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The relative importance of air, steam, and carbon dioxide as leavening gases in cakes made with different types of fats

Maude Pye Hood
Iowa State College

THE RELATIVE IMPORTANCE OF AIR, STEAM, AND CARBON DIOXIDE AS LEAVENING GASES IN CAKES MADE WITH DIFFERENT TYPES OF FATS

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Maude Pye Hood

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TABLE OF CONTENTS

INTRODUCTION

Good aeration of cake batter has long been considered of paramount importance. Prior to the use of baking powders in batters and doughs, the pound cake type, in which leavening was entirely dependent upon the air incorporated in the batter and steam from the vaporization of moisture in the ingredients, prevailed. Eight to twelve eggs, *i.e.*, a pound of eggs, leavened a pound of flour. Today more flour by weight than egg may be used, and the extra leavening needed is furnished by carbon dioxide gas, usually from baking powder. Other necessary adjustments in the formulas vary widely.

Fats for use in cake making have been selected primarily for their creaming properties, that is, their ability to form a stable network to entrap air. Some fats possessing high creaming properties are adaptable to various methods of mixing cake batters. Other fats of the oily type yield light and palatable products from only a limited pattern of mixing. Investigations of distribution of fat of different types in plain cake by Minard (36), Myers (39), and Morr (38) have shown characteristic variations in fat distribution with different types of fat. Their studies of methods of combining ingredients have shown the fat distribution of soft or oily fats to be more affected by method than the distribution of the more plastic fats. In this study the method selected was

Buel's (12) conventional-sponge method which has been shown (34, 36, 38, 39) to be suitable for the three types of fats used. The method was modified so that from each mix cakes were leavened (1) by steam alone, (2) by steam and air, and (3) by steam, air, and carbon dioxide gas from baking powder.

This investigation was undertaken to determine the effectiveness of the leavening gases, air, steam, and carbon dioxide gas, and to study the influence the type of fat used in the cake has on the incorporation and retention of the leavening gases. The three types of fat used were hydrogenated lard, butter, and oil. Dunn and White (20) have reported that steam cannot materially increase the volume of cake during baking unless air pockets are present into which the steam may vaporize. Thus another object of the study was to determine the leavening power of steam when little or no gas is present in the cake batter.

Evidence from previous studies indicates that certain qualities in cake batter are indices of quality in the finished product. Some of these have been chosen in this study as means of measuring the effects of leavening agents with different fats upon the cake quality. Hence in cakes made with three fats using three different leavening agents a study has been made (1) of the creaming qualities of fats, (2) of the specific gravity, viscosity, and electrical conductance of the batters, and (3) of the percentage of leavening contributed by each gas. These factors have been interpreted in terms of their effects on cake volume and palatability.

REVIEW OF LITERATURE

There has been little in the literature on the structure of batters and doughs during recent years. With the initiation of the flour enrichment program, emphasis shifted to vitamin retention studies and methods of determining the vitamin content of baked products. Prior to this period, interest was being manifested in the cell structure of baked products.

Leavening Agents

Baker and Mize (4) made a study of the conditions under which gas cells originate in bread dough and the manner of controlling their retention. They found that when a no-time dough is mixed in a vacuum the yeast is incapable of creating gas cells in sufficient number to produce good bread. In the presence of only a few cells the gas produced by the yeast diffuses into them without the creation of new cells. The gas occluded in the flour or beaten into the dough during an early stage of mixing was of little importance as compared to the latter portion of the mixing period. During this period all of the gas required to initiate the gas cells producing the bread texture can be occluded. By freezing dough they showed that the cells which formed the texture of bread were all present when the dough was placed in the baking pan. Differences in texture were accredited to coalescence of the cells during molding, proofing, or baking.

Dunn and White (20) investigated the influence air incorporated in the batter has on the volume of the finished cake. They estimated that approximately half of the increase in volume of a lean pound cake is due to the thermal expansion of air. In their calculation, however, the initial quantity of air incorporated in the batter was included in volume due to air expansion. When air in their cakes was completely exhausted, the resulting batter was described as a "custard-like cream," and there was no volume increase during baking. They found that even when a very small amount of air was occluded in the batter it resulted in a definite increase in cake volume. Results, when an evacuated batter was remixed to incorporate air, showed a reasonably good cake but with decided evidence of overmixing.

In Barmore's (7) investigation of the effects of altitude on evaporation and on the internal cake temperature of angel food cakes, he showed that increased temperature differences between the cake and the oven were dissipated by increased evaporation rather than an increase in the internal temperature of the cake. From an analysis made to determine how much evaporation was from the crust and how much from the interior of the cake he reported that all moisture loss occurred in the outer one-centimeter layer. Barmore showed that of the 1,120- to 1,620-milliliter increase in volume during baking only 350 milliliters could be attributed to the expansion of air, and the remainder of the expansion was due to steam. This increase in volume due to thermal expansion of air was from 20 to 30 per cent of the maximum volume the cake reached and approximately 83 per cent of the final cake volume. Barmore points out that a large amount of steam and air is lost during the baking but what per cent of each is not known. He postulates that the water vapor causing the expansion came from the sides and bottom of the cake and hence must pass through the main part of the cake to escape.

Barackman and Bell (6) investigating the temperature reached within batters and doughs during baking reported,

> . . . . baked products characterized by soft, spongy crumb do not attain internal temperatures over that of boiling water; only sufficient water is evaporated so that they will retain their cell structure when cooled.

Crusts of the baked products rose above 100° C as dehydration of the dough colloids proceeded. The rate at which the internal or crust temperature was reached was influenced by the size of the test products, the oven temperature, the ingredients used, and the character and shape of the pan. A white layer cake was tested in a 365° F oven, and the internal temperature reached 100° C in approximately 30 minutes. There was no increase in temperature during the remaining three minutes of baking.

In a study made by Perel'miter (43) the heat capacity and thermal conductance of sweet cakes and crackers were measured. It was found that as surface area (porosity) increased during baking heat capacity and thermal conductance decreased. High initial moisture necessitated longer baking, and shape also influenced the baking time. Sugar and fat in the dough weakened the gluten effect thus decreasing the water-absorption capacity and baking time. Cake analysis by zones showed progressively increasing water content from the outer surface to the center. In the sweet cakes the internal temperature reached 102° C and the crust temperature 148° C.]

Elion (21) emphasizes the importance of properly balancing the two factors gas-production and gas-retention in breadmaking. Good gas-production must be accompanied by good gas-retention during the period the gas is available. It seems reasonable that proper batter or dough development in other baked products at the time carbon dioxide is evolved would favor good gas-retention.

The results of a study by Noble and Halliday (41) showed that during the mixing of a simple batter a large proportion of the gas evolved is lost. In a mixing period just long enough to produce a smooth batter there was only slightly less loss of gas than in a period twice that length. The proportion of total gas evolved that was lost in mixing varied with the type of baking powder.

Barackman (6) investigated the distribution of carbon dioxide available from baking powders and found that loss during the mixing varied with the type of acid used in the baking powder. This loss is reflected in the volume of the baked product. Of the gas evolved during mixing about 70 to 80 per cent is lost. The carbon dioxide dissolved or adsorbed in the batter, and that made available from unreacted soda with the application of oven heat, are effective in expanding the dough during baking. In discussing his results Barackman says,

> . . . a variable of importance which has received little attention is that of the effect of residual salts of baking acid reactions as influencing not only the rate of reaction but also the colloidal properties of the doughs or batters, and finally, the results.

Fats

Properties affecting shortening power

In the studies given to various fats and their roles in baked products attention has been directed to the physical and chemical properties of the fats as well as the behavior of the fats in the baked products. The work of Langmuir (30) and of Harkins *et al.* (26, 27) regarding the molecular structure at interfaces is appreciated in any study centering around the phenomena at interfaces, as is the study of the colloidal structure of cakes. Briefly, the fundamental theory they developed is that of molecular orientation in which molecules are said to be oriented at surfaces and dineric interfaces in such a way as to reduce the surface energy or interfacial tension to a minimum. When an organic liquid and water make an interface, the polar group turns toward the water and the non-polar or organic radical turns toward the organic liquid. Langmuir (30) showed the wetting or spreading of oil on water to be due to the attraction of the polar groups of the oil for the water. The presence of a double bond as in oleic acid increased the area covered per molecule. However, linoleic acid with two double bonds does not proportionately increase the area covered, probably because the double bonds attract one another instead of the water. Harkings, Clark and Roberts (26) found the adhesional work of an organic liquid for water increased as the polar groups in the liquid increase; hence the presence of double bonds increases the adhesional properties of a fat.

In a review of the action of shortenings and the causes of differences in the shortening powers of various fats, Platt (45) designated plasticity and percentage of unsaturated glycerides as factors of prime importance in shortening power. He says that fats possessing plasticity at the temperature of mixing are mobile enough to extend through the dough yet firm enough that the film does not run together and out of the dough. It is logical that the increased spreading power of unsaturated glycerides would give increased shortening power. Platt pointed out that converting the iodine numbers into percentages of unsaturated glycerides would give some indication of the shortening power of a fat.

The shortening effect of fat Platt attributed to the fact that it is not wetted by water and hence, as it extends throughout the dough, it prevents hydrated particles' forming firm contact with each other and thus weakens the structure, *i.e.*, makes it short and tender.

Baker and Mize (4) 1942 observed that liquid fats did not improve bread quality as did semi-solid fats. Upon investigating the cause of this difference they found that the physical state of the fat was a determining characteristic. They suggested that when liquid fat is used the cell structure is so porous at points where the fat is located that gases in the dough can escape without rupturing the cell structure; whereas with semi-solid or hard fats the cells are less porous, the escape of gas is prevented, and the force of expanding gases breaks the cell wall. The ruptured cell wall makes bread that is more permeable to air, more tender, and with larger loaf volume. They further state that effects obtained by the fats in bread are associated with the blending of the added fat with the natural fat of the flour. It is assumed that the semi-solid and hard fats are not completely emulsified and blended with the natural fats in the dough and remain in masses which weaken the dough film in spots. They feel that the theory of a lubrication effect of fats is untenable in view of the difference in the effect of the two types of fats, inasmuch as oils have excellent lubricating qualities.

Hornstein, King, and Benedict (28) made a comparison of the shortening values of some commercial fats and found prime steam-rendered lard ranked first in shortening value, one of the hydrogenated oils was almost as good, and all were equal to or excelled leaf lard. The butterfats (water removed) were high in shortening power especially at high temperatures. They found no correlation between the breaking strength of pastries and either the congealing points or the iodine number of the fats. Of the fat properties tested plasticity or consistency was the only one that correlated shortening power of fats. The workers suggested that the shortening power of a fat may depend either upon the amount of liquid glycerides present or upon the ratio of liquid to solid glycerides. Enough evidence existed, they felt, to invalidate the theory that unsaturation is a deciding factor in determining the shortening power of fats.

Creaming quality

In some cake formulas workers (47, 19) have found a positive correlation between creaming volume and finished cake volume. Other workers (36, 38, 39) using a different formula and a number of fats have found negative correlations between the creaming volume and cake volume. One determining factor may be the source of leavening. In formulas in which air and steam are the sole leavening agents, as in the pound-cake type of cake, the correlation between creaming quality and cake volume has been positive, whereas in cakes in which baking powder has been added the correlation has been negative, with wide variations.

Dunn and White (19) believed good creaming quality essential for good cake quality. They found that conditioning the fat by storage at 70° F for 200 hours yielded highest creaming volume and cake volume. They found quality of creaming and of cakes improved with finer granulation of sugar.

Workers (47) in the Procter and Gamble research laboratory emphasize the importance creaming has in relation to cake quality and cake volume. They show a striking positive correlation between creaming volume and cake volume in pound cake. The incorporation and fine distribution of air within the fat and sugar cream was given as one of the main purposes of creaming. A second major objective in creaming, as given, was the physical conditioning of the fat so it would be distributed more easily and thoroughly throughout the batter. Factors affecting the creaming volume obtained were temperature, creaming proportions, granulation of the sugar, and time and speed of creaming. For the fat used they found an optimum temperature range above or below which creaming volume decreased. The proportion of sugar and shortening, by weight, found to give best results in their experiments was two to one. They reported very finely granulated sugar of crystalline shape to give results superior to coarsely granulated sugar or powdered sugar. Temperature was found to influence the desirable speed for creaming; a higher speed was favorable to low temperature and a low speed essential for high temperatures. The Procter and Gamble workers recommended that creaming be carried on until a maximum abount of air was incorporated. Under the conditions of their experiment the fat reached maximum creaming volume in 25 minutes.

Farnham (22), working with two small electric mixers and using butter and hydrogenated lard, found that it required a longer period of mixing to obtain maximum creaming volume at lower temperatures than at higher temperatures up to 80° F where maximum creaming volume decreased. The time required to reach maximum creaming volume was found to be slightly less on medium speed than on low speed. The two mixers gave slightly different maximum creaming volumes, but the time required for each mixer to obtain its maximum creamed volume was the same.

Buel (12) reported a highly significant negative correlation between the cake volume and temperature, *i.e.*, increased temperatures resulted in reduced cake volume with all fats and by all methods. She found a non-significant relation between creaming volume and palatability score and between cake volume and palatability score.

Minard (36) stated that good creaming quality is essential for velvety cake. She reported a positive highly significant correlation between creaming volume and palatability score and between cake volume and palatability score. A significant negative correlation was reported between creaming volume and cake volume.

The work of Martin (34) and Morr (38) substantiated that of Buel and Minard in the relation of creaming volume to cake volume. All these workers used the same formula, and although some of the workers used more than one method of mixing the conventional-sponge method was common to all.

The Cake Batters

Method of mixing

It is recognized that changes in type or proportion of ingredients in cakes necessitate changes in method or extent of combining the ingredients. Liquid and soft fats are readily emulsified, and Lowe (32) suggested that egg tended to disperse these fats as an oil-in-water emulsion which resulted in a poor quality cake. Therefore methods were devised wherein eggs were added to the cake batter late in the mixing process instead of being added to the fat and sugar mixture.

Lowe and Nelson (33) in reviewing the data from four studies (12, 34, 36, 39) of different kinds of fats in plain cake concluded that for optimum results, method of combining ingredients, temperature of ingredients, and technique of the worker were factors which needed to be varied with each particular fat. They found lard to be "outstanding in its ability to impart a soft, velvety texture to cake." The method of mixing found to be most favorable to soft lard was one in which the egg or egg white was added late in the mixing process.

Buel (12) tested 35 methods of combining ingredients using a soft fat and selected six to use in testing the cake-making qualities of four fats. Of the six methods chosen and the four fats used the most favored cakes were made from prime steam-rendered lard, by the conventional-sponge method.

