THE EFFECT OF BATCH SIZE UPON THE FLOW OF CHOCOLATE PIE FILLING

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THE EFFECT OF BATCH SIZE UPON THE FLOW
OF CHOCOLATE PIE FILLING

By

Grace A. Miller

AN ABSTRACT

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ABSTRACT

This study was directed primarily toward the objective measurement of flow of cooled, cut samples of starch-thickened chocolate pie filling prepared in 6, 8, 10, 12, and 14-gallon batch sizes.

The selected formula used throughout this study was one in which the proportion of ingredients was held constant and the thickening agents were limited to cornstarch and cocoa powder. These thickening agents were combined in equal weights and together constituted 7.5 per cent of the total weight of the mixture.

The treatment variable, introduced at the end of the heating process, consisted of holding the mass in the steam jacketed kettle after the mass had reached a temperature of 82°C. Holding periods were arbitrarily set at 0, 30, and 60 minutes.

Several pieces of equipment were designed for preparing samples and determining the amount of spread from cut samples of cooled filling. The testing equipment used in this research and the consecutive steps in the procedure for pouring the mold, cutting and leveling the sample, releasing the sample for flow, recording the image of the sample, and measuring the sample area are photographically illustrated in the thesis.

From the data of this investigation it appeared that flow characteristics of cooled, cut samples of starch-thickened pastes are not consistently affected by increases in batch size when procedure and proportion of ingredients remain constant. Batches of 6, 8, 10, and 12-gallon amounts produced gel structures of similar consistency. Although the 14-gallon amount produced a less stable gel structure than

did any of the other batch sizes tested, factors other than batch size may also have influenced the flow of samples.

In this limited study it was found that a progressively longer cooking period is required to reach the points of visible, initial viscosity and end cooking temperature for each consecutive increase in batch size. It appeared that the degree of swell of the starch granules is dependent upon batch size, rate of heating, and temperature of the mass during the heating and holding periods.

The length of the holding time, after the temperature of 82°C is attained, appeared to affect the stability of the gel structure in all batch sizes. Rigidity of gel structure increased more during the first 30 minutes of holding time than during the following 30 minutes of holding time. This fact suggests that the rate of heating and the length of the holding period are contributing factors in the final flow of the cooled paste.

The gels resulting from the 30-minute holding period were judged suitable for use as pudding for all batch sizes tested; samples from the 60-minute holding period gave gels acceptable for use as pie filling. In all cases gel structure of samples held 60 minutes was tender and stable. These facts suggest the possibility of regulating stability and tenderness of cooled starch-thickened mixtures, for specific batch sizes, by the control of time and temperature conditions of the cooking period.

The findings of this limited study emphasize that accurate prediction of the stability of gel structure of starch-thickened pastes is a complex problem. Additional investigation of the interaction of factors, such as rate of heating, temperature of the mass during the heating period, end cooking temperature, and length of holding period after the application of steam is discontinued, needs to be made before the effect of batch size upon flow can be accurately determined.

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INTRODUCTION

The lack of ability to predict accurately the amount of flow for cooled, starch-thickened pie filling is a very real problem to quantity food production workers. Daily adjustments in food production schedules often require batch-size changes in established formulas. The usual practice of increasing batch size by the direct multiplication of each ingredient in a basic recipe, with all procedure factors remaining constant, frequently has failed to produce a filling comparable to the one obtained from the original formula. Large batch formulas derived by this technique generally tend to produce a consistency too soft for serving. The pie-baker's solution for this dilemma is often simply to increase the proportion of thickening agent in an attempt to attain comparable consistency.

A survey of chocolate pie filling recipes in large quantity cook books revealed that wheat flour and cornstarch are the thickening agents most frequently used. Whole egg or egg yolk and chocolate or cocoa also contribute some thickening effect.

In an attempt to control as many ingredient variables as possible, cornstarch and cocoa powder were used in the formula for this study to obtain the desired consistency. Formulas including whole egg or egg yolk were not considered. Whole dried milk solids and tap water were substituted for whole fluid milk to obtain milk of constant composition.

The first objective of this investigation was to determine the effect of batch size on flow of the cooled filling by objective measurement. Throughout this study the formula contained constant proportions of all ingredients.

The literature contains reports of a few experimental studies in which the flow of hot, starch-thickened pastes has been measured objectively by line-spread tests. The investigator has not found any reports of the use of objective measurement of flow for cut samples of cooled filling. Some flow predictions for cut samples of cooled filling have been based upon measurable flow data obtained from hot paste samples. The second objective of this study, therefore, is to develop a technique to determine the amount of spread from a cut sample of cooled filling under specific conditions.

Contemporary starch chemists have now generally agreed that viscosity and gel strength are two separate and distinct properties of starch pastes and are not synonymous as believed earlier. Research workers have substantiated the theory that time and temperature relationships of starch-thickened pastes have a direct bearing on the physical characteristics of the finished product. Acceptance of this point of view suggests that the measurement of flow of hot pastes and of cold pastes are, in effect, testing totally different properties which are not comparable.

It is the hope of this investigator that the findings of this study will serve as a basis from which a production technique, in terms of time-temperature relationships, can be developed for use in producing starch-thickened chocolate pie filling with predictable stability and flow.

REVIEW OF LITERATURE

Frankel (18), in a treatise on starch, stated that starch or starch-flour was known to the ancient Egyptians and Greeks. At that time it was derived exclusively from wheat. The production and application of potato starch appeared first in Europe at the close of the sixteenth century. Probably the greatest use of starch prior to 1830 was as a hair powder, although it was used to a limited extent in the textile and paper trades. Starch is not only one of the most extensively diffused but also one of the most useful ingredients contained in plants. Late in the nineteenth century Frankel reported that products from the vegetable world such as potatoes, wheat, maize, and rice were found to be useful sources for the manufacture of commercial starch. Since the late 1930's, the research of carbohydrate chemists has advanced rapidly and real progress has been achieved in the study of the composition, structure and behavior of starch. Parallel advancements in modern colloidal chemistry have been valuable factors contributing toward this development.

Chemical Fractions

French (19), in reviewing the chemical properties of starch, stated that common starches may be fractionated into components which differ both in chemical properties and in physical behavior. Apparently starches from different sources, such as corn, peas, wheat, and rice, differ from each other particularly in composition.

In 1924 Alsberg and Rask (2) in their work with cereal starches discovered that certain of these starches produced a blue color with iodine and others gave a red color. Their findings further indicated that when a suspension of starch granules in water was heated, those slurries which gave a red color with iodine converted into more viscous pastes than did those which gave a blue color. Brimhall and Hixon (10) stated that starch pastes are a heterogeneous system, each constituent of which may react differently toward changes in the conditions of measuring viscosity. Many early investigators have advocated this theory. Only since 1941 has there been general agreement upon the nature of starch heterogeneity. The theory is now accepted that the majority of starches contain molecules which can be classified according to two quite different structural patterns.

Amylose is designated as the fraction which possesses unbranched starch chains, dissolves in water without the formation of a paste, and gives a blue color with iodine. Schoch (39) indicated that the normal starches, i.e. corn, wheat, rice, and potato, contain 15 to 30 per cent amylose. Whistler and Weatherwax (46) analyzed 59 unimproved varieties of corn and reported an average amylose content of 25 to 26 per cent. Heated amylose solutions from common corn, at concentrations of one per cent, retrograde or revert to an insoluble state on cooling. Hot solutions of five per cent concentration of amylose set up rigid, irreversible gels when cooled to room temperature. The tendency of amylose to retrograde decreases the stability of starch pastes and is considered a detrimental feature except in products where gel formation is the primary objective. Studies have shown that waxy strains of maize, rice, barley and rye contain 0 to 6 per cent amylose. Hanson and co-workers (22, 23) have experimented with the use of waxy rice flour in the preparation of pre-cooked puddings, sauces, and gravies for freezing.

They concluded that these frozen products, thickened with waxy rice flour, were more stable after thawing than similar products thickened with wheat flour or cornstarch.

Amylopectin represents the constituent of starch which has a branched chain structure, forms a paste with hot water, and gives a red color with iodine. According to the literature, the relative proportion of amylose to amylopectin in starch varies greatly. Amylopectin comprises the major proportion of the common starches, corn, potato, wheat, and rice. Aqueous solutions of this fraction are relatively stable on cooking (39). For this reason amylopectin is considered the most important element in starches which are used as thickening agents, emulsifiers, and sizing agents for paper and textiles. Samec (38) concluded that the viscosity of a starch paste depends on the relative quantity of amylopectin present in the starch.

The presence of small amounts of non-carbohydrate materials, such as phosphorous, fatty acids, silicon, and nitrogenous material in the common starches has long been an established fact. Of these substances the phosphorous and fatty acids seem to be present in the largest amounts. The quantity varies with the starch, and those starches which are low in phosphorous content are correspondingly high in fatty-acid content (43).

