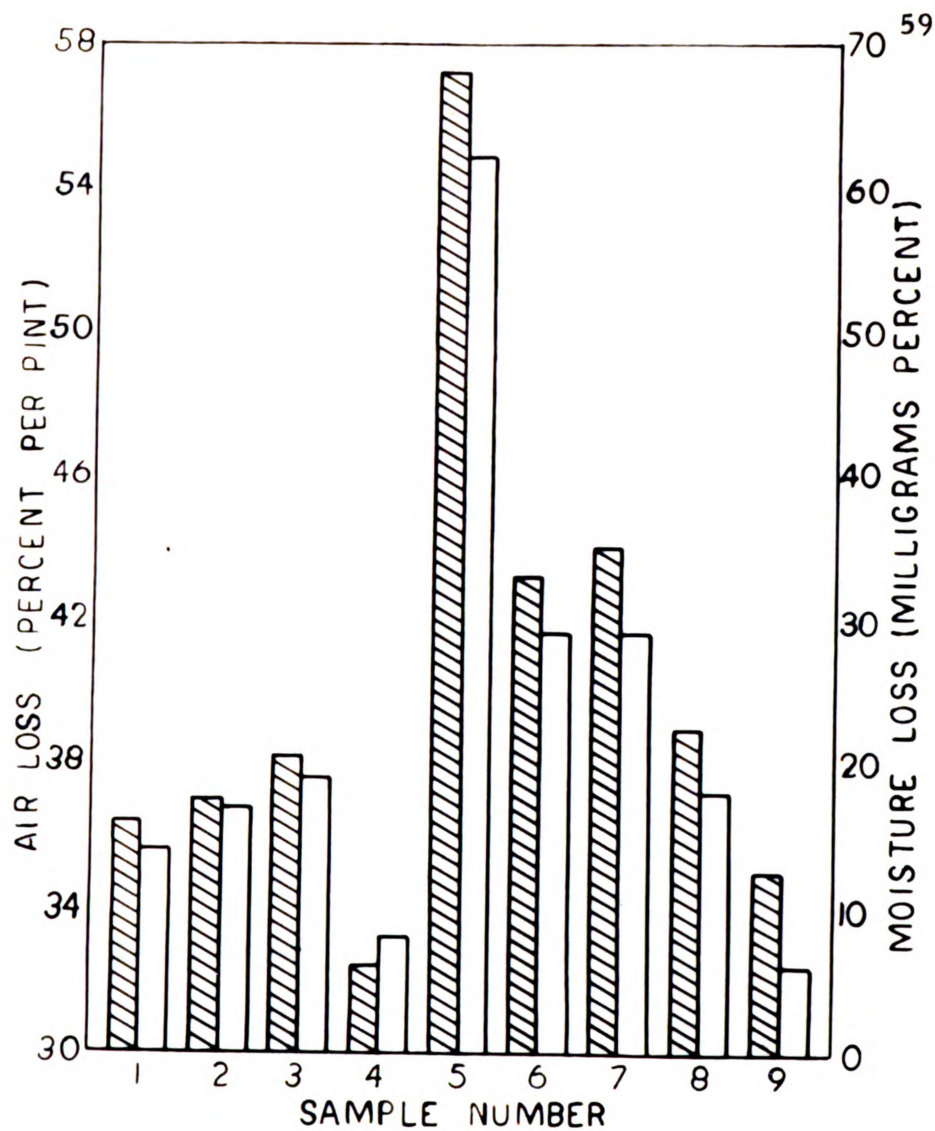


Figure 5. Comparison of air loss and moisture loss of ice cream in plastic coated containers. Hatched bar - air loss. Plain bar - moisture loss.

of ice cream. The percentage air loss recorded in this graph was obtained by dividing the calculated volume of air present in a pint of ice cream into the measured volume of air lost from the same pint of ice cream.