The texture of fat used, Minard (36) found, had less effect on the cakes when made by the conventional-sponge method than by any other method. Method of mixing and type of fat used has characteristic effects on the fat distribution in the cake as shown by microscopic examination. Butter was described as being more evenly distributed throughout the crumb than other fats. There were highly significant differences between the methods used and between the different fats used.

Myers' (39) and Morr's (38) work further confirmed the importance of the method of combining ingredients on cake quality. In Morr's work cakes containing oil and made by the conventional method were smallest of the cakes from the six fats investigated, whereas by the conventional-sponge method the oil cakes ranked second in volume. Butter was first.

Berrigan (9) obtained a batter of high viscosity and cakes of good quality and volume when an egg-white meringue was added at the end of the mixing process. She accredited this improvement to the elimination of an antagonistic reaction between egg and lard when the two were combined with other ingredients simultaneously.

There seems to be agreement that the physical state of the fat and the method of combining a particular fat with other ingredients in cake making is important although all of the conditions and causes do not appear to be fully explained. Butter is the fat which most generally produces superior quality cakes and which is most readily adapted to various methods of combining. Clayton (14) describes the physical structure of butter as "a solid system with a continuous fatty phase in which are dispersed fat globules, water globules, and air bubbles, all enveloped by hydrated protein." That then would appear to be the condition of the fat desirable for good cake.

That a water-in-oil emulsion of the fat is desirable in cake making is indicated by the growing use by commercial companies of emulsifying agents in fats used for baking purposes. Among these is a Danish invention patented in Sweden (48) which offers as a dough improver an emulsion of 70 parts fat treated with one and one-half to two parts of patent emulsifying agent and 30 parts water. A stable water-in-oil emulsion is formed. The emulsifying agent is a polymer or oxidation product of an oil containing linoleic or linolenic acid. Sodium or ammonium stearate, stearic acid, saponin, and glycerin are some of the emulsifying agents used. Several patents propose the use of Irish moss as the emulsifying agent. Dunham (18) has several patents which employ wheat flour or other starch material for the emulsion of 20 to 70 per cent cocoanut oil. Bennion (8) stated that milk serves as an emulsifying agent for confectionery articles using small amounts of fat.

Pink (44) reported studies on the relative phase volume on types of emulsions stabilized by magnesium oleate. The type of emulsion produced depends to some extent on the method of preparation and on the concentration of the soap. With suitable method and concentration emulsions containing 90 per cent water dispersed in benzene were obtained. When oil-in-water emulsions were formed a number of them underwent a reversal of type on standing.

An anonymous write (40) reported that oil-in-water emulsions made with a minimum amount of emulsifier and with a maximum particle size of the material being emulsified are termed "borderline" emulsions. The difference between "borderline" and stable emulsions as well as between oil-in-water and water-in-oil emulsions is shown in the building up of macroscopic films. "Films of oil-in-water emulsions are traversed by a network or honeycomb of the non-volatile portion of the aqueous phase. The oily film-forming material is held in these honeycombs. In water-in-oil emulsions of the border-line type a heterogeneous film formation is not noticeable. The film appears no different from the pure oil."

Grewe (24) made a study of the emulsion formed of creamed fat, sugar, and eggs. She obtained water-in-oil emulsions when the egg was added slowly to the fat-sugar mixture. Bailey and LeClerc (2) obtained a water-in-oil emulsion when milk and egg were added gradually to the creamed mixture. Grewe (24) described the creamed mixture as "a water-in-oil and air-in-oil foam."

Lowe (32) said there is a tendency for oil to be emulsified as oil-in-water emulsion in cake batters regardless of the method of mixing. Butter and hard fats may be partly emulsified as water-in-oil emulsion and partly as pools or films of fat. Both types of emulsions may be found in the same batter.

Viscosity

The viscosity of cake batter and the viscosity of various ingredients of the batter have been considered as indices of quality in the finished cake. Smith (49) reported to the Association of Cereal Chemists for the subcommittee on viscosity of cake flour. After considering data gathered over a two-year period the committee concluded that although the importance of viscosity as an index of the quality of flour when properly considered as one of many interrelated factors was recognized, the viscosity test for flour of and by itself was meaningless in predicting the score of a test cake.

Platt and Fleming (46) give viscosity minor importance in the shortening power of fats. They say "a very viscous shortening would evidently spread less easily through the dough (cookie dough) but would run out of the dough less readily."

Lisse (31) states that sols with smaller particles show a higher viscosity for a given concentration than do the coarser particles. The viscosity increases with concentration.

Batter viscosity has received favorable consideration as an index to superior cake quality. Lowe (32) states that thin runny batters produce inferior cakes while more viscous batters produce good cakes. Between these two extremes, she states, batters of varying degrees of viscosity can be produced using the same proportions and the same ingredients.

Baeder (1) used lard as a fat in cake studies and reported that with a change in method of mixing but identical weights of ingredients the viscosity of the batter was changed. A comparison of the type of batter with the finished cake indicates that viscosity was directly related to the quality of the finished cake. "An increase in viscosity of batter was invariably associated with cakes of superior quality."

Collins (17) typed the cake batters made in her study according to the type of emulsion that appeared to have been formed in the batter. The type of emulsion present in the batter was indicated by electrical resistance, dye solution, and microscopic study of the fat distribution. She reported a correlation between the viscosity of the batter and the type of emulsion. Low viscosity was associated with oil-in-water emulsions and high viscosity with water-in-oil emulsions. The high-viscosity batters were described as having "many small gas bubbles grouped in clusters; while in batters of low viscosity there are fewer gas bubbles, larger and less uniform in size and scattered irregularly throughout the batter."

Beyer (10) reported that viscosity was well correlated with cake quality in cakes made with soybean oil. Batters of higher viscosities produced higher-scoring cakes. The oil appeared to be dispersed in very small globules in batters which produced poor cakes.

Carlin (13) states that the data of his study are not sufficient to imply a correlation between batter viscosity and size frequency of dispersed fat globules but that results of the study indicate that lower viscosity may, especially when obtained by means of a finer dispersion of fats (use of emulsifying agents), produce cakes of increased volume.

Fat distribution

Several histological studies of cakes have been made by students (36, 38, 39) in Lowe's laboratory. These revealed characteristic differences in fat distribution in cakes baked under different conditions. The factors reported as having affected the pattern of fat distribution were method of combining ingredients, temperature of ingredients, and the kind of fat used. Minard (36) reported a more finely divided and evenly distributed pattern with butter than with lards. She found a similarity in the fat distribution in cakes made by two methods, the conventional and the conventional-sponge. When cakes were made by the modified conventional method, the fat appeared to be spread more thinly. Myers (39) studied cakes mixed at 25° C and at 30° C and found greater concentration of fat at the air-crumb interface in cakes mixed at 25°, while those mixed at 30° exhibited small fat particles more finely dispersed within the crumb. The conventional-sponge method seemed to accentuate the differences shown at the two temperature levels. Even distribution of the fat at the air-crumb interface seemed to accompany high scores in cake texture.

1939

Lowe and Nelson (33) summarized the effect of fat distribution on cake score and concluded that fat distribution was an important factor affecting cake quality but not the sole determining factor. They suggested that probably the dispersion of fat in a cake is heterogeneous but, in general, when the prevalent pattern of the cakes studied was one of finely and evenly distributed fat at the air-crumb interface the texture and velvetiness of the cake were enhanced.

A histological study of cake sections by Morr (38) showed characteristic differences between fats when mixed by the conventional-sponge method. Butter cakes, which constituted the highest scoring group, had the fat finely divided throughout the crumb with very little fat at the air-crumb interface. Hydrogenated lard cakes had more fat at the air-crumb interface and around the starch granules. The fat was not as finely dispersed as butter. The cakes made with oil showed a heavy margin of fat at the air-crumb interface with no evidence of starch granules embedded in the fat, and very little fat was exhibited in the crumb.

In a study of the structure of cake batters and the structural changes which occur in baking Carlin (13) made microscopic examinations of the batter using a microscope equipped with a heating stage in order that the changes in batter structure might be observed. Both pound cakes and white layer cakes were studied. He described the dispersion of fat as being in small lakes or pools with air bubbles suspended in the fat. The higher the degree of dispersion of the fat, the better was the volume of the finished cake. He observed that very few, if any, new gas cells were formed when baking powder was added to the cake formula. The carbon dioxide evolved seemed only to enlarge the air cells already present and not to form new cells.

During baking the fat melted and the air spaces moved into the aqueous-flour phase, apparently moving in a definite convection pattern until near the end of the baking when the movement was described as being "violent and without direction."

Bound water

Kuhlmann and Golassowa (29) stated that flour colloids possess the capacity of increasing their water-binding capacity when made into a dough. This capacity is further increased during baking until about 81-87 per cent of the total water is bound. They tested the effect of certain factors on the capacity of flour to bind water and found that the sponge method of mixing bread dough, scalding, addition of maltose, or addition of whey increased the water-binding capacity of the dough. These factors decreased the loss by evaporation during baking and also decreased rate of staling.

Bailey and Skovalt (3) used cryoscopic methods for investigating the amount of water bound in a simple dough and estimated an average of 51.4 per cent. Later Vail and Bailey used a slightly different technique. They estimated 35.5 per cent of bound water; calculated on the basis of bound water held per unit of weight of dry matter, this amounted to 28.6 per cent hydration capacity for the dough.

Electrical Conductance

Clayton (15) proposed an electrical conductance method of determining emulsion phases based on the fact that an oil-in-water type of emulsion will show electrical conductivity whereas water-in-oil, having oil (an electrical insulator) as the continuous phase, will not conduct electricity. Bhatnagar (11) used the method with success for the determination of emulsion types in petroleum oils; also for the detection of reversal points in emulsion reversal studies. Palmer (42) employed the conductivity method in his studies of the churning of cream to butter. He showed that the resistance of cream during churning increases to a maximum, remains stationary for about 30 minutes, then suddenly falls. He postulates that the maximum resistance marks the completion of a gradual inversion of the phase and that the "breaking" of the butter releases the buttermilk and restores the original electrical conductance.

Clayton (15) stated that the churning of cream causes the incorporation of air and the formation of a foam. Then quite suddenly the foam collapses and almost simultaneously the butter nuclei grow to macroscopic size. He quoted Sudel as showing that "prior to the foam collapsing, nearly all the fat had accumulated in the foam and the liquid menstrum had become very poor in fat."

Since air bubbles and fat globules may both be electrical insulators, the present investigator wonders if this is not evidence that the increase in resistance measured by Palmer was more likely due to increase in air bubbles incorporated than to a gradual inversion of phases. The approximate 30-minute period of stationary value probably measures the length of time the protein envelope (liquid menstrum) can withstand the strain of being stretched its maximum amount before it collapses. It separates from the fat and air and suddenly shortens the path of current to the original value.

Montefredine (37) found that electrical conductance could be used successfully to determine the amount of water added to milk. He found a fixed relation between the electrical conductivity and the specific gravity of milk; a low specific gravity corresponded to a proportionate increase in electrical conductivity.

Taylor (52) measured the specific conductivities of a series of milks. He then separated the fat from the milk and the conductivity of the milk increased, due probably to increase in the concentration of the salts and to the removal of obstacles from the path of the ions. He found that the addition of a per cent of water corresponding to the amount of fat removed did not decrease the conductivity of the milk to its original value. The difference he explained as due to fat globules having an obstructing influence on the ions in their passage through the solutions.

EXPERIMENTAL PROCEDURE

Preliminary Investigation

Approximately 210 cakes were made in the work preliminary to this study. During the preliminary work details in method of mixing and in means of measuring and evaluating results were selected and adjusted, and the worker's techniques brought to an acceptable degree of standardization. Data for this study were started when the data of the preliminary work indicated conditions were sufficiently controlled for variances within the procedure to be reasonably low.

Procedure

General plan

The work was conducted in a small laboratory where the temperature was held at 25.3° C ±2.5° C. Three groups of 24 cakes each were made from three types of fat, (1) butter, (2) oil, and (3) hydrogenated lard. Each group was subdivided into three groups in which different leavening agents were used, namely (1) air and steam, (2) carbon dioxide, air, and steam, and (3) steam alone. Eight replications of the series make a total of 72 cakes in the study. Two fat groups of three cakes each were baked each day. The order of the fats was rotated so that there were eight replications in the study. The position of the fats within a replication was assigned at random.

Formula, Method and Leavening Agent

The cakes were all made by a modification of the plain cake formula given by Lowe (32). The method of mixing followed was the one described by Buel (12) as the conventional-sponge method. Each mix represented a whole recipe which was divided into three portions at the necessary stages of weighing and mixing in order that each of the three cakes might have a different leavening agent, *i.e.*, (1) air and steam, (2) air and steam plus carbon dioxide, (3) steam alone. The batters for the cakes leavened by air plus steam and by steam alone were mixed together as one batter throughout and at the end of mixing the air was removed for the cake leavened with steam alone. For the batter to which baking powder was added to furnish carbon dioxide one-third of the whole recipe of milk and one-third of the flour were weighed separately and baking powder was sifted with the flour. At the end of the creaming period one-third of the creamed mixture by weight was removed and reserved for the cake with baking powder. Likewise, one-third by weight of the whole-egg meringue was reserved for the baking powder cake.

Weighing and mixing

With the exception of the eggs, milk, and baking powder the ingredients were weighed and stored overnight in a constant temperature cabinet held at 26° C ±1°. The eggs, milk, and baking powder were weighed and brought to room temperature (25.3° C $\pm 2.5^\circ$) just prior to mixing. An electric mixer* with wire whip was used for creaming the fats with sugar and for making the meringue. The fat with salt added was creamed on second speed of the mixer for 30 seconds; then one-half of the sugar by weight was added by tablespoonfuls at regular intervals. Two brief stops were made during the 14-minute creaming period, one at the end of four minutes, by which time the sugar had been added, and one at the end of 10 minutes. At the time of each stop the mixture was scraped down from the sides of the bowl with a spatula and mixing then resumed. At the end of the creaming period data were taken for the determination of the creaming volume, and one-third of the mixture was reserved for the cake to which baking powder was added.

Meringue

A meringue was made of the whole egg and the remaining half of the sugar. The egg was beaten on third speed of the mixer to a consistency judged by the eye of the worker to be desirable. (It was found that the time to reach this stage varied from one minute, fifteen seconds, to three minutes, depending on the quality of the eggs. In some instances eggs selected for high Haugh units were used and the time was noticeably less than when eggs were not selected.) The speed of the beater was then reduced to second speed and

*Kitchen-Aide Model G.

the sugar added by tablespoonfuls at regular intervals. At the end of four and one-half minutes the meringue was scraped down from the sides of the bowl and then mixed for 30 seconds longer. The determination of the specific gravity of the meringue was made by weighing a measured volume of the meringue and dividing it by the weight of an equal volume of water. One-third by weight of the meringue was reserved for the cake with baking powder.