Effect of Swelling on Physical Characteristics

In 1924 Alsberg and Rask (2) reported that when an aqueous starch suspension was heated, the granules swelled, then burst and finally, lost their anistropic properties. The original suspension was converted into a more viscous product which was usually termed a starch paste. These investigators further concluded that although the exact changes which took place were not completely understood, they probably involved the absorption of water by the starch grains with consequent swelling to a point at which the grains burst. The final result was conversion of the starch suspension into a sol which formed a rigid gel on cooling. This conversion they defined as gelatinization. In a later study Alsberg (1) substantiated the view of earlier workers that most types of starch heated in a water suspension do not disintegrate to form a colloidal solution. Starch granules merely swell and the process is a gradual one. Different starches increase their volumes to different degrees when heated in water, and even individual granules in the same sample swell to different degrees. On this basis Alsberg concluded that viscosity was attributable to unbroken swollen granules which still contained their quota of constituent amyloses.

Brimhall and Hixon (11) employed microscopic technique in observing the progressive swelling of granules in water suspensions. They concluded that the starch granules ceased swelling and became wrinkled when the temperature was increased beyond the point of maximum rigidity. Since there was no evidence of rupture in the membrane, they attributed these changes to the increased permeability of the membrane. Because of this increased permeability the membrane then offered no resistance to the exchange of contents with the outside medium. Anker and Geddes (3) commented that granule disintegration was unimportant to viscosity until swelling had progressed to the point where the granules became closely packed. The extent of granule rupture appeared to increase with concomitant increases in internal shearing stresses. In 1950 Bechtel (5) supported the theory that starch undergoes a complex series of changes during the cooking period. Chronologically these changes include swelling, collapse of the granule, solution of some of the constituents, and complete granule disintegration. Schoch (39) suggested that the starch granule is completely insoluble in water at room temperature but swells progressively upon heating until its outline becomes vague. The swollen granule is still present and the consistency and paste-like characteristics of the starch suspension are attributable to the mechanical jostling of these swollen masses. Kerr (28) reviewed the results of many research workers and presented evidence that swollen starch granules maintained in water in excess of 80° C slowly contract. Any application of high shearing stresses to these distended granules could result in their rupture.

Throughout earlier literature concerning the physical behavior of starch, confusion resulted from the inconsistent use of descriptive terms. More recent publications show greater compatibility in this respect. The term gelatinization may be defined as the process of converting a starch suspension to a sol which gels on cooling. Gelation is the formation of a gel or solidification of a sol. Gel is the term used to describe the jelly-like precipitate of a colloidal solution.

Viscosity

According to Radley (37), starch granules occupy a much larger volume in the system after swelling and gelatinization than before. Viscosity depends only on the volume of the dispersed phase and not on the degree of dispersion. Frequent references can be found in which the consistency of starch pastes is described as "apparent viscosity" (2, 7, 28). Bechtel and Fischer (7) stated that apparent viscosity is essentially a shear-dependent viscosity and is established by the ratio of shearing to rate of shear. Kerr (28) reported that starch pastes exhibit an anomalous viscosity. The effect measured is the result of a combination of many inherent properties of starch which has been gelatinized in aqueous media. Viscosity measurements are complicated by plasticity and elastic effects which arise from residual structure units of starch granules or new structural units in the paste which form through associative forces of the molecules. Sjostrom (41) concluded that viscosity of a paste is not identical to viscosity or fluidity of a homogeneous liquid. Viscosity in the paste is attributable to whole or disintegrated granules in suspension and is a measure of the degree to which the swollen granules crowd together. Schoch (40) concluded that much of the viscosity of a cooked paste must be attributed to swollen aggregates of granular structure because such pastes can be readily thinned by autoclaving or violent mechanical action.

Caesar (12) stated that consistency changes in a pure starch and water paste are comprised of four broad phases: starch and water suspension, gelatinization of the starch granule, partial rupture of the starch cells, and association or rethickening. Some of the variables which may affect the viscosity of a starch paste involve the inherent starch characteristics, treatment of starches during manufacture, concentration of the starch, presence of electrolytes, mechanical injury of the molecules, pH of the cooking medium, and the time and temperature of cooking.

Inherent Starch Characteristics

The findings of many research workers have indicated that the natural characteristics of starch granules influence the behavior of the granules during gelatinization. Kerr (28) asserted that starch granules from different sources show vast variety in shape and size. It has long been established that the larger granules of any particular type of starch gelatinize more easily than the smaller granules. It now appears that there may be some correlation between the dispersibility of a type of starch and its average granule size. Whistler and Smart (45) stated that starches may be distinguished by examination of the size and shape of granules, the temperature at which they gelatinize in water, the rate of swelling in various solvents, and the extent to which they combine with iodine.

In 1932, Caesar (12) experimented with 20 per cent starch pastes of high grade, commercial brands of tapioca, potato, sago, corn, and wheat. These pastes were prepared on the basis of moisture content, submitted to thorough agitation, and slowly heated to the boiling point. Caesar concluded that the consistency of the pastes tested was in the same order as listed, ranging from the greatest to the least.

Mangels and Bailey (33) experimented with hard spring patent, hard winter patent, soft winter patent, and durum wheat. Cold gelatinizing reagents were used and the swelling capacity was noted by viscosity measurement. From the results of this investigation they concluded that chemical differences which cause differences in physical properties of starch are complex in nature and may be attributable to structural differences in the starch granule.

Harris and Jesperson (23) studied the physiochemical properties of a series of experimentally prepared wheat starches. They found that the swelling power of wheat starch decreased with maturation irrespective of variety or environmental conditions. Gel strength and viscosity tended to increase with ripeness. Further research indicated little difference in viscosity and swelling power among wheat, rice, and barley starches. However, they reported data which suggested that potato starch possessed much higher viscosity and swell than the common cereal starches. In the same year, Harris and Jesperson (25) offered further data which substantiated the hypothesis that factors affecting the swelling property of the starch granule are complex. They found that differences in swelling power were significant among modified wheat, barley, and corn starches.

Woodruff and MacMasters (47) studied corn and wheat starches and concluded that the pasting results of some of these starches varied appreciably. In studying various commercial starches Nutting (35) observed that potato starch swelled most and produced the most viscous, unstable, and variable paste. This verified the earlier findings of Harris and Jesperson (25). Results of the experiment of Tanner and Englis (42) with different varieties and types of corn indicated that cereal starches tend to produce suspensions of low viscosity at relatively high concentrations, whereas non-cereal starches, such as potato, tapioca, and arrowroot, form highly viscous suspensions at relatively low concentrations.

From the studies of Campbell and co-workers (15) it appeared that specific use characteristics and finished product qualities of starch were closely related to water absorption, swelling, and granule rupture. In evaluating starches for specific uses, viscosity and gel formation were judged to be influential characteristics.

Treatment of Starch during Manufacture

Consistency changes in hot pastes from three different commercial cornstarches were studied by Caesar (12). His findings indicated that the three starches varied in swelling power and stability. Two starches thickened quickly and to a greater degree than the third sample. Some investigators (26, 46, 47) isolated starches in the laboratory. All found these prepared starches to differ measurably from the commercial types.

In his account of the manufacture of modified corn starches, Kerr (28) asserted that the degree of alteration of native starches affects the chemical properties of the starch granule and that these changes may range from the simple to the complex. Some industrial applications of starch require freedom from undesirable odors and discoloration. Kerr (28) reported that starch of superior whiteness without objectionable odors can be produced by the use of an oxidizing agent followed by a prolonged drying action.

Starches in which the physical characteristics have been modified are commonly classified as mobile, thin-boiling, and heavy-boiling starches. Evidence of mobility in a starch, according to Kerr (28), is characterized by its ability to create dust when agitated, to adhere and spread more evenly than normal starches, and to exhibit greater volume per unit of weight. Reasons for differences in mobility of starches are not clearly understood.

Sjostrom (41) stated that the modified starch granules in a thin-boiling starch paste still swell and disintegrate in hot water but have a lesser degree of hydration than ordinary starch granules. Sjostrom suggested that although other factors affected the difference in fluidity between thick-boiling and thin-boiling pastes, this relation in volume was the most important.

In 1941 Schoch (40) reported that it was possible to raise the solubility of starch by certain chemical modifications. Treatment of raw starch with oxidizing agents, such as alkaline hypochlorite or peroxide, increased solubility but decreased viscosity. With thin-boiling starches produced by acid treatment the reaction was one of glucosidic hydrolysis which reduced the size of the starch molecule from its highly associative colloidal dimensions. Reports by Kerr (28) indicate that the majority of starches which are marketed have viscosity below that of native starch. As a result of this reduction, a higher proportion of dry substance is required to thicken a given volume of liquid than the proportion of native starch needed to thicken the same volume of liquid. Furthermore, the pasted product from these so-called thin-boiling starches is fluid enough to be workable. The most common method used to modify starch for this purpose is by treatment with dilute acid. A thin-boiling starch granule swells considerably less than untreated starch, and the reduction in hot paste viscosity is the direct result of the decreased tendency to swell.

Schoch (40) presented evidence that prolonged dry-grinding in a ball unit disintegrated natural, unmodified starch granules. This resulted in a marked reduction in their pasting ability and further verified the data of earlier workers (1, 5, 28).