The code relative to the containers used in this study is as follows:

Sample	Treatment
1.	Plastic coating A (light weight)
2.	Plastic coating A (intermediate weight)
3.	Plastic coating A (intermediate weight)
4.	Plastic coating A (heavy weight)
5.	Untreated
6.	Plastic coating B (light weight)
7.	Plastic coating B (intermediate weight)
8.	Plastic coating B (intermediate weight)
9.	Plastic coating B (heavy weight)

Of the two plastic coatings used in this experiment, coating A was slightly superior to coating B. Since both plastics were of a vinylite nature, the reason for the differences

noted is not known. Relative to the weight of coating necessary to retard moisture loss and vacuum-induced shrinkage, heavy coatings appeared to be the most effective. This observation is in accordance with results obtained when cartons are paraffined. Evidently, treatments that allow paper fibers to protrude are not satisfactory. It is imperative, therefore, that experiments be conducted until the optimum coverage is discovered. Actually, this necessitates another specification for containers, namely, optimum coverage per square inch with moisture-proofing material. Undoubtedly, this requirement would vary considerably with the type of paperboard and coating material used.

Both methods of rating containers relative to their moisture resistant and shrinkage resistant capacities indicated the untreated nestle to be sample number five. Both methods rated samples four and nine as being superior; they were the heavy weight coatings. Thus, packaging materials may be rated according to their moisture transmission and air transmission abilities.

Preliminary Moisture Determination

It has been shown by Meiser (1950) that the resistance of different types of ice cream containers to moisture transfer will vary. It was also shown in this study that coatings of paraffin and plastic materials differed in their resistance to moisture transfer.

Body and texture deterioration of vanilla ice cream in a linerless carton, as reported by Smith (1935), occurred after 135 days of storage at -6° F., but only in one of the many vanilla samples studied. However, Schricker (1935) noted that vanilla ice cream exhibited undesirable flavors in four weeks from the date of manufacture.

In order to determine the ability of paper cartons to retard moisture loss of packaged ice cream, an experiment was designed whereby the increase in total solids of the ice cream would be used as the criteria for the determination of moisture losses. The samples were also scored for flavor and body and texture to determine the effect of the containers, coatings, and length of storage on the quality of the ice cream. Two types of containers were studied (nestle and cylindrical), and three types of treatment (untreated, paraffined, and

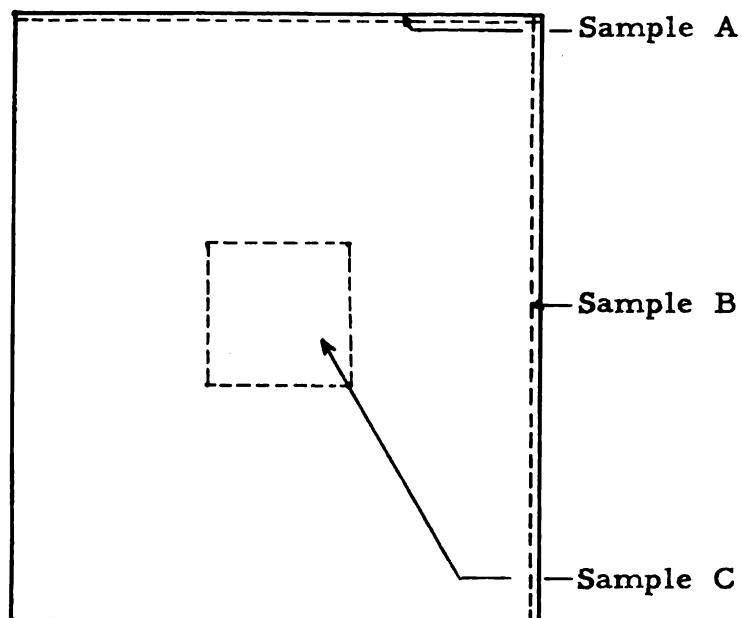
plastic-coated) were used on both cartons. The cartons were all manufactured commercially except the paraffined cylindrical carton, which was coated with paraffin in the laboratory.

The ice cream was packaged directly from the continuous freezer, and an analysis for total solids was made after hardening for 24 hours. At intervals of two and four weeks, duplicate samples of each type of carton were examined. One pint sample was scored for flavor and body and texture at three positions in the container, as shown in Figure 6. The duplicate pint sample was analyzed in triplicate for total solids at each of the three positions in the carton.