Addition of flour and milk

To the two-thirds portion of creamed fat-and-sugar two tablespoonfuls of flour was added and stirred by hand with a French balloon wire whip; two tablespoonfuls of milk was added and stirred 20 times; the procedure was repeated. Then one-half of the remaining flour and one-half of the remaining milk were added simultaneously and stirred 80 strokes with the hand whip. The last portions of the flour and milk were added and the batter stirred 90 strokes. Twenty-five folding strokes with the same wire whip were used to incorporate the meringue.

The cake batter

A measured volume (in milliliters) of the batter was weighed (in grams) to estimate its specific gravity. Line-spread measurement of the batter (to determine viscosity) was taken. The same amount of batter, 240 gms., was weighed into each pan with waxed paper fitted in the bottom. This batter was allowed to stand 11 ±1 minutes while the same procedure was followed in mixing the portion of batter to which baking powder was added. The only adjustment of the procedure for the smaller portion of batter was to add one instead of two tablespoonfuls each of flour and milk to the fat-sugar cream when addition of flour and milk was begun.

Small portions of each batter were reserved for use in measuring the electrical conductance. It was regrettable that batters for this measurement had to stand 40 to 50 minutes, but as all batters stood approximately the same length of time, the measurements were considered comparable.

Baking

Matched thermometers were inserted in the batters and held in place at approximately the center of the pans and one-half inch from the bottoms. The temperatures of the batters were recorded and the cakes baked in similar positions in the same oven at 185° C for 33 minutes. The oven was thermostatically controlled and also checked by a Centrigrade thermometer inside the oven.

Evacuating the batter

The remainder of the batter without baking powder was poured into a glass jar with a ground-edged mouth and on the jar was fitted the ground surface of a brass top with an outlet to which a rubber tube leading to the water aspirator was attached. (See Photograph I.) The vacuum was carefully applied intermittently to avoid loss of batter through the vacuum pump. When the sound of the pump indicated that the batter was giving up no more air, the vacuum was released. The same data were taken and the same baking procedure followed as for the cakes with air and with baking powder.

Data on cakes

The cakes were left in the pans until thoroughly cooled (32), then weighed, removed from the pans, and the volume measured by seed displacement method. With the aid of a miter box, slices one-half inch in thickness were cut and wrapped in waxed paper, stored in a tin cake box, and scored by five judges the next day - approximately 14 hours later. Other one-half-inch slices were used immediately after slicing for moisture absorption and sand tests.

Tests and Measurements

Specific gravity

The specific gravities of the meringue, the oil-and-sugar mixture, and the batter were computed from the weight in grams of a measure volume in milliliters. A small metal cup, the average weight of which when filled with distilled water at room temperature was 86.2 gms., was used for weighing the test materials, *i.e.*, meringue, oil-and-sugar mixture, and batters. For each measurement the cup was filled with meringue or batter, and leveled off by drawing the edge of a spatula across the top of the cup, and then weighed.

Creaming volume

The creaming volumes of the butter and of the hydrogenated lard were determined by alcohol displacement. Twenty-five grams of the fat sugar mixture was weighed on a square of waxed paper exactly three by four inches and immersed in 75 ml. of 95 per cent alcohol in a conical-shaped 125-ml. graduate cylinder, and the level read to the nearest 0.5 ml. The fat mix was held beneath the surface of the alcohol by pressing the same distance each time with a marked spatula. The displacement by spatula tip and waxed paper was a constant of negligible value and so was ignored in calculating the volume displacement. The difference between the initial volume (75 ml.) of alcohol and the volume reached when the mixture was immersed represented its creaming volume. After being drained thoroughly, the weighed portion was returned to the remainder of the creamed mixture.

The oil-sugar mixture was not of consistency to be handled as the plastic fats were; hence its specific gravity was computed as described above and therefrom its specific volume determined. The specific volume times 25 gms. gave the volume of a weight of the oil-sugar mix equal to that used in the other two fats. Care was taken not to let the oil separate in a layer on the surface of the mixture in order that the weighed portion be a representative sample of the mixture.

Computation:

$$\frac{86.2 \text{ ml. oil + sugar}}{92.7 \text{ gms. oil + sugar}} = 0.93, \text{ specific volume of oil - sugar}$$

0.93 x 25 gms. = 23.25 ml., volume of 25 gms. of the mix.

Line-spread

A method devised by Grawemeyer and Pfund (23) for determining the consistency of food products was used as a means of determining the viscosity of the cake batters. A flat glass plate was placed on a level surface over a diagram of concentric circles an eighth of an inch apart, the smallest with a diameter of two inches. Beginning with the second circle from the center, the circles were numbered consecutively beginning with one and progressing outward. A heavy metal ring two inches in diameter and three-eights inches deep was placed on the glass plate exactly above the circle of its own diameter. It was filled with the batter, leveled off with a spatula and carefully lifted straight up. The batter was allowed to spread exactly two minutes; then readings were taken at four approximately equidistant points marking the outer limits of the batter. The average of the four readings is the line-spread value. It represents the number of eighth-inch units the volume of batter has spread to in two minutes. Higher line-spread values then denote more fluid batter; hence the reciprocal of line spread would represent the viscosity of the batter.

Grawemeyer and Pfund compared line-spread with a precision penetrometer, a Stormer viscosimeter, and organoleptic scores as a means of measuring consistency and found the line-spread values to be comparable to the values by the other methods. Line-spread was used in this study because its simplicity gave the method the advantage of having the batters measured immediately after mixing.

Air factor

In order to determine the thermal change of the air in the batter during baking, a means was devised whereby two carefully matched centigrade thermometers could be inserted in the two batters that were baked simultaneously, viz., the batter with air and steam leavening and the batter with carbon dioxide from baking powder added for leavening. By recording the temperature of the batter as it was put in the oven and of the cake as it was taken from the oven it was possible to calculate the increase per milliliter of air due to thermal expansion of air.

Example of calculation:

Temperature of batter - 23° C

Temperature of cake - 102° C

Change per ml. of air (air factor) -

$$\frac{102 + 273 = 375^{\circ}A}{23 + 273 = 296^{\circ}A} = 1.26$$

Electrical conductance

The apparatus used to measure the electrical conductance of the batters (see photograph in Plate II) consisted of a battery of five Edison cells, a General Radio microphone hummer (audio oscillator), a tunable double telephone receiver, a Wheatstone bridge* and a glass cell with platinum electrodes approximately 6 x 12 mm. in size and 20 mm. apart.

The battery supplied a six-volt direct current which was changed to a 1000-cycle alternating current by the hummer. From the hummer the circuit went to the Wheatstone bridge and through the cell containing the batter. The earphones were connected to the galvanometer posts of the Wheatstone bridge. (See Photograph II.) The resistance of the Wheatstone bridge was balanced against that of the batter within 10 ohms. The null point was detected by low intensity of the tone in the earphones, and the reading of the resistance recorded.

No attempt was made to make an exact mathematical measurement of the conductivity of the batter system, but the

*Leeds and Northrup.

work was done on a comparative basis only. The cell was filled twice with each batter and two readings to the nearest 10 ohms were taken each time the cell was filled. An average of the four readings was used as the resistance of that batter. The batter conductance then is the reciprocal of its resistance.

In filling the cell with the batter to be tested, care was taken that no air was entrapped between the electrodes. Extreme care was exercised in cleaning the cell that the distance between the electrodes was not changed. The cell was alcohol-ether dried after cleaning.

Cake volume

The seed displacement method described by other workers in this laboratory (12, 34, 36, 38, 39) was used to measure the volume of the cakes. The cakes, cooled to room temperature, were weighed, removed from the pans, brushed free of loose crumbs, and placed in a tin box the capacity of which was 1120 ml. Rape seed was poured into the box at a constant speed from a constant height. This was accomplished by filling a funnel fitted with a plug with the rape seed and fixing it a definite height above the box, then removing the plug and allowing the seed to pour into the box with the cake. The seeds were leveled off by the same straight edge of the box cover each time a volume was taken. The same funnel at the same fixed height was used throughout the study. The box cover had a triangular hole in one corner. It was placed on the filled and leveled box and the seeds were poured into a second plugged funnel at a fixed height. From the second funnel seeds were allowed to run into a 1000-ml. graduate cylinder and the volume to the nearest milliliter recorded. The difference between the volume of the empty box and the volume of seed thus measured represented the volume of the cake.

Texture index

An objective test proposed by Swartz (51) was used to obtain an index of texture. Samples of cake for the tests were sliced one-half thick by means of a miter box and then cut with a circular cutter one and one-half inches in diameter. Adjacent surfaces of the two samples were sprinkled with fine, 40 mesh sand to thoroughly cover them. In order to remove the excess sand each sample was revolved two complete revolutions on a 45° angle inclined plane. The sample was then weighed and its weight recorded. Next the sample was inverted and given three staccato shakes. The force of the shakes was kept as nearly the same as possible. After the shaking had removed the sand held loosely within the cake cells the sample was again weighed and the difference between the two weights was taken as the texture index value. Values obtained from the two samples were averaged for the texture index of that cake.

Moisture absorption

Swartz's (51) test based on a correlation between good eating quality of cake and its ability to take up water rapidly was used as an objective measure of eating quality of cake. Two samples from each cake were cut in the same manner as for texture index, *i.e.*, rounds of cake one-half inch thick and one and one-half inches in diameter. Each sample was weighed to 0.1 gm., then conveyed on a two-tined fork and placed into a Petri dish containing 25 cc. of water at room temperature (25.3° C ±2.5°). The sample was allowed to absorb water for exactly five seconds, removed, inverted quickly onto the balance plate and weighed again. The difference in the two weights represented the water-absorbing ability of the samples. An average of the two sample values was taken as the water-absorbing quality of the cake.

Palatability scores

The cakes were scored for crumb or texture, tenderness, velvetiness, and eating quality. (Score sheet in appendix.) Five judges, either members of the Foods staff or graduate students in Foods, did the scoring. The cakes were scored the day after baking. Care was taken that each judge received the corresponding slice from each cake. Total scores of each judge for each cake were averaged for the palatability value of that cake.

Formula

The basic formula I given by Lowe (32) with her suggested modification of decreased amount of flour was used. Baking powder was omitted from all but one-third of recipe in which 2.6 gms. was used.

Fat	1/2 cup	112 gms.
Sugar	1 1/4 cups	300 gms.
Salt	1/2 tsp.	3 gms.
Eggs	2	96 gms.
Milk, whole	1 cup	244 gms.
Flour, cake	2 7/8 cups	284 gms.
Baking powder		8 gms. (see above)

Method of mixing (conventional-sponge)

(1) The fat and salt were creamed on speed two of the electric mixer for 30 seconds. Then half of the sugar by weight was added by tablespoonfuls and creamed for a total of 14 minutes.

(2) The egg was beaten on speed three for approximately one and one-half minutes, and then the speed was reduced to speed two and the sugar added by tablespoonfuls and beating continued to the end of four and one-half minutes. The mixture was scraped down and beaten for 30 seconds.

(3) Two tablespoonfuls flour was added to the fat and sugar mix and carefully mixed with 20 strokes, using a hand

balloon whip.

(4) Two tablespoonfuls milk was added and mixed with 20 strokes.

(5) Two tablespoonfuls flour was stirred in with 20 strokes.

(6) Two tablespoonfuls milk was stirred in with 20 strokes.

(7) One-half of the remaining milk and one-half the remaining flour were stirred in with 80 strokes.

(8) The remaining milk and flour were blended in with 90 strokes.

(9) The light whole-egg meringue was folded into the batter with 25 strokes of the hand balloon whip.

Selection and Storage of Materials

Flour

A carton of 24 two-pound boxes of cake flour* was purchased and kept in the Foods Department storeroom until needed. The boxes remained sealed until the day of weighing in order to keep the moisture content constant.

Flour for each mix was weighed in two portions (one-third of the total weight of the recipe, and two-thirds of the total weight of the recipe) and was wrapped in plain glazed paper and stored overnight in the constant temperature cabinet at 26° C $\pm 1^{\circ}$.

*Swansdown.

Sugar

Extra fine granulated sugar was used. A sufficient quantity for the entire experiment was stored in the storeroom in a tightly covered tin box to keep it as dry as possible.

The sugar for each mix was weighed in two equal portions (one to be combined with the fat and the other with the eggs). It was wrapped in plain glazed paper and stored overnight in the constant temperature cabinet.

Fats

Butter: The butter was made at the college creamery and a fresh pound each week was stored in the storeroom refrigerator.

Hydrogenated lard*: Sufficient amount of the lard for the entire study was bought and stored in a closely covered wooden bucket in the cooling pantry of the storeroom.

Oil**: Cottonseed oil in sufficient quantity for the study was stored in a closely covered brown glass bottle in the cooling pantry of the storeroom.

The fats were weighed and stored overnight in glass custard cups in the constant temperature cabinet.

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*Clix, made and distributed by Cudahy's, Omaha.
**Wesson, made and distributed by Southern Oil Co.

Salt

Plain table salt was stored in sufficient quantity for the study in a tightly covered glass jar in the laboratory. The salt was weighed and stored with the fat in the constant temperature cabinet. Four grams of salt was used with butter and six grams with the unsalted fats.

Milk

Fresh milk from the Dairy Industry Department of the College was used. It was brought to room temperature and weighed in two portions (one-third of the total and two-thirds of the total) just prior to mixing the cakes.

Eggs

Selected eggs from the College Poultry Farm were used. The eggs were stored in a mechanical refrigerator and were from one to four days old when used. Just before using, they were brought to approximately room temperature by placing in lukewarm water, then mixed with 35 twirls of a rotary beater and weighed.

Baking powder

A closely covered one-pound tin of combination phosphate-sodium-aluminum sulfate* baking powder was stored in the laboratory and the amount needed was weighed just before each

*Calumet.

mixing. It was sifted with the smaller portion of the flour three times.

Equipment

Balances

All ingredients were weighed on a Cenco trip balance. Flour, sugar, fat, milk, and eggs were weighed in counter-balanced bowls and transferred to papers or to glass cups for storage until they were needed.

The Cenco trip balance was also used to weigh the batter into the pans and to weigh the cakes before removal from the pans. Cake samples for water absorption test were weighed on this balance. Samples for the texture index were weighed on a Cenco triple-beam balance.

Mixer

An electric mixer* with four-quart bowls and a balloon wire whip that rotated in a planetary motion was used for creaming the fat and sugar and for making the whole-egg meringue.