Effect of Electrolytes

A major portion of the experimental work reported in the literature indicated that distilled water was used as the liquid medium of control on pasting tests for starch. Bechtel (5) stated that starch undergoes a complex series of changes during cooking and that the rate of change is partly attributable to the presence of materials other than starch. Bisno (9) concluded that variations in the chemical composition of the water supply were sufficient to result in significant differences in the consistency of pie fillings. A change to distilled or softened water frequently resulted in noticeable changes in stability, viscosity, and tendency to gel. Kerr (28) investigated the effect of salts on the precipitation of starch granules. Kerr reported that the starch from a suspension which contained no sodium chloride settled more slowly than did the starch from a second sample containing sodium chloride.

Bechtel (6) studied the effect of differences of pH on the pasting characteristics of several commercial starches. Adjustments in pH were achieved through the addition of small amounts of HCL or NaOh to starch slurries immediately preceding the viscosity test. This method was followed to approximate the commercial method of neutralizing starches after their modification and to avoid the introduction of ions contained in buffers. Bechtel suggested that such ions may have important effects on viscosity as shown by the variability found in results of tests at the same pH with different buffers. He concluded that differences in pH gave different effects on unmodified and acid-modified cornstarch. The temperature of initial viscosity rise and the temperature at maximum viscosity were appreciably altered. Bechtel found that a given degree of alkalinity proved more effective in changing the viscosity characteristics of all starches tested than an equal degree of acidity.

Harris and Banasik (24) examined the effects of some electrolytes on cereal starches during preparation and gelatinization. Tests were conducted with several laboratory-prepared wheat starches and one commercially manufactured cornstarch. Their findings indicated that chemical treatment during the preparation of the starch had a marked effect upon the starch properties. Treatment with NaOH raised the pH of the dry starch and greatly increased the swelling power. Preparation with H_2SO_3 lowered starch pH and increased swelling power very slightly. Exposure of wheat starch to dilute solutions of HCL also lowered the pH and augmented the swelling power. Cooking in the presence of acid greatly increased granule swelling at temperatures of 90° C and above. Suspensions containing NaOH increased swelling at a temperature as low as 70° C but at 95° C exhibited a lesser degree of swell than the acidified suspensions. Harris and Banasik concluded that the presence of electrolytes complicate the problems involved in the gelatinization of starch granules.

Hains (21) reported that additions of citric acid decreased the viscosity of cornstarch pastes made with no sugar or with 20 per cent sugar. However, in pastes made with 40 and 60 per cent sugar Hains presented evidence that acid did not measurably decrease viscosity. She further concluded that the gel strength of cornstarch pastes, at all levels of sugar tested, increased when the pastes were cooked with citric acid.

Concentration of Starch

The work of Bechtel and Fischer (7) on the effect of starch concentration on viscosity verified the findings of Anker and Geddes (3).

Their findings indicated that each increment in concentration resulted in a greater increase in apparent viscosity. As the starch concentration was increased, the following changes associated with gelatinization were noted: 1) initial viscosity rise occurred at successively lower temperatures; 2) the rate of viscosity rise was more rapid; 3) maximum viscosity occurred at lower temperatures; and 4) the decrease in apparent viscosity on continued cooking was more rapid. Lowe (32) stated that reductions in viscosity of cooked pastes, resulting from the rupture of swollen granules, was greater with a 20 than with a 10 or 15 per cent concentration of starch.

Brimhall and Hixon (10) confirmed the fact that, beyond the point of a critical concentration of starch, each increase in concentration resulted in enormous increases in viscosity and rigidity of the resulting pastes.

Effect of Time and Temperature

Caesar and Moore (14) studied the viscous and plastic changes of several varieties of starch at a 20 per cent level of concentration. Viscosity measurements were recorded over a wide range in temperatures with a Caesar consistometer. Their findings indicated that a definitely fixed and specific temperature of gelatinization for all the granules of a starch is not predictable. Although the process occurred over a considerable range in temperature, the majority of starch granules gelatinized within a narrow range. They concluded that the length of cooking time is an important factor since the range of gelatinization varied with the rate of heating. Caesar and Moore agreed with Ostwald (35) in the theory that the lowest temperature in the gelatinization range should be accepted as the gelatinization point of the starch under given conditions of cooking and concentration.

Alsberg and Rask (2) reported findings concerning the gelatinization of some commercial cornstarches by heat. In 4.5 to 5 per cent concentrations of cornstarch in a water medium they found no significant changes in viscosity up to 65° C. Between 65° and 68° C viscosities began to increase gradually and at a uniform rate. Maximum viscosity was reached at 91° C. They attributed these increases in viscosity to simultaneous and gradual changes in the starch grains over a temperature range of 25° C. Alsberg and Rask concluded that the gelatinization temperature is not the temperature at which gelatinization is completed but only that of an early part of the process. As a result of their studies, these investigators offered the following observations concerning the gelatinization of starch: (1) sharply drying or thoroughly wetting a starch modified the gelatinization temperature, (2) gelatinization was incomplete unless adequate quantities of water were available, (3) the rate of heating had a marked effect on the starch gelatinization temperature.

Lowe (32) stated that starch may swell to a certain extent at lower temperatures, but it does not reach maximum viscosity until a higher temperature is attained. The temperature of maximum viscosity varies with the sample of starch. She reported maximum viscosity temperatures for wheat as 95° C and corn as 91° C.

As early as 1925 Alsberg (1) reported that starch granules are capable of swelling in cold water but are restrained from doing so, beyond a certain limited degree, by the anatomical rigidity of the granule structure. When this rigidity is relaxed by heat, the granule substance swells further. Alsberg suggested that the ease with which the granule structure is softened by heat and the extent to which heat will cause swelling are influenced by the inherent swelling power of the starch granule and the relation of the mass of swelling substance to the surface area of the granule.

The findings of Anker and Geddes (3) emphasized the importance of maintaining a uniform rate of heating throughout the gelatinization process for consistent results. Starting temperatures exceeding 45° C resulted in a substantial increase in maximum viscosity.

Bechtel (6) reported that viscosity curves indicated that rapid heating lowers the temperature of the initial viscosity rise and decreases the time required for holding starch pastes at 90° C to reach maximum viscosity. From his findings Bechtel reasoned that there appears to be a temperature for each starch at which it gelatinizes rapidly and at which subsequent breakdown is slow. For unmodified cornstarch this was about 90° C. This data has been verified by other authors (3, 32). Bisno (9) recommended that rapid heating to the optimum temperature and quick removal of the starch paste from the cooking kettle, followed by rapid cooling was most conducive to the production of maximum viscosity in commercially produced pie fillings.

Effect of Fatty Acids

According to Schoch (40), some of the physical differences between tuber and cereal starches are ascribed to the presence of fatty acids in the latter. Cornstarch pastes are shorter, less slimy, and more opaque than pastes from tapioca starch. Schoch (40) found that a paste from a 5 per cent concentration of raw rice starch required a minimum aging period of 24 hours to give a weak gel, whereas a similar paste of defatted rice starch set up a strong gel immediately upon cooling to room temperature. He concluded that when unmodified starch was defatted, the maximum viscosity was lowered to approximately 50 per cent of the original starch. These findings were later verified by Bechtel (6).

Whistler and Smart (45) stated that fatty acids were first thought to be combined with the carbohydrate but were later found to be merely adsorbed on the carbohydrate and were completely removable by acid hydrolysis. Lowe (32) commented that fatty acids were found in the amylopectin fraction of starch. Potato starch was reported to contain no fatty acids, whereas corn and rice possessed a relatively high percentage. Whistler and Smart (45) indicated that waxy cornstarch contained only 0.06 per cent fatty substance.

Jordan and associates (27) compared the viscosity of cornstarch puddings made with homogenized and non-homogenized milk. Using a Brookfield viscosimeter, they found that puddings containing a concentration of cornstarch in excess of 3 per cent were more viscous when made from homogenized milk than when made from non-homogenized milk. The investigators reasoned that these differences in viscosities might be influenced by the comparative surface area of the fat globules in the two varieties of milk tested. Jordan and co-workers concluded that fatty materials (i.e. soaps, fatty acids and natural fats), when present in certain proportions, produced an increased viscosity in starch pastes.

The effect of nonfat dry milk solids on the viscosity and gel strength of starch pastes were studied by Morse and her co-workers (34). They used the Stormer viscosimeter to measure the viscosity of thin pastes and a Bloom gelometer to measure the gel strength of thick pastes.

They found that nonfat dry milk solids did increase the viscosity and gel strength of pastes in proportion to the amount of dry milk solids used. Morse and co-workers were able to make limited predictions from their data concerning the gel strength of mixtures containing different proportions of dried milk solids and thickening agent. These workers suggested that salt, in the amounts used in this experiment, had little or no effect on gel strength. However, in the thin pastes the NaCl did increase the viscosity to a small degree.

Effect of Sucrose

Starch chemists have long recognized the apparent changes in the behavior of the starch granule when starch is combined with materials other than water. The effect of sugar concentration upon the quality of the finished product has been a challenging problem to these investigators.