The determinations at the top, side, and core were made in order to illustrate where the moisture was being lost, and how this loss was affecting the quality of the ice cream. The results of this experiment are outlined in Table 3. The total solids data reported in the table is, in each case, the average of triplicate determinations.

The experiment was originally intended to cover a period of 16 weeks, but mechanical failure of the storage cabinet during the fifth week caused softening of the ice cream to the extent that it could no longer be used. Following a storage

FIGURE 6
POSITIONS OF SAMPLING



Sample A consisted of a horizontal $1/16$ inch layer of ice cream from a pint sample.

Sample B consisted of a vertical $1/16$ inch layer of ice cream immediately adjoining the side walls of the container. In cases where the ice cream adhered to the walls, this ice cream was included in the sample.

Sample C was taken from the center of the ice cream mass.

TABLE III*

PRELIMINARY DETERMINATION OF MOISTURE LOSS
AND QUALITY DETERIORATION

Storage	Top			Side			Core		
	T.S.	B. and T.	Fla- vor	T.S.	B. and T.	Fla- vor	T.S.	B. and T.	Fla- vor
Paraffined Cylindrical Container									
Start	38.53	28.5	34.0	38.53	28.5	34.0	38.53	28.5	34.0
2 wk.	38.45	28.0	32.0	37.96	28.5	34.0	38.51	28.5	34.0
4 wk.	39.56	28.0	32.0	39.54	28.5	32.0	39.49	28.5	34.0
Unparaffined Cylindrical Container									
Start	38.53	28.5	34.0	38.53	28.5	34.0	38.53	28.5	34.0
2 wk.	40.73	28.0	34.0	38.99	28.5	34.0	38.65	28.5	34.0
4 wk.	40.91	26.0	33.0	38.64	26.0	33.0	38.64	27.5	33.0
Cylindrical Glassine Container									
Start	38.53	28.5	34.0	38.53	28.5	34.0	38.53	28.5	34.0
2 wk.	39.54	28.5	34.0	38.75	28.5	34.0	38.84	28.5	34.0
4 wk.	40.22	28.5	34.0	38.75	28.5	34.0	38.81	28.5	34.0
Paraffined Nestle Container									
Start	38.53	28.5	34.0	38.53	28.5	34.0	38.53	28.5	34.0
2 wk.	39.38	28.5	34.0	39.09	28.5	34.0	38.97	28.5	34.0
4 wk.	39.70	28.5	34.0	38.65	28.5	34.0	38.65	28.5	34.0
Unparaffined Nestle Container									
Start	38.53	28.5	34.0	38.53	28.5	34.0	38.53	28.5	34.0
2 wk.	42.86	27.0	34.0	41.79	28.5	34.0	39.13	28.5	34.0
4 wk.	42.71	25.5	33.0	41.54	25.5	33.0	38.75	26.0	33.5
Vinylite Nestle Container									
Start	38.53	28.5	34.0	38.53	28.5	34.0	38.53	28.5	34.0
2 wk.	39.55	28.5	34.0	38.75	28.5	34.0	38.68	28.5	34.0
4 wk.	39.67	28.5	34.0	39.56	28.5	34.0	38.96	28.5	34.0

* The abbreviations that appear in the table, and their meanings are as follows: T.S. - the percentage of total solids; B. and T. - the score for body and texture; Flavor - the score for flavor.

period of four weeks, however, several significant facts were observed.

The untreated containers were poorer packages than the treated ones, in that the ice cream exhibited gumminess at the top surface in two weeks and at the sides in four weeks. The ice cream packaged in untreated nestle containers showed the greatest increase in total solids, and also lost the most in scores for flavor and body and texture. The paraffined and plastic-coated containers could be grouped together, since both exhibited about the same protective properties. These cartons were vastly superior to untreated cartons. Further distinction between the plastic-coated and parffined containers would be unjust, since no attempt was made to standardize such factors as: weight and porosity of paper; thickness of coatings; and tightness of the lids.

A pronounced increase in total solids of the ice cream at the fourth week was noted on the horizontal surfaces of all cartons used in this study. The vertical surface of the ice cream, in all cases, exhibited increases to a lesser degree. Also, the points showing the lowest scores for flavor and body

and texture similarly showed the greatest increases in total solids.