Pans

The cakes were baked in tin pans that measured 2-1/2 x 3-1/2 x 5-1/4 inches on the bottom and had slightly sloping

*Kitchen-Aide, Model G.

sides. Each pan was weighed with a slip of waxed paper fitted in the bottom before the batter was added.

Oven and thermometers

Two carefully matched centigrade thermometers were used to take batter and cake temperatures at beginning and end of the baking period. Another centigrade thermometer was used for room temperature readings.

The cakes were baked in a gas oven* regulated by thermostatic control and checked by a centigrade thermometer inside the oven.

Vacuum pump

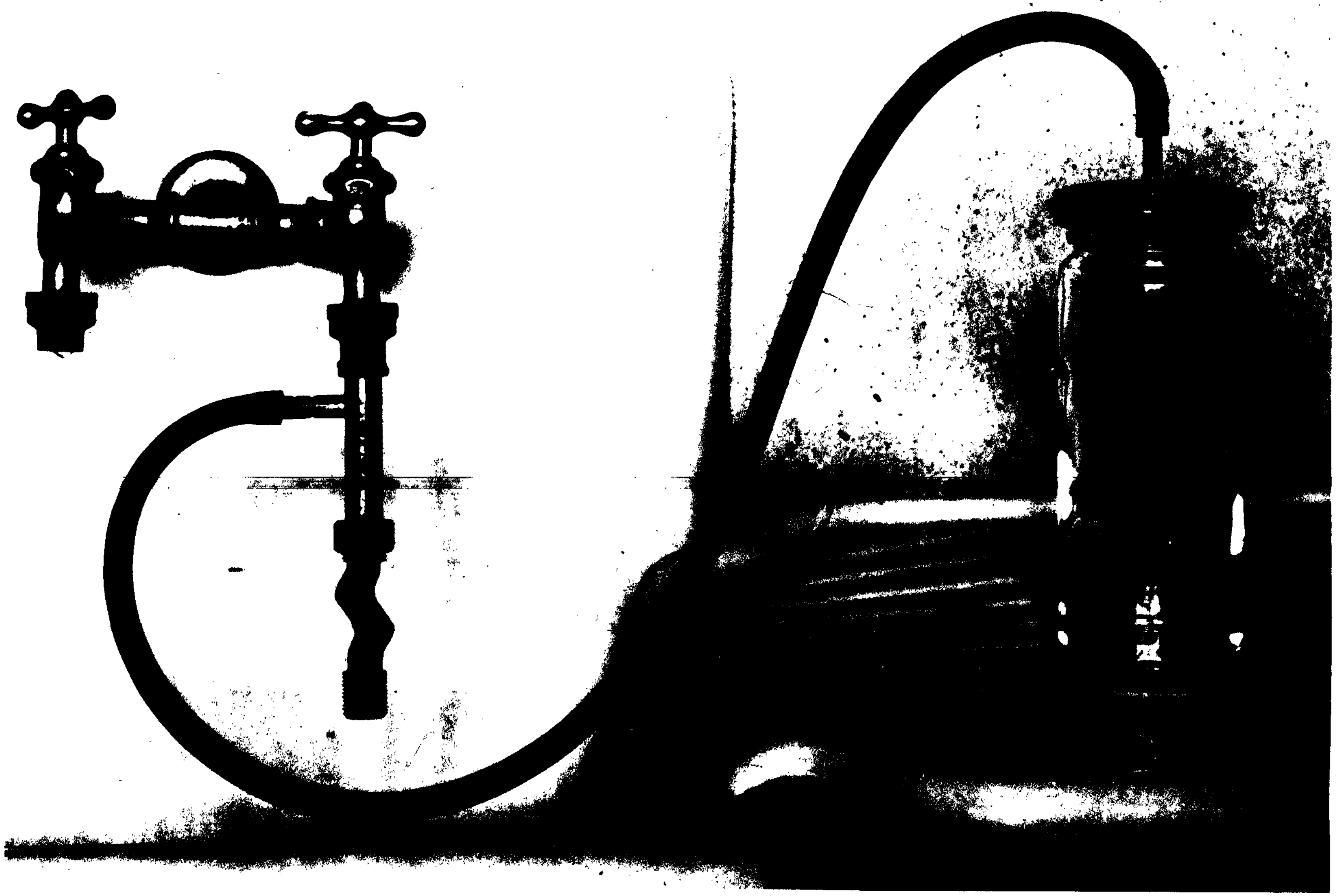
A water aspirator was connected to a water faucet in the laboratory and connected by means of rubber tubing to a heavy brass cover. The cover had a ground surface on the inside and was sealed with stop-cock grease to the ground mouth of a tall glass jar containing the batter which was evacuated by intermittent application of the vacuum. (See Photograph I.)

Electrical apparatus

The resistance of the batter was measured by a Wheatstone bridge**. The source of current was a battery of five Edison cells going through a 1000-cycle microphone hummer***.

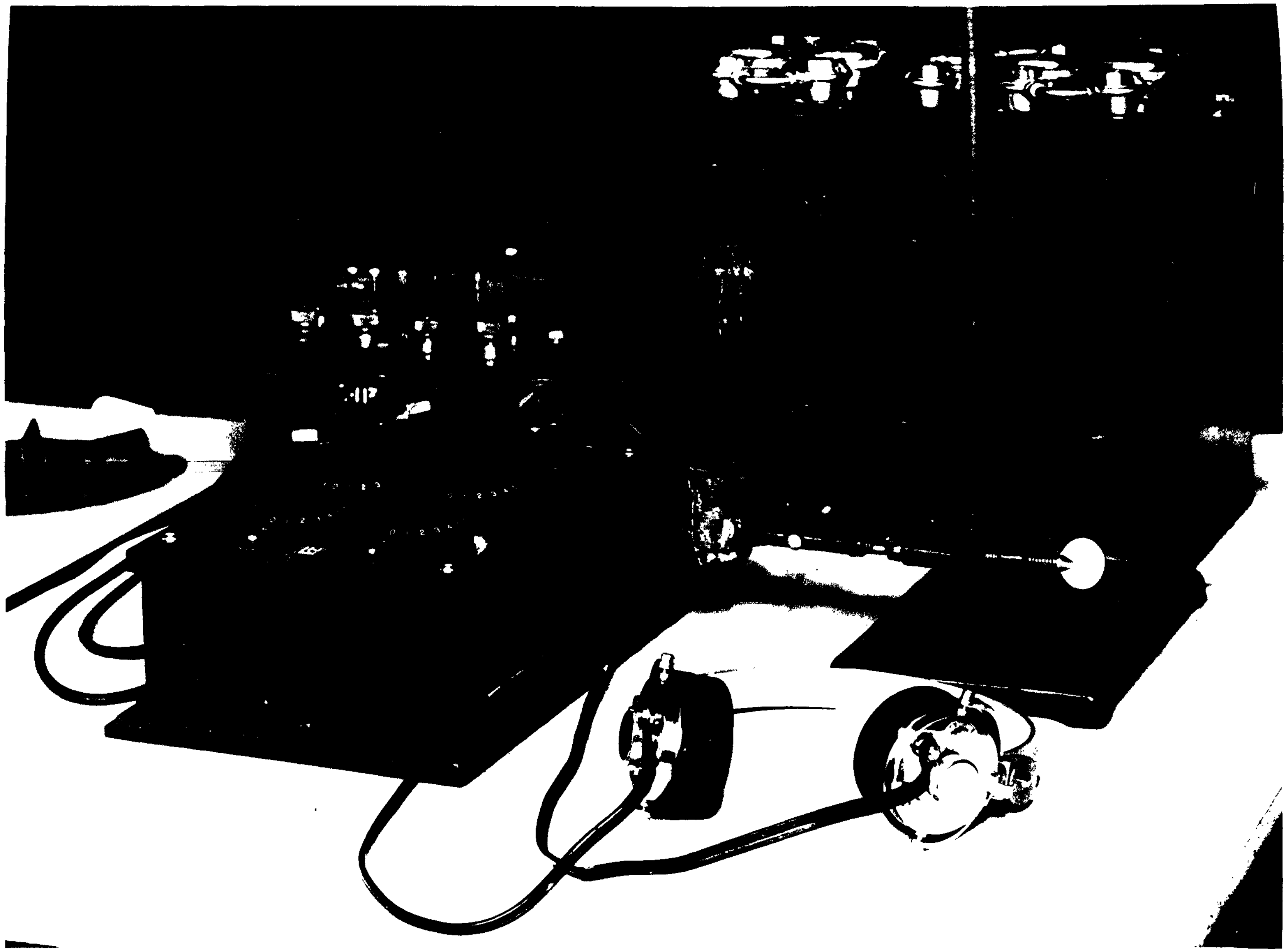
*Clark Jewel with Lorain thermostat.
**Leeds Northrup.
***General Radio.

Water Aspirator with Vacuum Cell



Photograph I

Set-up of Conductivity Apparatus



Photograph II

Balance of the resistances was detected by double tunable earphones connected to the galvanometer post of the Wheatstone bridge, as shown in Photograph II. For testing, the batter was put in a cup-shaped glass cell three centimeters in diameter. The cell contained platinum electrodes 6 x 12 mm. in size and 20 mm. apart. Copper leads completed the circuit.

DISCUSSION OF RESULTS

Three groups of cakes were made with different types of fat, (a) hydrogenated lard, (b) butter, and (c) an oil. Each group was then subdivided into three series. One series (referred to as air series) was leavened by air and steam. A second (referred to as carbon dioxide series) had baking powder added, so that the cakes were leavened by air, steam, and carbon dioxide. The third series (referred to as the steam series or the air-evacuated batters) had the air removed from the batter by means of a water aspirator, and therefore steam was the sole source of leavening.

Appearance

Typical sections from the centers of each type of cake made in the study are shown in Photograph III. The irregular contour of the sides, especially of those of the air series, is evidence of the shrinkage that was characteristic of the cakes. A decided gradation in volumes obtained with different leavening agents prevailed.

Air- and steam-leavened cakes

Exterior: The cakes of the air series had significantly smaller volumes than cakes to which baking powder had been

CAKE SECTIONS

Butter Cakes

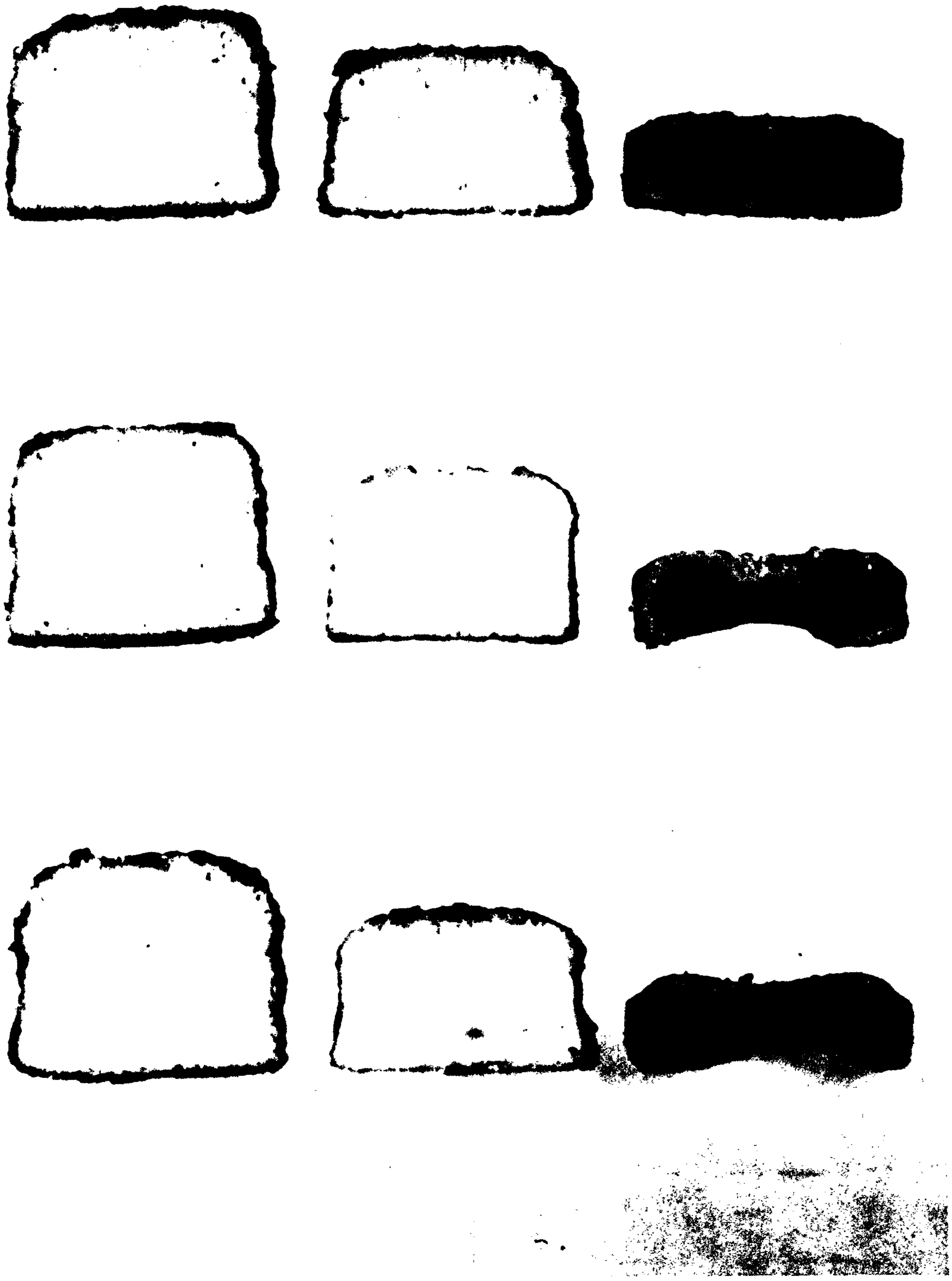
Carbon dioxide series	Air series	Air-evacuated series

Oil Cakes

Carbon dioxide series	Air series	Air-evacuated series

Hydrogenated Lard Cakes

Carbon dioxide series	Air series	Air-evacuated series



Photograph III

added. The top crust was often a dense sticky layer that did not brown well. When the cakes were removed from the oven, the sides were straight and close against the pan but immediately shrank until the sides were pulled away from the pans and were concave in contour. Shrinkage appeared to be greater in the hydrogenated lard cakes than in cakes from the other two fats. Other variances among cakes of the different fats were slight.

The volume increases in the batters of the air series were not sufficient to bring the tops of the cakes to the top of the pan so that the sides of the pan extending above the cake reduced the movement of the hot air across the surface of the cake, thus reducing the removal of moisture from the cake and preventing browning. This moist layer on top seemed to increase in frequency of occurrence and in degree during the period of the study above that of some periods during the preliminary work. Probably an influencing factor was the high humidity which prevailed almost throughout the test period.