In 1931 Woodruff and Nicoli (48) experimented with 5 per cent suspensions of corn, wheat, rice, potato, and cassava starches with varied proportions of sucrose. At that time no satisfactory methods of measuring viscosity or gel strength had been established. The conclusions of the investigators were drawn from changes observed in appearance and photographs of changes in pasting. The addition of 10 or 30 per cent sucrose produced increasingly softer gels in root starch pastes. The addition of 50 or 60 per cent sugar produced a syrup. The same percentages of sucrose were added to the cereal starches. These gels were more transparent and tender with each increase of sugar. The addition of 50 per cent sucrose produced a gel which would not mold successfully and the addition of 60 per cent sucrose produced only a syrupy, viscous mass. On the basis of these data, Woodruff and Nicoli speculated that the presence of large amounts of sucrose prevented the starch granules from imbibing the water required for swelling.

According to Trempel (44), the addition of sugar raised the gelatinization temperature of a starch and water suspension. He verified the findings of Woodruff and Nicoli (48) concerning the effect of high concentrations of sucrose on the swelling of starch granules. Trempel recommended that the proportion of sucrose should not exceed three and one-half times the amount of starch used. He reported that seven to eight pounds of sugar to one pound of cornstarch in a specific volume of water resulted in a cooled gel which was dull, thin and possessed a raw starch taste when prepared under ordinary conditions.

Hains (21) tested the viscometric effect of 20, 40 and 60 per cent sucrose concentrations in 12 per cent cornstarch pastes. She found that viscosity increased when sucrose constituted 20 per cent of the liquid weight. However, with additions of 40 and 60 per cent sucrose, the maximum viscosity of the pastes progressively decreased. Hains presented evidence that higher temperatures and much longer cooking periods were needed to obtain maximum viscosity when increased proportions of sucrose were added to starch pastes.

Ferree (17) studied the effect of the concentration of sucrose on the viscosity of cornstarch pastes made with different liquid mediums. She used sucrose in proportions of 9, 15, 21, and 27 per cent of the weight of the liquid. The liquid mediums used in her research were tap water, distilled water, reconstituted nonfat dried milk solids, and reconstituted whole dried milk solids. Ferree reported that, except for the paste made with whole dried milk solids containing 21 per cent sucrose, the maximum viscosity of sweetened and unsweetened pastes made with tap water was higher than that of similar pastes made with other mediums. In all cases maximum viscosity of those pastes made with whole dried milk solids were appreciably higher than that of pastes made with distilled water. Results of these tests showed the descending order of maximum viscosity for these mediums to be tap water, reconstituted whole dried milk solids, distilled water and reconstituted nonfat dried milk solids.

The observations of Hains (21) and Ferree (17) indicated that the effect of the proportion of sucrose on the viscosity of cornstarch thickened pastes cannot be accurately predicted without taking into consideration the proportion of the other ingredients used.

Gel Properties

Lowe (32) has stated that there is no distinct line of separation between a sol and a gel. A typical sol is fluid; a typical gel has a certain amount of rigidity. Gels are unique in having a dispersion medium which is still liquid but is held in the gel state by the miscelles forming a definite structure. Gelation is a function of contraction and the volume of the dry micelles plus that of the dispersion medium is greater than that of the two combined. The degree to which a specific starch paste gels on cooling is a primary concern in the food industry.

The literature contains numerous references concerning differences found in the properties of hot and cold starch pastes. According to Bechtel (5) the properties of starch gels depend upon the natural variety of starch, treatment during manufacture, and all conditions to which the starch is subjected during cooking. Bechtel conducted tests on unmodified cornstarch suspensions by heating them to 91° C. The resulting pastes were poured into molds and stored in a 25° C water bath for 24 hours before they were tested for gel strength. The data of Bechtel presented evidence that the percentage increase in rigidity and breaking strength of gels during aging was dependent upon the modification of the starch. The acid-modified starches which had been cooked to 91° C and cooled to room temperature exhibited greater increase in rigidity and breaking strength than did the unmodified starches which had been given identical treatment. The effect of final cooking temperature of starches on the properties of their gels varies with the degree of modification of the starch. The findings of Bechtel indicated that, with increased modification of the starch, the viscosity of the acid-modified cornstarches decreased to a greater extent than did the rigidity and breaking strength of their gels.

Woodruff and MacMasters (47) found that there was no relationship between the consistency of hot pastes of unmodified cornstarch and the properties of its gels. It has been established that when cornstarch is oxidized, rigidity and breaking strength of gels decrease more than does hot-paste consistency. These investigators proved that acid-modified cornstarch produced a smaller decrease in rigidity and breaking strength than in viscosity. Woodruff and Nicoli (48) experimented with various tuber and cereal pastes at a 5 per cent starch-to-water concentration. They reported that maximum gel strength was obtained in each starch when it was cooked to a temperature of 90° C or higher. The cereal starch gels were well-formed and had clearly defined outlines, whereas the tuber starches gave poorly formed gels. Bisno (9) verified the findings of Woodruff and Nicoli.

Knowles and Harris (30) observed the behavior of starch gels from different classes and varieties of wheat. They concluded that 90° C was the critical temperature for gel formation for 5 per cent starch suspensions. These investigators found that gels never formed below this temperature, that gels sometimes failed to form at 90° C if the conditions of gelatinization were not ideal, and that the resulting gels were usually week and displayed evidence of syneresis. They further decided that starches derived from soft wheats possess lower gel strengths than those prepared from hard wheat.

Throughout the starch industry it is a generally accepted fact that prediction of cold paste consistency of a starch from its hot paste viscosity is impossible.

Effect of Batch Size on Flow Properties

The literature contains reports of relatively few studies in which differences in starch behavior attributable to batch size have been considered.

Billings and associates (8) experimented with cream pie fillings prepared in multiples of an 8-pie batch. From preliminary tests the investigators found it necessary to modify the multiple of the formula by increasing the amount of soft wheat flour required to produce fillings of acceptable consistency. Using the 8-pie batch of pie filling as a base, the workers increased the flour 10 per cent for the 16-pie and 24-pie batches and 35 per cent for the 32-pie batch. According to Billings and associates, the increase in proportion of flour to liquid was necessary to compensate for the reduced thickening effect of the flour. Factors contributing to this reduced thickening power were slower rate of heating and lower final temperature as the batch size was increased. The radius of spread of hot fillings was considered a reliable and practical measurement for predicting the consistency of the final product. These workers reported that they found subjective tasting for the disappearance of raw starch flavor a more reliable criterion for determining the end point of cooking than final temperature or time of cooking. Billings and co-workers concluded that both final temperature and time were directly dependent upon the rate of heating.

Longrée (31) investigated the effect of increasing batch size from 1 to 4 gallons on cooking time, temperature of batch, and final viscosity of medium white sauces. The white sauces, designated as medium thick, contained 8 ounces of flour per gallon. Tests were made using all-purpose flour and soft wheat flour. The soft wheat flour displayed a greater thickening power than the all-purpose flour. With increasing batch size, the length of cooking time was increased and final viscosities of the finished sauces decreased. Differences between the 1- and 2-gallon batches were slight. The cooking time in the 4-gallon batches was unduly long and final viscosities were below the standard of control. Longrée commented that the additional stirring required during longer cooking may have been partly responsible for the low viscosity of the large batches.

Caesar (13) stated that batch size does have a tremendous effect on the properties of starch pastes and also of dextrins with the possible exception of the most highly soluble envelope type. In addition, Caesar suggested that the length of the heating period and the temperature of the paste may be relative to batch size but that the cooling period is even more important to the paste characteristics of starch than the heating period. Agitation plays an important role at all times and especially in the cooling process of starch pastes.

Objective Tests for Starch Pastes

The principle uses of starches in industry are directly dependent upon their colloidal paste properties. Some of the characteristics of cooked starch pastes are viscosity, plasticity, gel strength, and rigidity. These characteristics are measured in terms of hot paste viscosity and cold paste body.

Viscosity measurements

Industry has developed several procedures to test viscosity of starches. These objective measurements are made on both hot and cold pastes.

Scott test for hot paste viscosity (28). This test is probably the most widely used method for determining the hot paste viscosity of starch pastes. A quantity of starch at known pH is stirred to a slurry with 280 cubic centimeters of distilled water in a German-silver beaker. The beaker and contents are then placed in a boiling water bath in which, with stirring, the starch is gelatinized and heated for 15 minutes. Two minutes preceding the end of the cooking period, 200 cubic centimeters of the paste are transferred to a Scott viscosity cup which is also held in the water bath. At the end of the total heating period, the plunger valve which closes the orifice on the bottom of the cup is raised and the time in seconds is noted for a given volume of the paste to fall into a graduated cylinder. The specific Scott test viscosity value of the starch paste under consideration is measured in terms of the seconds required for the starch to flow from the test cup.

Standard starches are used to set up permissable limits of variation in the viscosity of other starches to be tested by this method. Scott test viscosity may also be considered as a relative viscosity in this sense.

Stormer viscosimeter (28). This instrument is used to evaluate the viscosity of cold paste body. It is comprised of a cylinder immersed in the test paste which is contained in a metal cup surrounded by a water bath. The immersed cylinder is rotated by a free-falling weight acting through a gear and pulley system. The time in seconds necessary for a given weight to produce a certain number of revolutions is taken as a measure of cold paste body. A revolution counter is a part of the instrument.