One interesting observation relative to storage of ice cream in paraffined containers appeared in that the ice cream exhibited a pronounced oxidized flavor following two weeks of storage. It was discovered later that these cartons had been paraffined in a copper pail. Evidently, sufficient amounts of copper were dispersed within the coating to accelerate the development of an oxidized flavor.

Moisture, Flavor, and Body and Texture Deterioration

The previous experiment indicated that the nestyle containers permit greater moisture loss than cylindrical containers. Therefore, an experiment was designed using only the nestyle containers in the belief that a greater difference would be shown relative to the types of treatment. The following three treatments (all containers manufactured commercially) were used:

1. Untreated control.
2. Heavy paraffin coating on the inside and outside.
3. Vinylite plastic coating on the inside.

Another modification of the previous experiment consisted of the use of two grades of mix. Five gallons of high-quality mix were obtained from a commercial ice cream manufacturer, with the purpose of determining whether the effect of container treatment and length of storage on the quality of the ice cream would differ between a high-quality mix and an average-quality mix.

The two 5-gallon batches of mix were frozen in the Cherry-Burrell batch freezer. The first and last portions of each batch were not used in the experiment. When 90 per cent overrun was reached, the ice cream was transferred in metal containers to a cold storage room, and the packages were filled immediately by hand and transferred to the hardening room.

After hardening for 24 hours, the ice cream was analyzed for total solids and scored for flavor and body and texture prior to transfer to the storage cabinet. At intervals of one, two, three, four, six, and eight weeks, duplicate samples of each type of ice cream and each type of container were examined. In one sample, triplicate total solids analyses were made at each of the positions shown in Figure 6. The other sample

was scored for flavor and body and texture at each of the positions. The results of the experiment are shown in Tables IV and V.

Moisture loss, the reciprocal of an increase in total solids, was almost identical for the two ice creams packaged in paraffined and plastic-coated nestyle containers. However, the better quality ice cream lost the greater amount of moisture when packaged in untreated nestyles. The reason for this discrepancy is not known.

The two mixes used in this study maintained their initial flavor score during the first two weeks of storage. Thereafter, the rate of deterioration was greater in the better quality mix, due to the higher initial score of the ice cream. The paraffined and plastic-coated containers protected markedly the flavor of the high quality ice cream, but offered little protection to the other mix. Of the three containers and two mixes studied, the horizontal surface exhibited the greatest decrease in flavor score.

The treatment of the vertical surface of the cartons had a decided influence upon the amount of moisture retained within the packaged ice cream. Both the paraffined and plastic-coated

TABLE IV*
DETERMINATION OF MOISTURE LOSS
AND QUALITY DETERIORATION
(Mix 1)

Storage	Top			Side			Core		
	T.S.	B. and T.	Fla- vor	T.S.	B. and T.	Fla- vor	T.S.	B. and T.	Fla- vor
Unparaffined Nestle Container (unparaffined lid)									
Start	39.56	28.0	39.5	39.56	28.0	39.5	39.56	28.0	39.5
1 wk.	44.15	28.0	39.5	41.22	28.0	39.5	40.25	28.0	39.5
2 wk.	42.96	28.0	39.5	41.02	28.0	39.5	40.29	28.0	39.5
3 wk.	42.31	26.0	38.5	42.86	27.0	39.0	40.34	28.0	39.0
4 wk.	50.65	25.0	37.0	46.60	26.5	38.5	39.77	28.0	38.5
6 wk.	43.99	25.0	35.5	53.77	25.0	37.0	40.34	27.0	38.0
8 wk.	50.38	25.0	35.0	71.24	24.5	36.0	40.23	25.0	37.0
Paraffined Nestle Container (lid lined with moisture-resistant paper)									
Start	39.56	28.0	39.5	39.56	28.0	39.5	39.56	28.0	39.5
1 wk.	43.16	28.0	39.5	39.88	28.0	39.5	40.11	28.0	39.5
2 wk.	41.39	28.0	39.5	39.81	28.0	39.5	39.89	28.0	39.5
3 wk.	41.72	27.0	38.5	39.82	27.0	39.0	39.98	28.0	39.5
4 wk.	42.89	27.0	38.0	40.01	27.0	38.5	40.12	27.5	39.0
6 wk.	42.20	27.0	38.0	39.79	27.0	38.5	39.96	27.5	39.0
8 wk.	42.33	26.0	37.0	40.16	26.0	37.5	39.93	26.5	38.0
Plastic-Coated Nestle Container (double thickness untreated paper lid)									
Start	39.56	28.0	39.5	39.56	28.0	39.5	39.56	28.0	39.5
1 wk.	42.38	28.0	39.5	39.42	28.0	39.5	39.99	28.0	39.5
2 wk.	43.48	28.0	39.5	39.71	28.0	39.5	40.02	28.0	39.5
3 wk.	44.52	26.0	38.5	39.78	27.0	39.0	39.99	28.0	39.0
4 wk.	47.23	25.0	37.5	40.02	26.5	38.5	40.02	27.5	39.0
6 wk.	46.04	25.0	37.0	40.01	26.0	38.0	40.06	26.5	39.0
8 wk.	45.68	24.5	36.0	40.47	25.5	37.0	40.06	25.5	38.0