Interior: The crumb of the cakes of the air series was velvety, tender, and moist but not as resilient as is desirable in cake. The grain was fine and uniform but in many cases too compact. A few of the cakes of this series were so moist and compact that they had a tendency to have soggy spots. The color and odor were in keeping with the ingredients used.

Carbon dioxide-, air-, and steam-leavened cakes

Exterior: The additional leavening power furnished by the baking powder in the cakes of the carbon dioxide series was evidenced by a decided increase in volume. The volume averages of the cakes in this series were higher than for cakes made by Morr (38) using the same formula, fats, and method of mixing but a different type of baking powder. The cakes were more symmetrical in shape with straighter sides than cakes of the air series. The tops were evenly and slightly rounded and delicately browned.

Interior: The crumb was tender, resilient and somewhat moist but had a tendency to be harsh. The grain was open and loose, sometimes coarse. The tendency for a harsh, coarse texture and for crumbliness was shown in the oil cakes more frequently than in the butter and hydrogenated lard cakes.

Air-evacuated cakes

Exterior: The air-evacuated cakes were extremely small in volume and distorted in shape. The shapes varied widely, but always the bottoms were very uneven, having buckled away from the bottom of the pan. Often the cake cracked open, as shown by the hydrogenated lard cake of this series in Photograph III. They showed relatively little shrinkage when removed from the oven. The hydrogenated lard cakes frequently had much better volume than cakes with other fats in this series.

Interior: There was little evidence of cell structure in the steam series. The interior had more the appearance of a custard or starch pudding than of a cake. Often the texture was so moist and compact that the center of the cake was sticky and had an uncooked appearance. Hydrogenated lard cakes occasionally exhibited some cell structure, usually extremely coarse and with very thick, dense cell walls. These cakes were sweet in flavor and relatively tender for a structure so compact. In general, the products were unpalatable, as indicated by the extremely low scores of Table 1.

Palatability

Scores: total, texture, and velvetiness

Statistical analysis of the palatability scores showed no significant difference among the total scores of cakes with different fats but a highly significant difference among scores of different leavening agents.

Air- and steam-leavened series: The total scores in Table 1 exhibit only slight differences among the cakes of the air series. The oil cakes averages highest within the series with 82.6, butter next with 81.0, and hydrogenated lard least with 77.4. There was a nonsignificant difference between cake scores of this series and the corresponding cake scores of the carbon dioxide series. The oil cake total score of the air series was higher than the oil cake score of

Table 1. Means for Total Palatability Scores, Sand Test, and Moisture Absorption.

Cakes	Palatability scores	Sand test	Moisture absorption
Butter series			
Air	81.0	0.23	4.03
CO_2*	83.5	0.37	7.01
Steam	6.8	0.11	0.68
Oil series			
Air	82.6	0.22	4.63
CO_2*	82.4	0.34	6.91
Steam	2.1	0.15	0.38
Hydrogenated lard series			
Air	77.4	0.23	3.43
CO_2*	82.3	0.35	7.62
Steam	8.7	0.21	0.97

*Carbon dioxide from baking powder.

the carbon dioxide series, but cakes with the other two fats scored slightly higher in the carbon dioxide series than in the air series. All cakes of the air series had scores significantly higher than the air-evacuated cakes.

The texture scores of the air-leavened cakes were always ranked slightly lower than those of the carbon dioxide series and decidedly higher than cakes of the air-evacuated series. From a possible score of 30 for perfect texture, air series cakes averaged a score of 23.0. Hydrogenated lard cakes had a score of 21.6, which was lowest in the air series. The chief criticism of the judges concerning this series was a tendency toward compactness; hence the scores indicate that hydrogenated lard was the most compact of the series.

The velvetiness scores for the air series were: butter 17.2, oil 18.1, and hydrogenated lard 17.6. These were higher than velvetiness scores of corresponding cakes of the other two series. Cakes of the air series were often described as being more velvety than the cakes of the carbon dioxide series.

Carbon dioxide-, air-, and steam-leavened series: Total scores of the cakes in the carbon dioxide series were nearly the same: 83.5, 82.4, and 82.3 for butter, oil, and hydrogenated lard respectively.

It is interesting to note that whereas the hydrogenated lard cake of the air series scored lowest in texture, it scored highest in this series with a score of 25.0. The scores of butter cakes, 24.2, and of oil cakes, 24.6, are only slightly lower. As will be seen later, this shift from the lowest in the air series to the highest in the carbon dioxide series of the hydrogenated lard cakes is repeated in other evaluations of the cakes.

Velvetiness scores of this series were very close to those of the air series but consistently lower. Hydrogenated lard was highest, 17.2, butter next, 17.1, and oil lowest, 16.1. Cakes of the carbon dioxide series were often described by the judges as being less velvety in texture than those of the air series. Although the amount of baking powder use in this study was the lowest quantity recommended by McLean (35), the cakes tended to have a coarse, crumbly and harsh texture typical of too much baking powder. The oil cakes were frequently described as poor in flavor and in several cases one judge noted a more pronounced flavor of oil in the cake with baking powder than in the corresponding cake of the air series.

Air-evacuated series: The total palatability scores of cakes from air-evacuated batters were extremely low, butter cakes 6.8, oil cakes 2.1, and hydrogenated lard 8.7. This is indicative of the unpalatability of cakes in this series.

As would be expected from the total palatability scores, texture scores were very low, averaging 1.1 out of a possible 30. Texture scores ranged from zero to 2.0 among fats.

The score for velvetiness for all cakes in this series averaged less than one.

Objective Tests

Sand index test

The sand index test was used to indicate the texture of the cake crumb, whether coarse or fine. Cakes having coarse cells and thick walls would allow more sand to be retained in the sample than cakes which had fine cells. There was a non-significant difference among cakes of different fats but a significant difference among cakes of different leavening agents.

Air- and steam-leavened series: The amount of sand retained by cakes in this series was approximately the same for all fat groups, 0.23 grams for butter and hydrogenated lard and 0.22 grams for oil cakes. The sand retention exhibited by air-leavened cakes held an intermediate position between the carbon dioxide and the steam series. The difference between the air and carbon dioxide series was of greater magnitude than the difference between the air and the steam series.

Carbon dioxide-, air-, and steam-leavened series: The retention of larger amounts of sand by the carbon dioxide series (Table 1) was indicative of the more open texture of these cakes. Sand retention of this series (butter 0.37, oil 0.34, and hydrogenated lard 0.35 grams) was greater than for the air series.

Air-evacuated series: There was a highly significant difference between the carbon dioxide series and the steam series but a nonsignificant difference between the air series and the steam series. The test is probably not a valid one for cakes of the steam series since their moist, sticky surfaces would retain sand in spite of the lack of cell structure. Even so, the amounts retained were lowest of all series, namely, butter 0.11, oil 0.15, and hydrogenated lard 0.21 grams. It is interesting to note, however, that hydrogenated lard cakes had the highest sand index values and, as described above, were the only cakes from air-evacuated batter that exhibited any cell structure.

<u>Comparison of sand test and palatability score</u>

Comparisons of the total palatability scores with the sand index (Table 1) show a significant difference between sand retention values of the air series and the carbon dioxide series, whereas the palatability scores of the two series show a nonsignificant difference. This may be taken as an indication that the two groups were about equidistant from the perfect texture, with the carbon dioxide series too coarse in texture, whereas the air series was too compact.

<u>Moisture absorption</u>

The water-absorbing ability of cake is used as an objective measure of the eating quality of the cake. By "eating quality" is meant all those qualities which make cake desirable or undesirable for eating. One important factor influencing eating quality is the tactile sensation on the tongue. Cakes that absorb moisture readily give a pleasing sensation whereas others give a dry feeling in the mouth.

Air- and steam-leavened series: Cakes of the air series were always between cakes of the other two series in moisture-absorbing ability. The difference among fats was slight. The mean (Table 1) of oil was highest with 4.63, butter next with 4.03, and hydrogenated lard lowest with 3.43 grams. The values for cakes were significantly higher than those for cakes of the steam series but the difference between this series and the carbon dioxide series was nonsignificant.

Carbon dioxide-, air-, and steam-leavened series: Cakes of the carbon dioxide series had the highest moisture-absorptive ability of any series. Whereas hydrogenated lard cakes were lowest in the air series, the mean in this series was highest, 7.62, with the means of butter and oil cakes slightly less, 7.01 and 6.91 respectively.

Air-evacuated series: The mean values for cakes of this series, as shown in Table 2, were significantly lower than means of the other two series with an average of 0.67 grams for all fats. The difference among fats was nonsignificant.

Comparison of moisture-absorption and palatability scores

Total palatability scores paralleled grams of moisture absorbed in that neither showed a significant difference between the air series and the carbon dioxide series; both showed significant or highly significant differences between air series or carbon dioxide series and the air-evacuated series. There were no significant differences among palatability scores or moisture-absorption values of cakes with different fats.

From the data given in Table 2 a comparison may be made of the subjective scores and the objective tests used on the texture and eating quality of cakes. There was not perfect agreement between the ranks of sand index and texture score, but with each, the carbon dioxide series received the three top places and the air-evacuated cakes received the three lowest places. The moisture-absorption test paralleled eating quality scores in approximately the same manner. There was only four-tenths of a point difference between the highest score for eating quality; hence, even though hydrogenated lard cakes of the carbon dioxide series ranked first in moisture absorption and fourth in eating quality, the discrepancy was negligible.

Table 2. Rank and Means: Texture Scores and Sand Test. Eating Quality and Moisture Absorption.

Highest texture score, 30. Highest eating quality score, 30.

Cakes	Texture		Sand test		Eating quality		Moisture absorption	
	Means	Rank	Rank	Means	Means	Rank	Rank	Means
Butter series								
Air	23.4	5	4	0.23	24.4	3	5	4.03
CO_2*	24.2	3	1	0.37	24.6	1	2	7.01
Steam	1.2	8	9	0.11	1.3	8	8	0.68
Oil series								
Air	24.1	4	6	0.22	24.5	2	4	4.63
CO_2*	24.6	2	3	0.34	24.4	3	3	6.91
Steam	0.02	9	8	0.15	0.5	9	9	0.38
Hydrogenated lard series								
Air	21.6	6	4	0.23	22.2	6	6	3.43
CO_2*	25.0	1	2	0.35	24.2	5	1	7.62
Steam	2.0	7	7	0.21	1.4	7	7	0.97

*Carbon dioxide from baking powder.

Leavening Agents

From the data taken on batters and cakes, computations (see Computation Scheme, page 64) were made to ascertain (1) the total number of milliliters each cake increased in volume over the volume of its initial batter, (2) the percentage of increase attributable to air and that attributable to steam, (3) the percentage of increase due to the combination of air and steam and that due to carbon dioxide. The increase in volume was considered a criterion of leavening. A summary of above percentages and volume increases in milliliters is given in Table 3.

In Photograph III a striking difference is evident in cake volumes obtained with different leavening agents. The differences in volumes among the different fats are not as decided as those among the leavening agents, but they, too, are highly significant. Comparison of individual fats showed a highly significant difference between the volume means of oil cakes (423.4 milliliters) and butter cakes (388.7 milliliters), a significant difference between means of oil cakes and of hydrogenated lard cakes (402.0 milliliters) but no significant difference between hydrogenated lard and butter cakes.

Computation Scheme
for
Air- and Steam-leavened Batters

$$\frac{\text{Temperature of batter as it goes in oven} + 273}{\text{Temperature of cake as it comes from oven} + 273} = \text{air factor.}$$

$$\frac{1}{\text{Specific gravity of batter}} = \text{specific volume of batter.}$$

Specific volume of batter x weight of batter in pan =
volume of batter weighed into pan.

Measured volume of cake - volume of batter weighed into pan =
total increase in volume at end of baking period.

Specific volume of air-evacuated cake x weight of batter in pan
= weighed volume of air-evacuated batter.

Scaled volume of batter - weighed volume of air-evacuated batter
= volume of air in batter.

Air factor x volume of air in batter = volume of heated air.

Volume of heated air - volume of cold air in batter =
volume increase due to air expansion.

$$\frac{\text{Increase due to air expansion} \times 100}{\text{Total increase in volume}} = \%\ \text{volume increase due to air expansion.}$$

$$\frac{\text{Total vol. increase at end of baking} \times 100}{\text{Weighed volume of batter}} = \%\ \text{total increase of cakes.}$$

Percentage leavening by each gas

Leavening by air: When air and steam were the leavening agents, the percentage increases estimated to be due to air were hydrogenated lard 25, butter 19.8, and oil 11.4 per cent, as shown in Table 3. This was in inverse order to the total volume increase as measured in milliliters, *i.e.*, hydrogenated lard 66.8, butter 88.1, and oil 142.3 milliliters (shown in Table 3, column one).

Percentage increases interpreted in terms of milliliters show the volume increases attributable to air were very nearly the same, *i.e.*, 16.1, 16.7, and 17.4 milliliters for oil, hydrogenated lard, and butter, respectively. (Table 3.) This indicates that all cakes had very nearly the same amount of air incorporated in the initial batter. Another indication that this is true is the similitude of the specific gravities of the batters from the three types of fat. (Table 4.)

Since the remainder of the volume increase was attributable to steam, the wide variance in total volume increases in this series was a variance in the leavening effected by steam. As shown in Table 3, this variance ranged from a 50.1 milliliter increase in hydrogenated lard cakes to a 126.2 milliliter increase in oil cakes.

There can be no doubt that adequate steam for leavening was available in all air-steam-leavened cakes. The average loss in weight during baking was approximately 21 grams. If

Table 3. Volume Increases and Percentage Increases of Cakes over Initial Volumes of Batters.

	Total vol. increase over initial vol. (ml.)	ml. of vol. increase attributed to:--			% total vol. increase attributed to:--		
1. Air- and steam-leavened batters							
		air	steam	CO_2	air	steam	CO_2
Butter	88.1	17.4	70.7		19.8	80.2	
Oil	142.3	16.1	126.2		11.4	88.6	
Lard (hydrogenated)	66.8	16.7	50.1		25.0	75.0	
2. Carbon dioxide, air, and steam batters							
		air - steam		CO_2	air - steam		CO_2
Butter	216.8	87.4		129.4	40.3		59.7
Oil	286.7	142.4		144.3	49.7		50.3
Lard (hydrogenated)	247.5	66.6		180.9	26.9		73.1
3. Air-evacuated batters							
		air	steam	CO_2	air	steam	CO_2
Butter	24.0		24.0			10.3	
Oil	24.0		24.0			10.3	
Lard (hydrogenated)	61.6		61.6			24.1	

this entire loss represented loss due to evaporation, only two-tenths per cent of the available steam (from 21 gms. moisture lost) was needed to produce the average volume increase (81.2 milliliters) accredited to steam. Therefore, in this study, the effectiveness of steam in leavening cakes varied with the type of fat used.