The starch is gelatinized and cooked for a 15-minute period. The paste is placed immediately in a constant temperature water bath, preferably 25° C in a closed container. At the end of a specified aging period, any surface skin on the paste is carefully removed and discarded. The remaining paste is very gently stirred with a spatula for several seconds and then transferred to the cup of the Stormer viscosimeter. The viscosity of the paste is noted at 25° C.

Hoeppler viscosimeter (28). This instrument involves the use of a principle different from that of the Stormer viscosimeter. Measurements are made of the time required for a given weight to fall, in vertical motion, through a measured column of paste. The column is surrounded by a constant temperature bath so that, with only slight modifications, the instrument can be adapted to the measurement of hot paste viscosity as well as cold paste body.

Brookfield Viscosimeter (28). This is torsional type of instrument. Spindles of various types are driven by a synchronous motor. The force of the thickening starch paste, acting on the spindle, is recorded in terms of poises and is taken as a measure of the viscosity.

Brabender amylograph (28). This instrument is a comparatively complicated one. It is a modification of the Brookfield viscosimeter but involves the same general principle. In this method the paste is held in a cup surrounded by an air bath for temperature control. The cup is revolved at constant speed. The measuring and stirring device consists of a disc to which are attached several short rods extending into the paste. The torque impressed on the measuring unit is transmitted to a recording torsion balance. A continuous, graphical record of the gelatinization process is traced by the instrument over the entire period of the test. The temperature of the starch may be increased at a fixed rate and may be checked at any point and held at this level by thermostatic control. By switching off the heat supply, the paste may be cooled to any desired temperature and the change in viscosity noted.

A cooling coil is provided for the circulation of cold water and the acceleration of the cooling of the cooked paste.

Caesar consistometer (28). This instrument may be used to measure several characteristics of starch simultaneously. This apparatus records a continuous history of the pasting operations. Characteristics of the starch paste which may be evaluated from this record include the gelatinization point of the starch, peak viscosity obtainable with a definite cooking procedure, specific viscosity after a prescribed cooking operation, rate of increase in paste body with falling temperature, and cold paste body after a controlled cooling period. For the test a standard paddle, connected by a shaft to an electric motor, is suspended in a beaker containing the starch slurry. The beaker is surrounded by a heating bath, and the temperature is raised at a regulated rate. The paddle and motor move at constant speeds. Changes in paste body are indicated by the differences in the electrical input to maintain a constant motor speed. After the starch is cooked, cold water may be introduced into the bath to cool the paste.

Caesar and Moore (14) reported that the principle function of this instrument is to measure the viscous and plastic changes in starch pastes at any temperature at relatively high concentrations. They stated that significant differences in observed values were more readily obtained with a 20 per cent starch solution than with starch solutions of lesser concentrations.

<u>Corn Industries viscometer</u>. Keeler and Bechtel (29) used this instrument in their work on the comparison of the flow properties of different type starches. They felt that this instrument provided a controlled and reproducible method for pasting as well as a record of the change in consistency as cooking progressed. The instrument consists of a stainless steel beaker immersed in a thermostatically controlled bath which contains water or a liquid with a higher boiling point. The starch slurry is stirred by an agitator which consists of a scraper and a propeller. The scraper serves to remove the layer of pasted starch from the walls of the vessel. The

propeller, driven through a gear differential, stirs the center of the paste and also serves as a means of measuring the viscosity changes. The force which the propeller encounters is continuously balanced by a dynamometer, consisting of a weighted arm which moves through a vertical arc. A series of interchangeable weights are provided for the dynamometer so that it covers a relatively wide range of torques between 250 and 2000 gram-centimeters. The pen, which is attached to the dynamometer, continuously traces the record of viscosity changes on a strip-type recorder. The cover acts as a condenser and prevents evaporation of water from the paste during the heating period. The viscosity changes of the paste are recorded in terms of torque which is the measure of the force the propeller encounters as it turns through the gelatinizing paste.

To make a determination the metal beaker is placed in the preheated bath and the stirring device is attached and set in motion. The starch paste is prepared by stirring the starch into the quantity of water needed to yield a slurry of 1000 grams. The water should be at room temperature. The slurry is poured into the viscometer and the recorder is started immediately. The condenser cover is then put in place and the remainder of the test is accomplished automatically. Readings of the paste temperature at desired intervals are easily obtainable from the strip-type recorder chart which unwinds at a constant speed.

Line-spread test

Grawemeyer and Pfund test. Grawemeyer and Pfund (20) have developed a line-spread test for determining the flow of cooked pastes. This test is effective in measuring the spread of both hot and cold samples. Grawemeyer and Pfund made objective measurements on applesauce and cream fillings.

Longrée (31) used this type of viscosity measurement in her comparative study of thin, medium, and thick white sauces.

In this test a flat glass plate was placed on a surface checked for evenness with a spirit level. A diagram of concentric circles was placed beneath the glass plate. The diameter of the smallest circle was 2 inches and the gradations of the surrounding circles were at one-eighth inch intervals. A hollow cylinder of the exact diameter of the smallest circle was used to hold the poured sample. This cylinder was placed directly over the innermost circle, filled with the paste to be tested, and then leveled with a spatula. The cylinder was lifted carefully and the sample allowed to flow for two minutes. Readings were taken at four widely separated points which designated the outer limits of flow of the sample. The average of the four readings was considered the value representing the line-spread of the paste.

Gel strength tests

A variety of instruments incorporating different principles have been used for the measurement of the gel strength of starch pastes. Kerr (28) stated that several of the instruments used in practice are the rigidometer, Tarr-Baker jelly tester, and the penetrometer. The rigidometer measures the rigidity or lack of elasticity of a gel. The Tarr-Baker jelly tester gives a value which is proportional to the force necessary to rupture the gel and which may also be a function of the elastic limit. Penetrometers are of two types. The blunt plunger type tests a combination of plastic and elastic effects. The tube type of plunger measures the resistance of the gel to cutting action.

Exchange Ridgelimeter (16). For this determination the paste samples are stored in jelly glasses provided with sideboards. At the end of a controlled aging period, the sideboards are removed and the samples leveled to the rim of the glass. Each sample gel, after removal from the glass by inverting it on a glass plate, is allowed to stand for two minutes. A micrometer screw is adjusted and the per cent of sag is read. This test measures the rigidity of a gel in terms of percentage of sag.

Tarr-Baker jelly tester (28). The principle of this test is the gradual application of pressure to a plunger of known area which rests upon the surface of the gel. The pressure is read the instant that the gel breaks.

In this test the starch slurry is placed in a porcelain cup and cooked in a boiling water bath for 30 minutes. The cooked paste is cooled quickly, immediately covered with a film of light mineral oil, and aged for one hour in a water bath at 20° C. The oil is drained off and the gel is placed under the plunger of the tester. With 500 cubic centimeters of water in the testing jar at the start, the flow of water is adjusted so that the manometer column rises 60 cubic centimeters per minute. The manometer is read when the gel breaks. Tests are made in triplicate and readings are averaged. The gel strength is reported as the height in centimeters reached by the liquid in the manometer at the breaking point of the gel.

Kerr modification of Saare and Martens test. One of the first tests proposed for the measurement of gel strength of a cold paste was developed by Saare and Martens. This test consists of determining the weight required to withdraw a disc from a gel in which it has been imbedded. A modification of this method by Kerr (28) is used frequently. In this test the hot, cooked starch paste is immediately poured into a glass container to a definite level. A circular metal disc of known diameter is suspended into the paste by means of a metal rod connected to the center of the upper surface of the disc. The metal rod is crooked at the top and is hung over a bar which rests on the top edges of the container holding the sample. The length of the rod is such that, when it is suspended over the horizontal bar, it permits immersion of the test disc in the paste to a depth of three centimeters. A thin film of light oil is placed on the top of the paste as soon as the disc has been inserted and properly centered. The test vessel is held in a constant temperature bath at 25° C for 24 hours. The test container is then removed and placed on a bridge over one pan of a large, sensitive beam balance. A specially made hook, suspended from this beam, fits into the bend in the rod attached to the disc. Small size shot are added at a fixed rate to the other pan. The weight of shot is noted at the time when the disc fractures the gel. The weight of shot, less the weight of disc and all connections to the beam of the balance, divided by the exact area of the lower surface of the disc is taken as the gel strength. The result is expressed in grams per square centimeters for a given concentration of starch.

<u>Fuchs penetrometer</u>. Kerr (28) reported that most penetrometers are not sufficiently sensitive to distinguish between the various grades of acid-modified industrial starches. However, Kerr admitted that the instrument constructed by F. W. Fuchs is as sensitive and accurate as the modified Saare method of determining gel strength. The cooked starch

paste is immediately placed in a closed, wide-mouthed container for storage in a constant temperature bath. At the end of a specified aging period the cover is removed and about a one-fourth inch layer of gel is cut off and discarded. The plunger in this instrument is a highly polished, sharpened, hollow metal tube which resembles a cork borer. This plunger is adjusted so that it rests on the top surface of the gel. The plunger is released and the time required for the hollow tube to cut the gel up to a predetermined depth of paste is noted.