* The abbreviations that appear in the table, and their meanings are as follows: T.S. - the percentage of total solids; B. and T. - the score for body and texture; Flavor - the score for flavor.

TABLE V*

DETERMINATION OF MOISTURE LOSS
AND QUALITY DETERIORATION
(Mix 2)

Storage	Top			Side			Core		
	T.S.	B. and T.	Fla- vor	T.S.	B. and T.	Fla- vor	T.S.	B. and T.	Fla- vor
Unparaffined Nestle Container (unparaffined lid)									
Start	40.09	28.0	38.0	40.09	28.0	38.0	40.09	28.0	38.0
1 wk.	41.86	28.0	38.0	40.66	28.0	38.0	40.26	28.0	38.0
2 wk.	41.99	27.5	38.0	40.78	27.5	38.0	40.26	28.0	38.0
3 wk.	42.37	26.5	37.0	42.99	26.5	37.5	40.38	27.0	37.5
4 wk.	44.99	26.0	36.0	41.22	26.5	36.5	40.13	27.0	37.5
6 wk.	43.55	25.0	36.0	44.94	25.5	36.0	40.44	27.0	37.5
8 wk.	43.13	25.0	35.0	61.81	25.5	35.5	40.45	26.0	37.0
Paraffined Nestle Container (lid lined with moisture-resistant paper)									
Start	40.09	28.0	38.0	40.09	28.0	38.0	40.09	28.0	38.0
1 wk.	41.23	28.0	38.0	40.02	28.0	38.0	40.31	28.0	38.0
2 wk.	41.77	28.0	38.0	40.09	28.0	38.0	40.34	28.0	38.0
3 wk.	41.83	27.5	37.5	40.23	28.0	37.5	40.38	28.0	37.5
4 wk.	43.59	27.5	36.0	39.91	28.0	36.5	40.31	28.0	37.0
6 wk.	44.94	26.0	36.0	40.34	26.5	36.5	40.50	27.0	37.0
8 wk.	42.42	26.0	36.0	40.73	26.0	36.0	40.53	26.0	37.0
Plastic-Coated Nestle Container (double thickness untreated paper lid)									
Start	40.09	28.0	38.0	40.09	28.0	38.0	40.09	28.0	38.0
1 wk.	42.05	28.0	38.0	39.76	28.0	38.0	40.18	28.0	38.0
2 wk.	42.73	28.0	38.0	40.01	28.0	38.0	40.31	28.0	38.0
3 wk.	43.38	27.0	37.0	40.18	27.5	37.5	40.49	28.0	37.5
4 wk.	47.24	26.0	36.0	39.85	26.5	36.5	40.65	27.5	37.0
6 wk.	44.18	25.5	35.0	40.22	26.0	36.0	40.63	26.5	37.0
8 wk.	44.23	25.5	35.0	40.57	25.5	36.0	40.41	26.0	37.0