All cakes shrank noticeably upon removal from the oven. No data were taken whereby the shrinkage could be estimated, but it was evident in the air series that the shrinkage was of the same order as the percentage of leavening by air, i.e., hydrogenated lard greatest, butter next, and oil least.

The volume measurements used in these computations were the final volumes and not the maximum volumes the cakes reached during baking. Hence, they do not account for the air and water vapor lost during baking.

If the percentage leavening due to each gas were compared, using the air-evacuated cake as basis, and the air occluded in initial batters considered a part of the increase due to air, the values obtained would be 38.3, 54.5, and 66.3 per cent for oil, butter, and hydrogenated lard cakes, respectively. These percentages are more nearly in keeping with the approximate 50 per cent reported by Dunn and White (20), although not computed in the same manner. It seemed to the present investigator, however, that the computation used in this study was more nearly a true estimation of the increase attributable to air since, though the volume of air occluded in the

Table 4. Means of Batter Specific Gravity and Volume Increases Effected by Individual Gases.

Cakes	Batter specific gravity	Vol. increases by air (mls.)
Air series		
Butter	0.80	17.4
Oil	0.81	16.1
Lard, hydrogenated	0.80	16.7
CO_2 series		Vol. increases by CO_2
Butter	0.79	129.4
Oil	0.77	144.3
Lard, hydrogenated	0.80	180.9
Steam series		Total vol. increases
Butter	1.03	24.0
Oil	1.03	24.0
Lard, hydrogenated	1.06	61.6

initial batter contributed to the final volume of the cake, only the thermal expansion of the air effected an increase.

Leavening by carbon dioxide, air, and steam: After the total volume increase above the initial volume of the batter was computed, the percentage attributed to carbon dioxide was derived by subtracting the total increase of the corresponding cakes leavened by air and steam. While this could not be taken as an exact measurement, it seemed a logical relative measurement since the batters and baking conditions were identical except for the addition of baking powder to this series (Computation Scheme 2). The percentage increase attributable to carbon dioxide was of the same order as that attributable to air, namely, hydrogenated lard greatest (73.1 per cent), butter next (59.7 per cent), and oil least (50.3 per cent). The volume increase measured in milliliters varied among fats but not in the same order as the percentage increases. Here again is exhibited a difference in the effectiveness of a leavening agent with the type of fat used. Hydrogenated lard exhibited the highest increase with 180.9 milliliters, oil showed an increase of 144.3, and butter 129.4 milliliters.

A high viscosity in batters might be expected to assist in the retention of carbon dioxide evolved during mixing, thereby increasing the amount of carbon dioxide available for leavening the more viscous batters. Estimated on the basis of 14 per cent available carbon dioxide from the baking powder (32), the approximate volume of carbon dioxide available from the baking powder used in these cakes was 200 to 225 milliliters (see appendix, page 110). The maximum volume increase attributed to carbon dioxide in this study was 180.9 milliliters. The type of baking powder used was slow-acting; it therefore evolved from one-fifth to one-third of its gas at room temperature (5). If as according to Barackman (5) 70 to 80 per cent of the gas evolved during mixing is lost, there would remain approximately 144 to 193 milliliters of available carbon dioxide. Morr (38) worked with the same fats as those used in this study but used a quick-acting baking powder. That would involve the possibility of greater carbon dioxide loss during mixing, yet the volumes she obtained (butter 481, oil 479, and hydrogenated lard 461 milliliters) were not of the same order as the viscosity of the fats used. As shown in Table 4, there was no correlation between the viscosity of the batter and the volume increase attributable to carbon dioxide. Oil batters were the least viscous, yet were second in volume increase due to carbon dioxide. Hence it would seem that, while probably the retention of carbon dioxide evolved during mixing is an influencing factor, it does not appear to be the only one.

To test the effectiveness of carbon dioxide in the absence of air, baking powder was added to an air-evacuated batter of each of the fats. The volumes obtained were 540, 540, and 545 milliliters for butter, hydrogenated lard, and oil, respectively. These volumes compared favorably with the volumes when air (Table 5) was present, but the crumb was very coarse-grained, harsh in texture, and had thick greasy cell walls. Little or no shrinkage was evident.

Leavening by steam alone: The data in Table 1 show very low volume increases for the butter and oil cakes, but the total increase of the hydrogenated lard cakes were within approximately five milliliters of the corresponding cake of the air series. Dunn and White (20) reported no increase in the volume of the air-evacuated pound cake of their study but a decided increase, though poor structure, when only a small amount of air was occluded in the batter. Some of the cakes in this study exhibited no increase in volume, but those that had air occluded in the batter made definite increases, which brought average increase for all air-evacuated cakes to almost 15 per cent.

The appearance of the air-evacuated batters was similar to the description of the air-evacuated batter given by Dunn and White (20), a "custard-like cream." Under the vacuum the batter crept up the sides of the cell and had a honeycombed structure. Upon removal of the vacuum, the batter collapsed. Sometimes in collapsing air might have been entrapped in the batter. Also throughout the experimental period difficulty was encountered in removing the air from the batters with hydrogenated lard. On one occasion a vacuum desiccator pump was used without success. The hydrogenated lard had a much higher melting point than butter or oil. This gave an immobility to the fat at room temperature and a viscosity of batter that probably accounted for the difficulty in removing the air from these batters. Whatever the explanation, the hydrogenated lard batters held their air tenaciously and on one occasion the final volume of the cake was within 30 milliliters of the corresponding cake of the air- and steam-leavened series. Putting the cell containing the batter in a hot-water bath while the batter was under vacuum did not seem to aid in the removal of air. Dunn and White (20) suggested that air spaces in the batter were necessary for the vaporization of steam in the batter. Barmore (7) postulated that the steam responsible for the leavening of the cake had to pass from the bottom and outer edges of the cake through the interior of the cake. This would indicate that air spaces are needed for the passing of steam through the cake. In this study moisture that was condensed beneath the cakes in the pans when the cold cakes were removed gave evidence that more steam had been formed than was able to escape either around or through the cake.

The computations for these series have been based on the assumption that the air incorporated in the batter was 100 per cent effective as a leavening agent. That such is actually the case is doubtful. Nevertheless the results do represent the maximum amount of increase the air is capable of effecting and show the relative importance of air to other leavening agents. When even a very small amount of air is occluded in the batter the disproportionate increase in volume would indicate that the presence of air is favorable to the effectiveness of steam as a leavening agent.

Fats

Creaming volumes

Creaming quality of fats: As shown in Table 5, the average volumes of 25 grams of the creamed sugar and fat as expressed in milliliters were hydrogenated lard 48.5, butter 42.9, and oil, which does not cream, 23.3. This order of creaming quality is in keeping with that of Morr (38) when she worked with the same fats using the same ratio of sugar to fat. The creaming volumes obtained in this study do not necessarily represent the maximum creaming capacities of the fats but are the volumes obtained under the conditions arbitrarily chosen for this study, namely, conditioning the fat for approximately 24 hours at 26° C ±1° and creaming 14 minutes at 25.3° C ±2.5° with the wire whip of an electric mixer on speed two.

(a) Butter: The temperature of the incubator was such that the butter became quite soft with some evidence of oiliness caused by the less saturated glycerides separating from the firmer portion of the fat. As the creaming process

Table 5. Means of Creaming Volumes, Cake Volumes, and Palatability Scores.

Cakes	Creaming volume (ml.)	Cake volume (ml.)	Palatability score total
Butter series			
Air	42.9	388.1	81.0
CO_2*	42.9	521.2	83.5
Steam	42.9	256.8	6.8
Oil series			
Air	23.3	417.5	82.6
CO_2*	23.3	596.2	82.4
Steam	23.3	256.8	2.1
Hydrogenated lard series			
Air	48.5	366.8	77.4
CO_2*	48.5	547.5	82.3
Steam	48.5	291.8	8.7

*Carbon dioxide from baking powder.

progressed, the mixture became quite light and foamy in appearance. The color was characteristically lighter, probably due to a difference in the refraction of light through thinner layers of fat spread around the air bubbles and sugar crystals.

(b) Hydrogenated lard: The conditioning period softened the hydrogenated lard, but there was no expression of oils or unsaturated glycerides. The creaming produced an exceedingly light and fluffy mass that held its shape better than the creamed butter mix. It had a glossy white appearance.

(c) Oil: The oil possessed no creaming quality and readily separated from the sugar when beating was discontinued. The mixture had the grayish appearance of moist sugar with no visible evidence of incorporated air although it is likely that some was carried into the mix in the recesses and irregular surfaces of the sugar crystals.

Cake volume: The difference among the volumes obtained with cakes made from different fats was highly significant. However, the relation of creaming volume to cake volume varied with the leavening agent used.

(a) Air- and steam-leavened cakes: In cakes leavened by air and steam there was a negative correlation of creaming volume to cake volume. Oil, with a creaming volume of only 23.3 milliliters produced the largest cake, 417.5 milliliters. Hydrogenated lard had the highest creaming volume, 48.5 milliliters, yet the hydrogenated lard cake was smallest in volume, 366.8 milliliters. The values for butter were intermediate: creaming volume 42.5 milliliters, and cake volume 388.1 milliliters.

(b) Carbon dioxide-, air-, and steam-leavened cakes: Again the volume mean for oil cakes was highest, 596.2 milliliters, as shown in Table 5. However, between the two fats possessing creaming qualities, butter and hydrogenated lard, there was a direct relation of creaming volume to cake volume. Hydrogenated lard, with the higher creaming volume, showed a cake volume of 547.5 milliliters while butter cakes averaged 521.2 milliliters. This is in keeping with the findings reported by workers (47) in Procter and Gamble laboratories when they used a different formula and a longer creaming period in which they reached the maximum creaming power of the fat.

Morr (38), Buel (12), and other workers (33) in this laboratory used the same formula and approximately the same procedures as followed in this study. All found a negative relation between creaming volume and cake volume. Creaming volumes obtained in this study were higher than those of the other workers. A slight difference in creaming procedure in this study may account for this increased creaming volume and direct relation to cake volume. The other workers added all of the sugar to the fat at the beginning of the creaming period and creamed it 15 minutes on speed two of the electric mixer. In this study the sugar was added by tablespoonfuls at regular intervals during the first four minutes of creaming and the total creaming period was 14 minutes on speed two of an electric mixer. Thus the variances in results obtained with different procedures suggest that it is only when the creaming volume approaches the maximum for that particular fat that a positive relation exists between creaming volume and cake volume.

(c) Air-evacuated cakes: In the steam-leavened cakes the oil and butter gave cakes of the same mean volume, 256.8 milliliters. Hydrogenated lard cakes averaged 291.8 milliliters. It seemed impossible to remove all air from the batters containing hydrogenated lard; hence air probably contributed to this larger volume.

Viscosity

Often in the literature (1, 17, 32) references are made to high viscosity in cake batters as an index to good quality cake with increased cake volume. This study offered opportunity to examine the influence on batter viscosity of two factors, namely the incorporation of gas and the viscosity of the fat used.

Effect of fats

Table 6 gives the reciprocal values of the line-spread measurements taken as a relative measurement of batter

Table 6. Means of Viscosity, Cake Volume, and Palatability Scores.

Cakes	Viscosity (Line-spread reciprocal)	Cake volume (ml.)	Palatability scores
Butter series			
Air	1.11	388.1	81.0
CO_2*	1.08	521.2	83.5
Steam	0.20	256.8	6.8
Oil series			
Air	0.21	417.5	82.6
CO_2*	0.25	596.2	82.4
Steam	0.14	256.8	2.1
Hydrogenated lard series			
Air	1.82	366.8	77.4
CO_2*	1.96	547.5	82.3
Steam	0.35	291.8	8.7

*Carbon dioxide from baking powder.

viscosity. There was a decided difference in the viscosities exhibited among batters with different fats. As would be expected from the physical characteristics of the fats, oil batters showed the lowest viscosities (0.14 to 0.21), butter batters were next (0.20 to 1.11), and hydrogenated lard batters were highest (0.35 to 1.96). Between oil batters and either of the other two batters there was a highly significant difference; between butter and hydrogenated lard, a significant difference.

Effect of leavening agents

The differences among batters of different leavening agents were significant due largely to the effect removal of air from the batters had on viscosity.

Air- and steam-leavened series: In the air series the viscosity means were of the same order as the viscosity of the fat used, namely, hydrogenated lard highest, 1.82, then butter, 1.11, and oil falling considerably lower with a mean of 0.21. In comparison to other series air-leavened cakes held the middle position except in the case of butter cakes, which were highest in this series. The difference between viscosity means of this series and of the carbon dioxide series was only 0.03 and hence may be considered negligible.

Carbon dioxide-, air-, and steam-leavened batters: There was very little difference in the viscosity means of the air-leavened cakes and those of the carbon dioxide series. The hydrogenated lard cakes exhibited the greatest difference, an increase of 0.15 above the hydrogenated lard cake of the air series. The other two fats exhibited nonsignificant differences of 0.03 above or below the means of the corresponding cakes in the air series. Variances between cakes within this series had a wider range than in the air series, *i.e.*, hydrogenated lard was highest with a mean of 1.96, butter intermediate with a mean of 1.08, and oil lowest with a mean of 0.25.

Air-evacuated batters: When air was removed from the batters, the viscosity difference among fats was much less than in the air series. This may be taken as indicative of the influence of incorporated gas on batter viscosity, while the difference still existing among the batters may represent the effect of the fat itself on batter viscosity. The order of viscosity means of the batters in this series in decreasing viscosity was hydrogenated lard 0.35, butter 0.20, and oil 0.14. Thus, it is apparent that under the conditions of this study both the incorporation of gas and the viscosity of the fat had a significant effect on the viscosity of the batter.

Electrical Conductance

In the electrical conductance measurements taken on batters of this study no attempt was made to make an exact mathematical measurement of the electrical conductivity and capacity of the system. However, it was thought that in view of the vast differences in the conductivities of fat and of the aqueous phase containing electrolytes a measurement of the conductivity of the batter might offer a means of measuring the fat distribution. Cognizance was taken of the effect air bubbles (another electrical insulator) might have on batter conductance.

Specific gravity

It was thought that specific gravities of the batters and the corresponding electrical conductances, if compared, might reveal the effect of the presence of air on the conductivity. Table 7 presents the data for such comparison.