PROCEDURE

Development of Testing Equipment

Several pieces of specially designed equipment were necessary in developing a technique to determine the spread from a cut sample of cooled chocolate pie filling.

A glass plate 12 x 12 x .25 inches from which a circle 9.375 inches in diameter had been removed was superimposed upon a second glass plate 12 x 12 x .25 inches. These two plates were bound together by four rubber bands 3 x .375 inches. One rubber band was mounted one half inch from each side for the purpose of binding the plates together with an equal distribution of tension.

A mold was devised from a standard metal baking pan 1.5 inches high and 9 inches in diameter with a circle 7 inches in diameter removed from the bottom. Before the hot sample was poured into the mold the pan was inverted and placed within the 9.375 inch cut-out area of the upper glass plate.

The round, stainless steel sample cutter was constructed with a diameter of 3.125 inches and a height of 1 inch. An outer band of metal .375 inch wide and .0625 inch thick was welded .25 inch from the top edge of the cutter to form a base for the expansion band.

The round, stainless steel expansion band was constructed with a diameter of 3.25 inches and a height of .75 inch. When mounted in place, the expansion band rested upon the .0625 inch ridge formed by the thickness of the outer band of the sample cutter. The cutters and their respective expansion bands were matched and coded.

Nine complete sets of the testing equipment described above were required for each replication of this experiment.

Basic Formula

The formula used in this limited experiment was developed through preliminary study of products made from selected formulas in which cornstarch and cocoa powder were used as thickening agents. No formulas in which whole egg or egg yolk constituted a part of the thickening effect were considered.

The selected formula consisted of constant proportions of cornstarch, whole dried milk solids, cocoa powder, granulated sugar, butter, salt, vanilla and cold water. Proportions of ingredients for all batch sizes tested are listed in Table 9. Percentages of ingredients, based on the total weight of the mixture, follow:

Ingredients	Percentages
Cornstarch	3.8
Whole dried milk solids	9.0
Cocoa powder	3.8
Sugar	18.6
Butter	0.8
Salt	0.1
Vanilla	0.8
Water, cold	63.2
TOTAL	100.1

Cold water, in which the natural degree of hardness had not been subjected to alteration by the addition of chemicals, was used for this study. A sample of water used in each replication was sent to the laboratory of the College Sanitarian for analysis of the degree of hardness.

All remaining ingredients, except butter, were obtained from the College Food Stores and stored at room temperature throughout the study.

The cornstarch and the superfine granulated sugar were kept in separate, covered, stainless steel bins. The cocoa powder and iodized salt were stored in their original fiber containers. Spray process Parlac, manufactured by the Borden Milk Company, was the type of whole dried milk solids used throughout this experimental work. The entire lot of Parlac was purchased in five pound, hermetically sealed tins.

Imitation vanilla was purchased in four 1-gallon glass jugs from the same case lot and was composed of vanillin, caramel, water, propylene glycol and 0.1 per cent benzoate of soda.

Butter, in chiplet form, was obtained from the College Dairy and stored in a deep freeze unit.

It was necessary to transport the ingredients from the laboratory to the institutional kitchen for the cooking process. All ingredients for each batch were weighed or measured in advance. The sugar, cornstarch, and cocoa were put into separate, brown paper bags and the bags were fastened with freezer tape; the dried milk solids were weighed into a polyetheylene bag and fastened; and the butter, salt, and vanilla were placed in separate, covered, plastic containers. No ingredients were weighed or measured for more than two weeks in advance of their intended use. During this interval, with the exception of the butter which was returned to the deep freeze unit, the weighed ingredients were kept in dry storage at room temperature.

Treatment

Cold water was measured into a 40-gallon steam jacketed kettle and heated to a temperature of 55° C. This kettle was equipped with an

Ashcroft 30# pressure gauge and the water was heated by steam with a pressure range of 16 to 19 pounds.

A centigrade thermometer was suspended in the kettle in such a manner that the bulb was centered within the mass. Adjustments in the position of the thermometer were necessary in relation to batch size to insure comparable readings. This thermometer registered the temperature of the mass during the entire preparation period.

The whole dried milk solids were blended manually with approximately one half of the sugar. This sugar and milk dry mix was scattered on the surface of the water, which had been heated to 55° C, and blended with a french whip. After thorough blending, the mixture was allowed to stand 20 minutes to allow time for reconstitution of the dried milk solids. Time required for blending the sugar and milk dry mix with the water and any change in temperature noted during this procedure were recorded.

The cocoa powder was sifted and then blended for 10 minutes with the cornstarch and remaining portion of the sugar with the paddle attachment on a 3-speed mechanical mixer operating at first speed. At the end of the 20 minute reconstitution period for the sugar and milk mixture, the dry mix of cocoa, cornstarch, and sugar was scattered on the surface of the sugar and milk solution and stirred manually. The time required for this addition and the final temperature of the mass at this stage were recorded.

The steam was turned on and the mass was heated to 82° C, with frequent, moderate stirring. Steam pressure of approximately 16 to 19 pounds was maintained throughout the cooking period. The temperature of the mass and the pressure poundage of the kettle were recorded at 2-minute intervals. The first visible evidence of thickening within the mass was noted in relation to the heating time required and the temperature attained.

The end cooking temperature was arbitrarily set at 82° C. When this point was reached, the steam was turned off and the butter, salt and vanilla were manually stirred into the mass. The time required for this blending and the accompanying temperature change of the mass were recorded.

Batch Size

Batches were prepared in 14, 12, 10, 8, and 6 gallon amounts. An end cooking temperature of 82° C was kept constant for all batch sizes. After the incorporation of the butter, salt, and vanilla, the holding periods of the mass in the steam jacketed kettle remained constant for all batch sizes.

There were four replications for each batch size indicated above.

Preparation of Samples

In this investigation it was the intent of the worker to determine the effect of batch size upon the flow of chocolate pie filling under conditions which most nearly paralleled current quantity food preparation practices. Since chocolate pie is most frequently served at room temperature, it seemed more realistic to measure the flow of a sample cut from a molded amount of cooled filling than from a sample of hot filling.

<u>Pouring of mold</u>. The hot filling was removed from the kettle at the end of each of the stipulated holding periods in an amount sufficient to pour 3 molds of 3 pints each into specially designed metal molds which had been adjusted upon the double glass plates. The 3 molds within each series were

poured at 1-minute intervals and coded in the order in which they were poured. Nine molds from each replication were poured as follows:

Series	No. of Samples	Minutes Held at 82° C
A	3	0
B	3	30
C	3	60

Through preliminary work on the technique of pouring and handling the filling, it was found necessary to devise a method to prevent the formation of a heavy "skin" layer on the surface of the poured mold. Neither Saran wrap nor absorbent paper alone offered sufficient protection, but their combined use served this purpose adequately.

After the filling was poured through the opening of the metal mold, the opening was covered with a double thickness of absorbent paper plus an outer layer of Saran wrap. The poured molds were allowed to cool undisturbed for 3 hours at room temperature. From this point, the individual molds within each series were handled at 7-minute intervals. This resulted in progressive cooling periods of 3 hours, 3 hours 7 minutes, and 3 hours 14 minutes, respectively, for the 3 molds of each series. The order in which the individual molds of the Series A, B, and C were poured established the sequence in which the molds were handled throughout subsequent testing.

Cutting the sample. At the end of the cooling period, the rubber bands were carefully severed to release the tension on the glass plates. The layer of Saran wrap and the double thickness of absorbent paper were removed in a single, swift operation. Since there was evidence of excess moisture trapped between the absorbent paper and the Saran wrap during the cooling period, care was taken to prevent the condensate from draining back on to the surface of the molded filling.

The cutting edge of the sample cutter was lubricated by dipping it into salad oil. The excess oil was removed with an absorbent paper towel. This step was necessary to lessen the resistance encountered when the cutter came into contact with the filling. One sample was cut from the center of each mold of filling. After the sample cutter, complete with expansion band, was inserted into the molded mass, the upper glass plate was elevated and removed. Next, the metal mold was removed.

With the cutter still in position, the excess filling around the outer edge of the cutter was removed with the aid of a rubber squeegee and a common household rubber scraper. A damp, lint-free cloth was used to remove any remaining film from the glass plate. The expansion band was then removed from the cutter and the sample was leveled, by means of a thin-edged utility knife, to a constant depth of 1 inch. This depth was equal to the height of the cutter without the expansion band.

The cutter was removed at the end of the sixth minute in the seven minute work period allotted for each sample cutting. This procedure released the sample and allowed it to flow freely. Each sample was permitted to flow for a period of 90 minutes before measurements of flow were taken. All sample plates were coded for series and sample cutters.

Recording the sample. The image of the sample was recorded by means of a photoflood lamp casting the shadow of the sample upon Technifax Diazo blue line paper. The photoflood lamp was inserted into a 9-inch metal reflector and mounted on a ring stand in such a manner that the bulb was suspended 12 inches above the upper surface of the glass plate holding the sample.