* The abbreviations that appear in the table, and their meanings are as follows: T.S. - the percentage of total solids; B. and T. - the score for body and texture; Flavor - the score for flavor.

containers afforded excellent protection at this position. However, the horizontal surface of the ice creams packaged in treated containers was not afforded this protection in that this surface showed marked increases in total solids, and also showed the first signs of deterioration of flavor and body and texture. The results for the top surface varied considerably, however, as to moisture losses between periods of storage. This is probably due to variations in the tightness of lids, which allowed greater dehydration where lids fit loosely. It may be concluded that container lids manufactured for paraffined and plastic-coated containers are inferior to the body of the carton. Further experimentation as to bettering these closures must be conducted.

Following two weeks storage, the ice cream exhibited a slightly coarse body in the untreated cartons; this developed into gumminess at the sides during the third week. The ice cream in treated cartons showed icyness during the third week; this developed into a sandy texture during the sixth week. By the fourth week, the product in untreated cartons became objectionably gummy, coarse, and icy, while the ice cream in treated cartons remained saleable through the sixth week. At

eight weeks of storage, the ice cream in untreated cartons showed noticeable volume loss, with the ice cream pulled down from the top of the carton and away from the sides. This defect did not appear in either the paraffined or plastic-coated containers during the experimental period.

DISCUSSION

In the early part of this study, it was established that packaged ice cream would lose weight during extended periods of storage at cabinet temperatures. Further study indicated that the evaporation of moisture from the ice cream was the fundamental cause of this loss of weight. This is in agreement with the findings of Meiser (1950).

Moisture losses from rigid plastic containers and uncovered packages indicated that transpiration of moisture from packaged ice cream was due, in part, to a movement of total volumes of water vapor. In this method of moisture transfer, the vapor passed through the pores of the packaging material, through openings in the seams, and through the minute fissures allowed by an unsealed closure.

Another method of moisture transmission in packaged ice cream was indicated as occurring through sorption of moisture by the packaging material, with subsequent release of this moisture to the surrounding atmosphere. This mechanism, as previously outlined by Meiser (1950), was found to approach a steady rate of moisture transmission after saturation of the

package had been attained. Containers saturated prior to filling with ice cream exhibited a steady rate of moisture loss during storage, whereas unsaturated containers lagged for a period before a steady rate was reached.

Further indication of sorption as a mechanism of moisture transmission was shown through analysis of the ice cream immediately adjoining the wall of the container. This ice cream was found to decrease considerably in moisture content during extended storage periods, particularly when packaged in untreated paper containers. Since this portion of the ice cream had no opportunity to transmit moisture to other areas, it is reasonable to believe that the hygroscopic property of the package material accounted for the loss of moisture. Carson (1938) and McDermott (1941) have attested to the hygroscopic properties of packaging materials.

Observation of the amount of ice cream adhering to the package after peeling the container from the ice cream also indicated that sorption had occurred. It was found that containers allowing the greatest degree of moisture loss also retained the greatest deposit of ice cream on the peeled carton. Containers treated to prevent sorption retarded moisture loss

and decreased the amount of deposit on the peeled container.

Moisture losses initiated by sorption and evaporation accelerated flavor deterioration of ice cream, since containers which allowed the greatest degree of dehydration also permitted the greatest decrease in flavor score. This deterioration of flavor following storage was most pronounced on the top surface of the frozen product, and appeared in ice cream packaged in treated as well as untreated containers. Mixes compounded from ingredients of excellent quality offered little resistance to sorption and flavor deterioration, especially when packaged in untreated containers.

The deterioration of body and texture in the packaged ice cream appeared to be more closely related to the length of storage than to the amount of moisture lost. However, surface films did occur on the ice cream during extended storage. These films appeared in all the containers studied, although the cartons differed as to the severity of the film and the length of storage required for this defect to appear. The surface of the ice cream in untreated containers exhibited a slight gumminess after three weeks of storage; whereas, the

treated containers required a storage period of six to eight weeks before gumminess was discernible. Following eight weeks storage, the surface of the ice cream in untreated containers exhibited the tough, leathery film that was noted by Smith (1935) and Meiser (1950). This surface film was due to dehydration and was accelerated by loosely-fitting lids.