Air- and steam-leavened batters: Within the air series the specific gravity means are almost identical: butter 0.80, hydrogenated lard 0.80, and oil 0.81. The conductivity means are not as close as that but are of the same order, namely, butter 1.30, hydrogenated lard 1.35, and oil 1.39, showing a slight increase in conductivity with a similar increase in specific gravity.

Carbon dioxide-, air-, and steam-leavened batters: With carbon dioxide-leavened batters the relation of specific gravity to conductivity is consistent with that of the air series in two fats only; *i.e.*, in hydrogenated lard batters and oil batters specific gravity means of 0.77 and 0.80 were accompanied by conductivity means of 1.36 and 1.36 respectively.

Table 7. Means of Conductivity, Viscosity, and Specific Gravity of Batters.

Cakes	Conductivity (reciprocal ohms 10^{-3})	Viscosity (line-spread reciprocal)	Specific gravity
Butter series			
Air	1.302	1.11	0.80
CO_2*	1.345	1.08	0.79
Steam	1.976	0.20	1.03
Oil series			
Air	1.394	0.21	0.81
CO_2*	1.362	0.25	0.77
Steam	2.309	0.14	1.03
Hydrogenated lard series			
Air	1.347	1.82	0.80
CO_2*	1.358	1.96	0.80
Steam	1.934	0.35	1.02

*Carbon dioxide from baking powder.

Butter, however, had an intermediate specific gravity mean of 0.79 but the lowest conductivity mean of 1.35. In this series the divergences in the relation of the two factors may be due to variances in the age of the batters at the time conductivity measurements were taken. Two counteracting factors are involved: (1) the solution of electrolytes tending to increase conductivity and (2) the formation of gas bubbles tending to decrease conductivity. Hence, as the batter ages, the degree of solvation of the electrolytes and the percentage retention of gas bubbles might cause variances, accurate measurement of which would involve much more controlled conditions than were possible in this study.

Air-evacuated batters: Removal of air from the batter, which of course increased the specific gravities thereof, was accompanied by a highly significant increase in batter conductivity. Within the series of air-evacuated batters, however, there was considerable irregularity in the correlation of specific gravity and conductivity. The oil and butter batters had the same specific gravity mean of 1.03, but oil had a much higher conductivity mean, 2.31, than that of butter, 1.98. Hydrogenated lard batters had a specific gravity mean of 1.06 and a conductivity mean of 1.93. According to the statistical analysis the conductivities of batters with the various leavening agents were significantly influenced by the fat used in the batters. Hence it seems probable that the decided irregularity in the correlation of specific gravity and conductivity in this series might be due to the increased influence felt by fats when air is removed from the batters. The effect of fats on conductivity is probably due to both viscosity of the fat and its distribution in the batter.

Viscosity

An attempt was made to separate the effect of fat or fat distribution from the effect of incorporated gas upon the viscosity of cake batter. Since fats are electrical insulators, it would seem that the distribution and mobility of the fat in a batter would affect the conductivity thereof. Table 7 gives the data for comparison of the viscosity and conductivity of batters in this study.

Air- and steam-leavened batters: The order of viscosity means with significant decreasing viscosity was hydrogenated lard, butter, and oil, whereas the order of conductivity means with negligible decreasing conductivity was oil, hydrogenated lard, and butter. Thus it appears that some other factor overpowers whatever influence the viscosity among fats may effect on the conductivity of the batters.

Carbon dioxide-, air-, and steam-leavened batters: The same order of viscosity means and the same order of conductivity means as exhibited among batters of the air series prevailed among batters of the carbon dioxide series. Again the difference in conductivity means was negligible, the maximum difference being 0.01, while the difference in viscosity means was significantly high.

Air-evacuated batters: Here the relation changed. Viscosity values dropped considerable but still maintained a substantial difference among fats. Oil is lowest with a mean of 0.14, butter next with a mean of 0.20, then hydrogenated lard with 0.35. The conductivity means varied from 2.31 in the oil batters and 1.98 in the butter batters to 1.93 in the hydrogenated lard batters. Thus upon removal of air an inverse relation between viscosity of the batters and conductivity of the batters becomes apparent. Hence, in the light of this comparison and of the close correlation of specific gravity and conductivity pointed out earlier, it seems evident that in batters of this study the incorporation and distribution of gas bubbles had a greater influence on batter conductivity than did the fat.

It may be noted that when the effect of the difference in fats was exhibited the magnitude of the effect was in direct relation to the mobility of the fat; i.e., oil, the most mobile fat, showed highest conductivity and hydrogenated lard, the least mobile, showed lowest conductivity.

Discussion

Creaming volume

A great deal of significance has been given the ability of a fat to cream well. In some formulas only fats that cream well were thought to produce cakes of good volume and good quality. High creaming volume was associated with high cake volume and with high palatability rating. In recent years, however, workers (12, 34, 36, 39) in this laboratory made a series of studies with a number of fats with widely varying creaming properties. Whereas all workers were not in perfect agreement in all cakes, there was a general tendency for smaller cake volumes to result from larger creamed volumes. In this study there was an inverse relation in the air series, but when baking powder was added there was a direct correlation between creaming volume and cake volume in the two plastic fats. Oil, of course, possesses no creaming properties.

Method of mixing

It is interesting to note in this study that the highest volumes were almost invariably obtained by the oil cakes. This is probably attributable to the method of mixing used, in which a sugar-egg foam is added as the last step in mixing. Of the many methods of combining ingredients tested in this laboratory by a former worker (12) the only one which gave satisfactory results with soft fats and oils was the conventional-sponge method. Beyer (10) working with soybean oil in cakes reported that satisfactory cakes were made when egg was added in a meringue as the last step in mixing.

Two possible reasons present themselves as explanations for the acceptability of this method of combining ingredients. One is that eggs favor an oil-in-water emulsion, and oil is so easily emulsified at room temperature that addition of egg to the oil may stabilize it in an oil-in-water emulsion. Lowe (32), by using an emulsion method of mixing, has shown such a distribution of fat to be undesirable in cake making. Another possibility is that the addition of egg late in the process as an egg-sugar foam furnishes a means of incorporating in the batter the air which in plastic fats could be added in the creaming process.

Leavening agents

It would seem that the aeration of cakes has a function beyond that of increasing cake volume and that the incorporation and fine distribution of air in the batter is of major importance. Although in this study, the thermal expansion of air accounted for a relatively small percentage of the volume increase, the air incorporated apparently formed the cell structure which was maintained during baking. Thus the amount and dispersion of incorporated air must have greatly influenced the texture of the finished cake.

The cell structure formed by the air bubbles presumably provides spaces into which the water vapor could readily escape and thereby distributes the expansive effect of the steam more evenly throughout the cake.

It seems reasonable to suppose that the favorable effect of high viscosity in batter found by many workers (17, 19, 32) can be attributed, in part at least, to the size and frequency of air bubbles in the batter.

Mention has been made of the shrinkage that was evident in all cakes made in this study. Although no measurements were made, the proportion of shrinkage appears to have been greater in the air-leavened cakes than in other series. It was also quite evident hydrogenated lard cakes, which had the highest percentage leavening by air, always shrank more than other cakes in the series.

The effect of baking powder on cakes and cake batters is doubtless more than merely furnishing carbon dioxide for leavening. Barackman (5) mentioned the effect of residual salts of baking powders on the colloidal properties of the dough. In hydrogenated lard cakes the volume change with different leavening agents suggests that such an effect was present. In the air series the volume increase was the least of any of the cakes but the percentage increase attained when baking powder was added exceeded that of any of the cakes. Lowe (32) states that the hydration capacity of flour protein may be increased by electrolytes. Hence it seems that the striking difference in volume increase of hydrogenated lard cakes with and without the presence of baking powder may be partly due to the residual salts. In the air-leavened cakes the combination of the less mobile fat and of the less hydrated, hence less elastic, gluten would offer more resistance to the leavening gases and hence not expand as much. When additional electrolytes in the form of residual salts of baking powder are added, the more hydrated and elastic protein lessens the resistance to the gases.

Viscosity and fat distribution

The present investigator proposes to consider the structure of cake batter as a composite phase system with air and water dispersed within the fat, and the fat in turn dispersed within a system of hydrated protein, starch, and so forth. The fat then encloses air bubbles and water globules. In turn, this mixture becomes the dispersed phase of the colloidal solution. According to Clayton (14) the viscosity of the continuous phase of any emulsion aids in stabilizing that emulsion only by hindering the coalescence of the dispersed globules. It is to be expected that within the same series of cake batters the viscosity of the hydrated protein-starch phase would be approximately the same, so that differences in batter viscosity would come in its dispersed phases. Then (1) viscosity of the fat itself, (2) the concentration and the degree of dispersion of air and water within the fat, (3) the degree of dispersion of the fat, and (4) the amount and degree of dispersion of gas bubbles within the hydrated protein-starch phase, could cause differences in batter viscosity. Thus for any one fat a high viscosity batter might indicate an emulsion of widely dispersed fat enclosing a dispersion of air and water, i.e., an oil-in-water (or oil-in-hydrated-colloid) emulsion wherein the fat or oil is also the continuous phase of a second system enclosing air and water.

According to Clayton (15) butter is a solid fat system enclosing water, air, and fat globules. The extraordinary adaptability of butter to various methods of combining ingredients indicates that such a state may be desirable for fats used in cake making. Many commercial concerns use emulsifying agents which form water-in-oil emulsions in fats to improve the baked product and also reduce the amount of fat required.

It is likely that in this study the fats were at least partly emulsified in a water-in-oil emulsion. As aforementioned, that is the normal state of butter. It is probable that in the addition of small quantities of milk and flour (one tablespooonful each) to the fat-sugar mix some emulsion of the water-in-oil type takes place. At room temperature oil probably emulsified more readily than the less mobile hydrogenated lard and hence may have incorporated more milk droplets. It may be recalled that in the air series hydrogenated lard cakes had the smallest volume increases. There arises a question then as to whether or not the incorporation of less liquid in the fat contributed to the small volume increase (66.8 milliliters) and the high percentage of that increase (25 per cent, Table 3) due to air in the hydrogenated lard cakes of the air- and steam-leavened series; and conversely, the incorporation of more liquid in the oil cakes contributed to their high volume increase (142.3 milliliters), a small percentage of which (11.4 per cent) was due to air. Clayton's (15) discussion of the making of margarine lends support to this idea. In this process oil is run into the milk because if oils are in the churn and milk run in, a water-in-oil type of emulsion is formed. Clayton states that the same thing happens "if both phases are placed in bulk in the churn (say 80 per cent oil and 20 per cent milk) without undue mixing, and then the agitating device set in motion." The volume factors favor a water-in-oil emulsion, but such an emulsion is not permanent because the emulsifying agent present, viz., milk colloids, favor the oppositely-phased type. However, according to Clayton, the water-in-oil emulsion can be "fixed" by methods used in the margarine industry (rapid chilling), but the texture of the final product is poor. It seems reasonable that the starch particles present in the flour might tend to stabilize the water-in-oil emulsion. In histological studies of cakes Morr found starch inbedded around the fat at the cake-air interface and around the fat in the crumb. This was more evident in cakes made by the method used in this study than by the conventional method.

In the method of combining ingredients used in this study one or two tablespoonfuls of milk and of flour were added to the oil and sugar or creamed mixtures and stirred 40 strokes. The remainders of the milk and flour were added later. The amount of milk added in the first portion was approximately in the same ratio of oil to milk (4:1) referred to in margarine making. Scheu's (48) patent for improving fats for baking was an emulsifying agent which produced a water-in-oil emulsion of 30 per cent water and 70 per cent fat. Hence it seems the volume factor at this point in the cake batter favored a water-in-oil emulsion. Upon addition of the small quantities of milk and flour to the oil-sugar mix, the whole became milky in appearance, and the oil apparently had less tendency to separate in a layer on the surface. This seemed to be evidence that the oil was emulsified to some extent. The addition of the remainder of the flour and milk would reverse the volume phase and might tend either to emulsify the oil with air and water dispersed in it to form an oil-in-water (or hydrated colloid) emulsion, or merely to scatter the oil in small pools or lakes throughout the batter. Whatever the distribution of the fat, if it is effected without breaking or reversing its (assumed) water-in-oil emulsion, a composite phase system is thus formed.

The water assumed to be dispersed in the fat would be free water and presumably during baking would probably vaporize into the air globules, enlarging them and thus forming the "air cells" of the cake. Accordingly the amount and distribution of air and water enclosed in the fat would be a factor that might vary the quality of cakes having the same fat distribution. A scarcity of finely dispersed air bubbles and water globules within the fat would give a cake with smaller cells, hence thicker cell walls and less air-crumb interface.

Electrical conductance

In planning this study it was thought that among batters of different fats some variances in degree of fat dispersion might be detected by measuring batter conductivity. Fat globules, being electrical insulators, would act as interfering substances in the path of the electric current. As the proportion of the fat emulsified increased and its dispersion increased it is reasonable to suppose that the conductivity would be reduced. A greater number of clusters of globules on non-conducting substances would make a more circuitous path of higher resistance by squeezing the continuous conducting phase thinner. Since smaller particles in suspension produce a higher viscosity for a given concentration than larger particles, it would be expected that in batters using the same fat an increase in fat dispersion would be accompanied by high viscosity. The same amount of fat in a few larger "pools," "lakes," or clusters would allow shorter, thicker aqueous-flour paths through the batter and hence increase the conductivity of the batter and be accompanied by low viscosities.

Regardless of the manner in which the fats are dispersed in the cake batters, in this study no direct relationship was shown between batter viscosity and conductivity. However, Collins' (17) study in which different methods of mixing batters using the same fat showed a correlation between viscosity and conductivity need not be in disagreement with this study. Collins used butter only, whereas in this study three fats were used. It appears that the effect of gas bubbles in the batter cannot be disregarded in measuring batter conductivity. It is difficult, however, to accept Collins' results as evidence that conductivity may be used as a means of typing the emulsion of cake batters, i.e., a means of determining whether the fat is distributed as an oil-in-water or as a water-in-oil emulsion. If the whole batter were a water-in-oil emulsion (which is not likely) and hence oil the conductor of current, the conductivity would be practically nil, whereas an aqueous phase would show much greater conductivity. Collins' data showed many overlapping values for the two types of emulsions. Differences in conductivity seem to be more a matter of degree of dispersion. Unless the whole batter were a water-in-oil emulsion, the path of the current would always be through the aqueous colloidal solution. Thus the magnitude of the current probably depends largely on the size and concentration of fat globules and air bubbles enclosed in the aqueous phase.

CONCLUSIONS

Observations made in this study led to these conclusions:

1. Differences between palatability scores of plain cakes made with and without baking powder were nonsignificant. Scores of cakes leavened by steam alone were extremely low.