The light-sensitive paper was placed in position under the glass plate. The exposure time was arbitrarily set at 2 minutes and remained constant for all samples.

The ammonia fumes required for the development of these images were obtained by heating household ammonia to 100° C in a 9-inch stainless steel bowl. The exposed Technifax paper was held manually in a horizontal position approximately 6 inches above the surface of the boiling ammonia for a period of 2 minutes. All images were developed within a period of 15 minutes following the completion of the exposure time.

Objective Measurement

In determining the amount of flow for each cut sample after the 90-minute flow period, it was necessary to use an accurate means of calculating the final area of the sample and the initial area of the cutter used to obtain the sample. A compensating polar planimeter adequately served this function. This scientific measureing instrument was operated manually to trace the circumference of the printed image. The recording wheel automatically presented the area measurement in terms of square centimeters.

To determine the initial area of the sample before it was released for the 90-minute flow period, the cutting edge of the sample cutter was heavily coated with a red wax pencil. It was then pressed firmly against a sheet of white mimeograph paper. This imprint gave an accurate outline of the cutter from which the area was determined by the compensating planimeter.

The amount of flow for each sample was determined by subtracting the area of the cutter from the area of flow of the cut sample. This value, expressed in square centimeters, was read to the nearest 0.1 square centimeter.

The results of the spread tests for all samples were compiled for four replications of each of the five batch sizes tested. This data was analyzed to determine the effect of batch size and holding time on flow.

Time-temperature curves, based on the average for each specific batch size, were plotted. In evaluating the effect of batch size on flow, these relationships were also studied.

Illustration of Technique

The development of the testing equipment, preparation of the samples, and the technique of objective measurement of flow of the cut samples have been previously described.

The testing equipment used in this research and the consecutive steps in the procedure for pouring the mold, cutting and leveling the sample, releasing the sample for flow, recording the image of the sample, and measuring the sample area are illustrated in Figures 1 through 10.

Key to Photographs

A. Glass plate 12 x 12 x .25 inches
B. Glass plate 12 x 12 x .25 inches with circle removed
C. Metal mold 9 x 1.5 inches with 7 inch circle removed
D. Glass plates bound together with rubber bands
E. Complete assembly of molding equipment
F. Pouring the mold
G. Saran wrap
H. Absorbent paper circles
I. Stainless steel expansion band for cutter
J. Stainless steel sample cutter
K. Assembly of sample cutter and expansion band
L. Inserting the sample cutter assembly
M. Removing of glass plate
N. Removing the metal mold
O. Removing the excess filling from around the sample cutter
P. Leveling the cut sample
Q. Removing the sample cutter
R. Ring stand and photoflood
S. Technifax diazo blue-line paper in position
T. Compensating polar planimeter

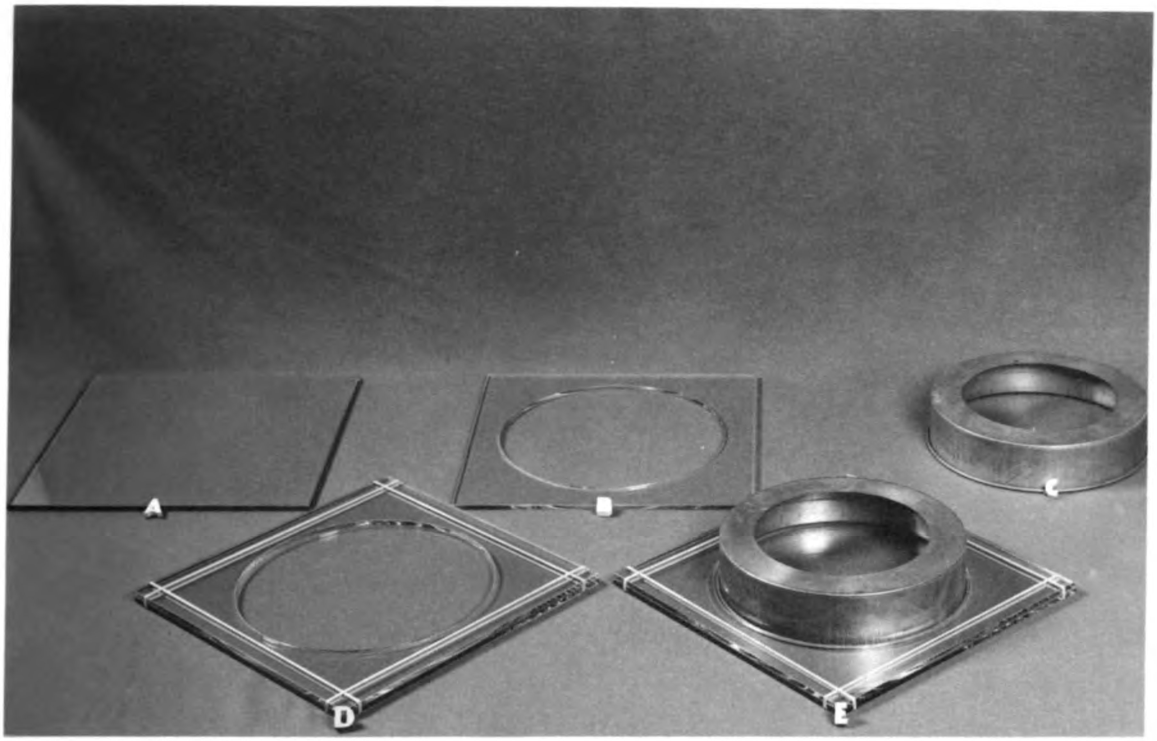

Figure 1. Molding equipment: individual parts, partial and complete assembly.

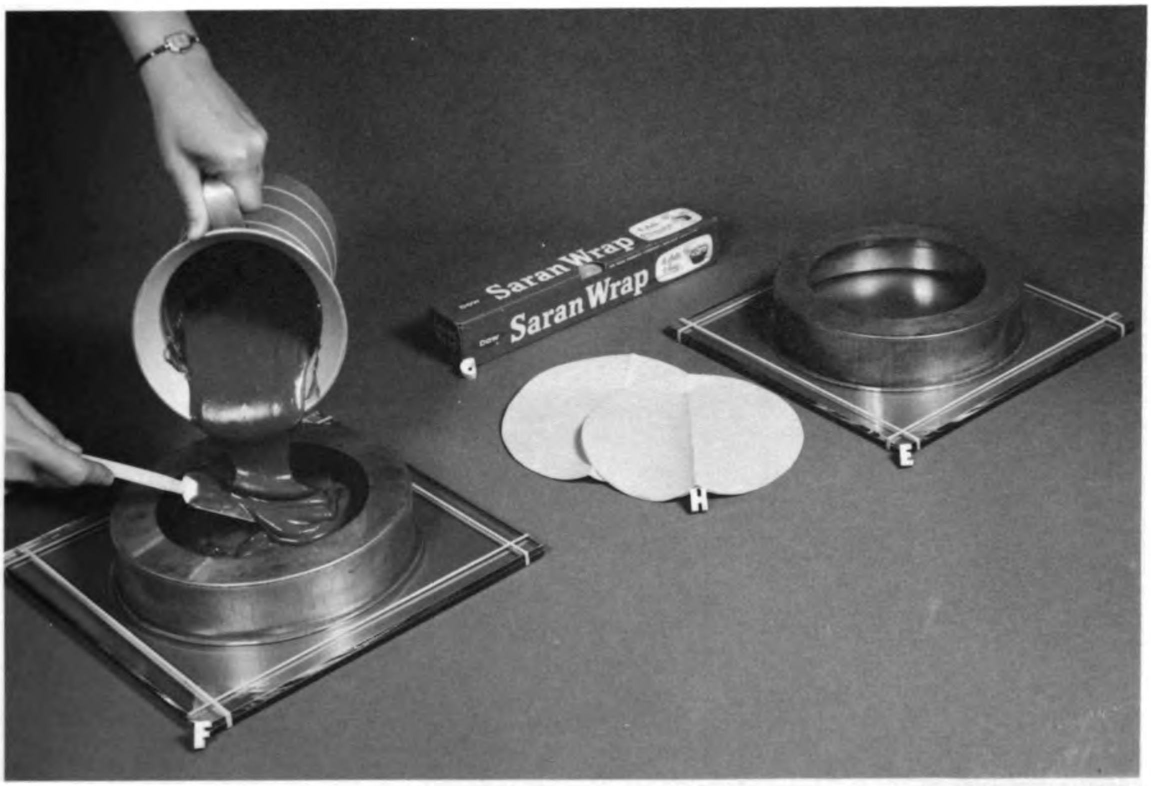

Figure 2. Pouring the mold.