Severely dehydrated samples of ice cream, as noted by Meiser (1950), possessed a shrunken appearance. This defect was noted at eight weeks of storage in untreated cartons, but did not appear in the treated containers during the experimental period.

It was observed in this study that the length of storage of packaged ice cream was a limiting factor so far as moisture loss and flavor deterioration was concerned. Storage periods in excess of three weeks were required to produce changes in the initial flavor and body and texture scores of the ice cream packaged in untreated containers. Similar results were obtained with packages coated with protective materials, although there was a tendency for these cartons to resist these changes during longer storage periods.

Air circulation affected adversely the retention of moisture within the ice cream. In several experiments, the upper horizontal surfaces of containers which were exposed to the air within the cabinet exhibited greater moisture losses than did the vertical and lower horizontal surfaces, which were sheltered from air circulation by neighboring packages. An attempt to estimate these losses indicated the top surface of an untreated cylindrical container to be losing 0.149 grams of moisture per square inch following eight weeks of storage, as compared to losses of 0.129 and 0.065 grams per square inch for the vertical and bottom surfaces, respectively.

Variations in the amount of moisture lost from the top surface of ice cream stored in similar containers were observed. These variations were of such a magnitude as to eliminate errors in sampling and measurement as a possible cause, thus it was believed that poor-fitting closures were responsible for the differences encountered. It is possible that two containers identical in other respects, will vary greatly as to the tightness of their closures.

Since the original intent of this experimentation was to determine the point of greatest dehydration in ice cream

containers, and the effect of this desiccation upon certain physical properties of the frozen product, one might question the validity of advancing theories as to means of retarding moisture losses in paper containers. However, it is apparent following re-examination of the data and literature cited, that improvement in the design of container lids will do much toward retarding moisture loss in ice cream.

Also, newer and better packaging materials may be used in the fabrication of these lids as well as the container proper. A wide variety of these packaging materials are being developed for use in the frozen foods industry and should be investigated as to their adaptability to ice cream packaging. The ice cream industry has almost ignored the importance of a "water-vapor proof" closure seal; whereas, the frozen foods industry, in its few years of development quickly recognized this fact.

Considering the limited data obtained in these experiments, it appears that much investigational work remains to be done on the behavior of ice cream packages and packaging materials at low temperatures. Ultimately, the establishment of packaging specifications would appear desirable. At any rate, since the retention of quality and food value of ice cream

during handling and storage is dependent upon efficient protection against dehydration, the problem is of immediate importance to manufacturers, distributors, and consumers of ice cream. It is possible that the future of the ice cream industry will be affected considerably by the progress of packaging.

SUMMARY AND CONCLUSIONS

1. Packaged ice cream lost weight during extended periods of storage at cabinet temperatures.
2. Evidence was advanced to show that the evaporation of moisture from ice cream was the fundamental cause of the weight loss.
3. The transpiration of moisture from packaged ice cream was due, in part, to the movement of total volumes of water vapor through apertures provided by the pores, seams, and unsealed closures of the containers.
4. Another mechanism of moisture transmission in packaged ice cream was sorption of moisture by the packaging material, with subsequent release of this moisture to the atmosphere surrounding the container.
5. The greatest loss of moisture appeared on the upper horizontal surface of the packaged ice cream, thus extended storage periods resulted in the formation of pronounced surface films on this surface.

6. Storage periods in excess of three weeks produced discernible flavor deterioration in ice cream.
7. The "peel test" was a crude but practical method of rating packaging materials.
8. Plastic containers and cartons coated with moisture-resistant materials such as paraffin and plastics resisted desiccation and flavor deterioration in packaged ice cream.
9. Containers retarding moisture losses also retarded shrinkage.
10. Loosely-fitting container closures are believed to be the cause of variations observed in the quality and moisture content of the top surface in moisture-resistant containers.
11. Improvement is needed in the design of container lids on all cartons used in this study.
12. Much investigational work remains to be done on the behavior of ice cream packages and packaging materials at low temperatures.

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