2. The palatability scores for the air and the carbon dioxide series cakes were approximately the same. Sand retention was lower in the air series, which indicates the two groups were equidistant from the ideal texture, the air series cakes being compact and those of the carbon dioxide series coarse.

3. There was a correlation between moisture absorption and eating quality scores. Cakes of the air series were between cakes of the other two series in moisture absorption.

4. Creaming volume did not consistently parallel cake volume. There was an inverse relation in the air series, but when baking powder was added, there was a direct correlation between creaming volume and cake volume in cakes using the two plastic fats. Oil has no creaming properties.

5. Fats of high viscosity produced batters of high viscosity, and conversely low viscosity fats produced low viscosity batters. The more viscous of the oil batters produced cakes that compared favorably with the cakes from the more viscous of the hydrogenated lard or butter batters.

6. Electrical conductance was affected by fats and leavening agents. Incorporation of gas in batters as measured by

specific gravity had greater influence on conductivity than fats had. The effect of fats was detected only in the air-evacuated batters; therein batter viscosity seemed to be a function of fat viscosity, and apparently the more viscous the fat the lower the conductivity of the batter.

7. The carbon dioxide-air-steam-leavened cakes gave the largest, the steam-leavened ones, the least volume. The addition of carbon dioxide produced a volume-increase over cakes of the air series. Extremely low volumes were obtained by cakes leavened by steam alone, even though there was the same amount of moisture available to produce steam in this series as in the series leavened by air and steam. In the absence of gas pockets into which the steam might pass, steam lost its power of leavening. Hence it appeared that the effectiveness of steam as a leavening agent is affected by presence and distribution of gas bubbles in the batter.

8. There was a variance in the volume-increase among cakes of the air series from different fats, which was due to a difference in the effectiveness of steam among the fats. The percentage increase credited to carbon dioxide in the carbon dioxide series also varied among the fats. It seemed, therefore, that the type of fat used influenced the effectiveness of leavening gases. The most mobile shortening, oil, gave the largest total volume-increases with either air or carbon dioxide as the leavening agent. Hydrogenated lard cakes had larger increases than butter cakes when baking powder was added, but lower increases than butter cakes of the air series.

SUMMARY

This study was made in an attempt to determine the effectiveness of three leavening gases in plain cakes made with three types of fat with especial interest as to whether or not air is necessary in batters for steam to be effective. The plan of study involved the following grouping and sub-grouping of cakes baked:

I. A. Cakes made with butter

- (a) Leavened by air and steam
- (b) Leavened by carbon dioxide, air, and steam
- (c) Leavened by steam alone.

B. Cakes made with oil

- (a) Leavened by air and steam
- (b) Leavened by carbon dioxide, air, and steam
- (c) Leavened by steam alone.

C. Cakes made with hydrogenated lard

- (a) Leavened by air and steam
- (b) Leavened by carbon dioxide, air, and steam
- (c) Leavened by steam alone.

II. Nature of the study

A. A total of 72 cakes was divided equally among the nine groups mentioned above. Each day two different fats were used in batters and the resulting batters divided so that one cake was baked with only the occluded air and potential steam as leavening agents, one had a baking powder added, and the third had no additional leavening agent and also had the air removed from the batter by means of a water aspirator and vacuum cell.

B. Data recorded during the study were room and incubator temperature, batter temperature before and at end of baking, meringue specific gravity, specific gravity of each batter, batter line-spread, creamed volume, cake weight, cake volume, sand index, moissure absorption, electrical conductivity of batter, and the scores of five judges scoring crumb, tenderness, velvetiness, and eating quality.

III. Results

From data taken the percentage leavening by each leavening gas was computed. Cakes were compared for effect of fat and of leavening agents and of their interaction on batter viscosity, specific gravity, and electrical conductivity and on cake volume and palatability. Statistical analyses were made of the data.

A. Effect of leavening agent

1. Air-leavened cakes

(a) Usually assumed a position between those of the other two leavening agents for such data as:

(1) specific gravity

(2) batter viscosity

(3) electrical resistance

(4) moisture absorption

(5) sand index

(6) cake volume.

(b) Palatability scores compared favorable with scores of the carbon dioxide series. Cakes of this series seemed more velvety than others.

2. Addition of baking powder

(a) Slightly increased the viscosity in oil and hydrogenated lard cake batters.

(b) Specific gravity of cake batters was significantly decreased.

(c) Decidedly increased the volume over that of air cakes.

(d) Palatability scores of carbon dioxide cakes ranked: 1, butter; 3, oil; 4, hydrogenated lard. Oil cakes of the air-leavened series ranked second.

3. Removal of air

(a) Decreased batter viscosity.

(b) Increased batter conductivity.

(c) Increased batter specific gravity.

(d) Prevented appreciable increase in volume of cake during baking.

(e) Resulting cake was very unpalatable.

B. Effect of fats

1. Creaming volume did not consistently parallel cake volume, and the relationship is influenced by type of leavening agent.
2. Viscosity of batter varied with viscosity of fat.

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APPENDIX

Table 8. Summary of the Means of Factors Studies.

	Butter			Oil			Hydrogenated lard		
	Air	CO_2	Steam	Air	CO_2	Steam	Air	CO_2	Steam
% Leavening	19.8	59.7	80.2	11.4	50.3	88.6	25.0	73.1	75.0
Sp. gr. batter	0.80	0.79	1.03	0.81	0.77	1.03	0.80	0.80	1.02
Sp. vol. batter	1.25	1.26	0.97	1.23	1.29	0.97	1.25	1.25	0.98
Creaming vol.	42.9			23.3			48.5		
Resistance	768	743	506	717	734	433	742	736	517
Reciprocal	1.30	1.35	1.98	1.39	1.36	2.31	1.35	1.36	1.93
Line spread	0.90	0.93	5.00	4.66	4.00	7.21	0.55	0.51	2.84
Reciprocal viscosity	1.11	1.08	0.20	0.21	0.25	0.14	1.82	1.96	0.35
Cake vol.	388.1	521.2	256.8	417.5	596.2	256.8	366.8	547.5	291.8
Cake wt. loss	19.3	21.9	24.5	24.6	22.5	18.6	19.8	23.9	22.4
Palatability	81.0	83.5	6.8	82.6	82.4	2.1	77.4	82.3	8.7
Moisture absorption	4.03	7.01	0.68	4.63	6.91	0.38	3.43	7.62	0.97
Sand test	0.23	0.37	0.11	0.22	0.34	0.15	0.23	0.35	0.21

Computation Scheme 2

Carbon Dioxide-, Air-, and Steam-leavened Batters

Specific volume of Batters x weight of batter in pan = weighed volume of batter.

Measured volume of cake - weighed volume of batter = total increase in volume at end of baking period.

Total volume increase - total volume increase of air- and steam-leavened cakes = volume increase due to carbon dioxide.

$$\frac{\text{Increase due to carbon dioxide} \times 100}{\text{Total increase in volume}} = \%\ \text{volume increase due to carbon dioxide.}$$

Carbon Dioxide Evolved

2.6 gms. baking powder evolved:

$2.6 \times 14\% = 0.364$ gms. CO_2

Specific gravity CO_2 = 1.5290 (air = 1)

$\frac{1.529}{0.364} = 0.238$ liters CO_2 = 238 milliliters

Or

Density of CO_2 at 0° C, 760 mm. = 1.9769 gms. per liter

$\frac{1.9769}{0.364} = 0.185$ liters CO_2 at standard conditions.

At 26.5° C

$$\frac{273 - 26.5}{273} = \frac{299.5}{273} = 1.09$$

$1.09 \times 0.185 = 0.201$ liters = 201 milliliters.

SCORE CARD FOR CAKE

Number:

	Perfect Score		
<u>Crumb</u>	30		
1. Texture, cell walls thin and fine.			
2. Cells rather small in size but not too compact.			
3. Crumb springy and elastic.			
<u>Tenderness</u>	20		
Tender, not tough or gummy.			
<u>Velvetiness</u>	20		
Silkiness or smoothness and softness to tactile sense (finger or palate).			
<u>Eating quality</u>	30		
This includes aroma, flavor, velvetiness and all qualities that make cake agreeable or disagreeable.			
	100		

Means of Palatability Scores

Quality	Perfect score	Butter			Oil			Hydrogenated lard		
		A	B	E	A	B	E	A	B	E
Crumb	30	23.4	24.2	1.2	24.1	24.6	0.0	21.6	25.0	2.0
Tenderness	20	16.0	17.6	3.4	16.0	17.5	1.50	15.9	16.9	3.7
Velvetiness	20	17.2	17.1	0.92	18.1	16.1	0.10	17.6	17.2	1.5
Eating quality	30	24.4	24.6	1.30	24.5	24.4	0.50	22.2	24.2	1.4

Replications of Data

	Butter			Oil			Clix		
	A	B	E	A	B	E	A	B	E
Specific gravity of batter	0.806	0.834	1.059	0.820	0.761	1.049	0.815	0.828	1.055
	0.807	0.785	1.017	0.820	0.790	0.979	0.798	0.812	0.961
	0.793	0.785	1.035	0.813	0.764	0.990	0.819	0.821	1.084
	0.802	0.799	0.937	0.822	0.759	1.002	0.813	0.807	0.936
	0.791	0.784	0.936	0.806	0.766	1.058	0.785	0.803	1.018
	0.786	0.772	1.077	0.806	0.741	1.054	0.777	0.796	0.996
	0.783	0.792	1.066	0.786	0.750	1.080	0.767	0.773	1.051
	0.794	0.785	1.084	0.796	0.762	1.064	0.792	0.795	1.030
Mean	0.795	0.792	1.026	0.808	0.774	1.034	0.795	0.804	1.016
Meringue specific gravity	0.537			0.552			0.520		
	0.534			0.530			0.520		
	0.547			0.526			0.542		
	0.558			0.526			0.545		
	0.516			0.531			0.519		
	0.533			0.527			0.522		
	0.536			0.518			0.539		
	0.529			0.544			0.526		
Mean	0.536			0.531			0.529		
Creaming volume	44.0			23.4			48.0		
	43.0			23.7			49.0		
	43.0			23.0			49.0		
	42.5			23.0			47.5		
	44.0			23.0			49.0		
	44.0			23.0			48.0		
	40.0			23.5			48.5		
	43.2			23.2			49.0		
Mean				23.6					

	Butter			Oil			Clix		
	A	B	E	A	B	E	A	B	E
Viscosity	0.60	0.96	4.47	4.25	3.75	7.45	0.32	0.17	2.47
	0.77	0.47	4.20	4.40	3.55	6.75	0.22	0.00	2.00
	1.02	0.87	5.02	4.90	4.02	7.36	0.45	0.45	3.50
	0.57	0.50	4.60	5.00	4.47	5.75	0.62	0.47	1.77
	1.80	1.25	4.25	4.62	4.20	8.40	1.05	0.90	3.70
	0.95	1.07	5.35	4.67	3.80	7.55	0.70	0.80	2.32
	1.40	1.85	5.62	4.77	4.17	7.75	0.50	0.85	2.92
Mean	0.90	0.93	5.00	4.66	4.00	7.21	0.55	0.51	2.84
Resistance	935	765	540	845	890	470	770	760	550
	885	861	605	770	793	490	795	790	585
	720	706	460	770	790	460	767	790	520
	805	805	615	680	713	420	745	775	580
	710	750	530	640	650	405	640	650	440
	685	690	405	690	745	420	740	727	490
	715	725	450	675	660	410	740	735	490
	690	725	445	670	670	395	740	665	485
Mean	768.1	743.3	506.2	717.5	734.1	433.7	742.1	736.5	517.5
Cake volume	420	545	250	430	645	245	355	530	310
	400	520	305	420	590	290	380	615	310
	385	520	255	420	600	290	360	545	220
	360	525	310	415	530	230	350	550	330
	380	510	290	420	590	235	350	520	290
	380	510	205	415	620	230	360	520	320
	390	500	230	410	580	245	405	550	280
	390	540	210	410	615	290	375	550	275
Mean	388.1	514.5	256.8	417.5	596.2	256.8	366.8	565.0	291.8

	Butter			Oil			Clix		
	A	B	E	A	B	E	A	B	E
Palatability	79.3	76.0	4.8	84.0	80.2	3.7	70.0	86.4	3.6
	79.4	88.8	5.4	84.2	78.2	3.4	73.8	80.8	19.2
	80.2	86.6	1.0	81.8	80.6	1.4	84.0	84.8	1.4
	73.0	85.7	3.1	75.2	86.6	1.4	76.0	89.2	1.2
	90.8	73.6	6.8	83.4	86.8	2.0	73.2	80.8	12.0
	78.5	88.2	2.5	86.2	82.0	2.5	89.4	70.8	14.4
	87.6	88.0	2.4	81.6	88.2	2.0	80.0	86.6	4.4
	79.6	81.4	1.6	84.4	77.2	1.0	73.4	80.2	3.0
Mean	81.0	83.5	6.8	82.6	82.4	2.1	77.4	82.3	8.7
Moisture	4.00	6.50	0.20	4.95	7.00	0.30	2.95	7.30	0.80
	4.55	7.10	0.50	4.70	6.20	0.50	3.80	7.60	1.40
	4.70	6.95	0.50	4.35	5.75	0.50	2.70	6.65	0.30
	3.20	6.95	1.70	3.65	7.20	0.30	2.55	7.40	1.00
	3.25	7.20	1.40	4.85	7.25	0.50	3.10	8.35	1.00
	3.35	6.80	0.10	5.20	7.00	0.10	2.95	7.30	1.50
	3.50	7.45	0.60	3.90	7.45	0.60	5.10	8.50	0.90
	5.70	7.15	0.50	5.50	7.45	0.30	4.35	7.95	0.90
Mean	4.03	7.01	0.70	4.63	6.91	0.38	3.43	7.62	0.97
Sand	0.220	0.330	0.040	0.220	0.355	0.050	0.225	0.415	0.400
	0.330	0.335	0.120	0.280	0.330	0.130	0.230	0.345	0.190
	0.185	0.402	0.110	0.260	0.395	0.410	0.245	0.365	0.270
	0.215	0.495	0.190	0.185	0.250	0.140	0.185	0.335	0.180
	0.235	0.295	0.140	0.140	0.295	0.010	0.195	0.340	0.150
	0.200	0.340	0.120	0.230	0.430	0.150	0.275	0.395	0.230
	0.225	0.385	0.130	0.215	0.300	0.150	0.260	0.250	0.140
	0.200	0.355	0.040	0.245	0.325	0.070	0.210	0.345	0.070
Mean	0.23	0.370	0.11	0.22	0.34	0.15	0.230	0.350	0.21