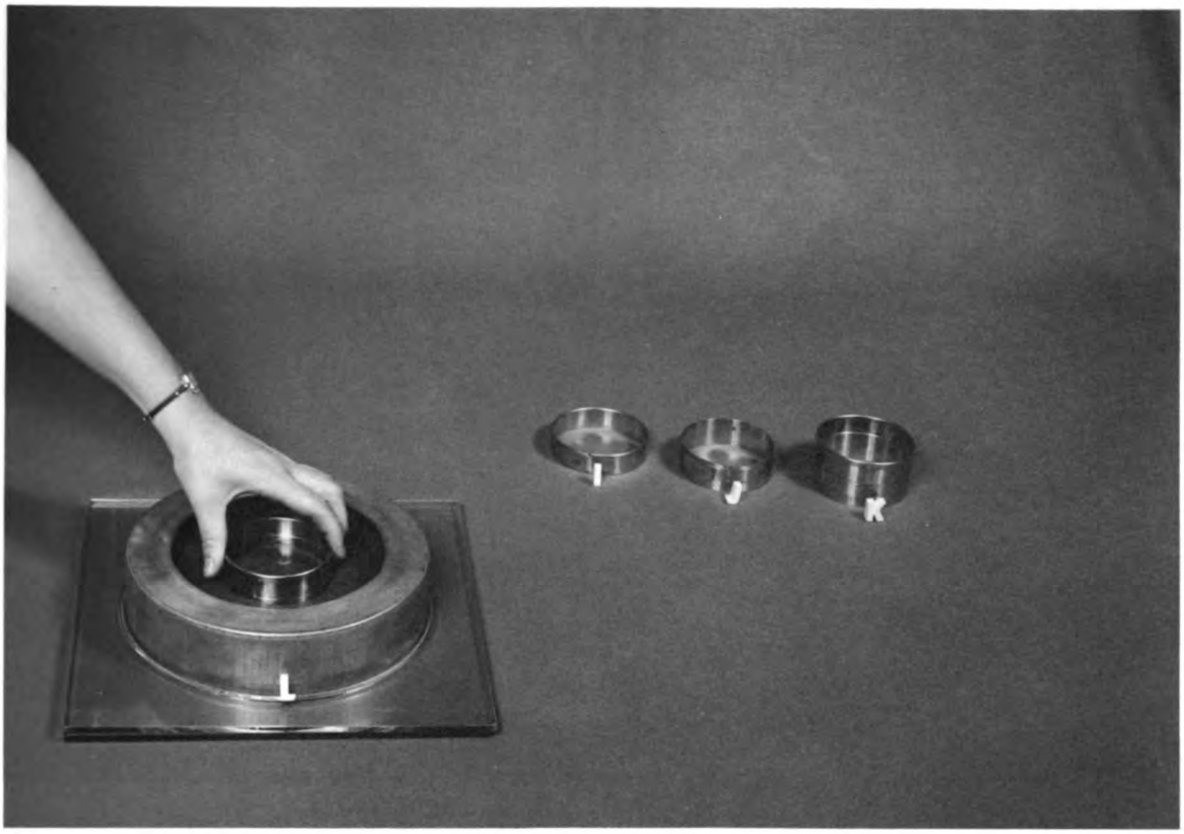

Figure 3. Inserting the sample cutter. Individual parts and complete assembly of sample cutter.

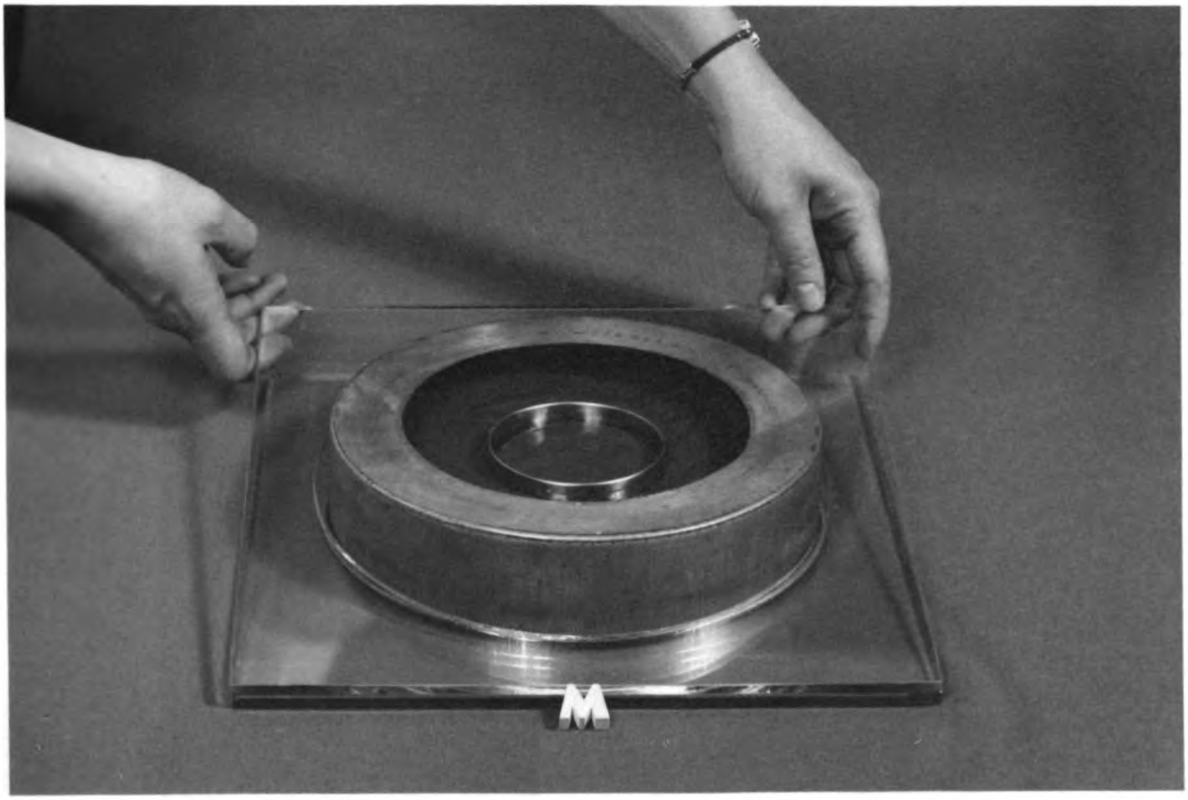

Figure 4. Removing the upper glass plate.

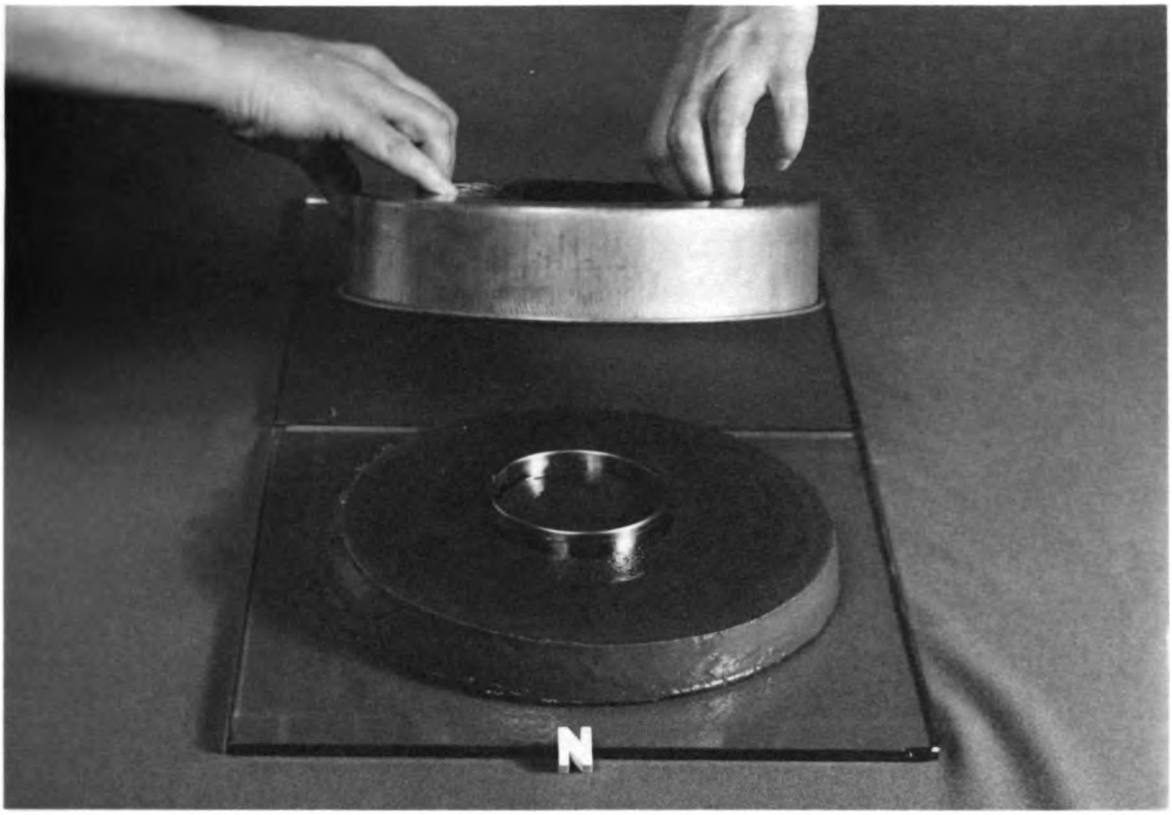

Figure 5. Removing the metal mold.

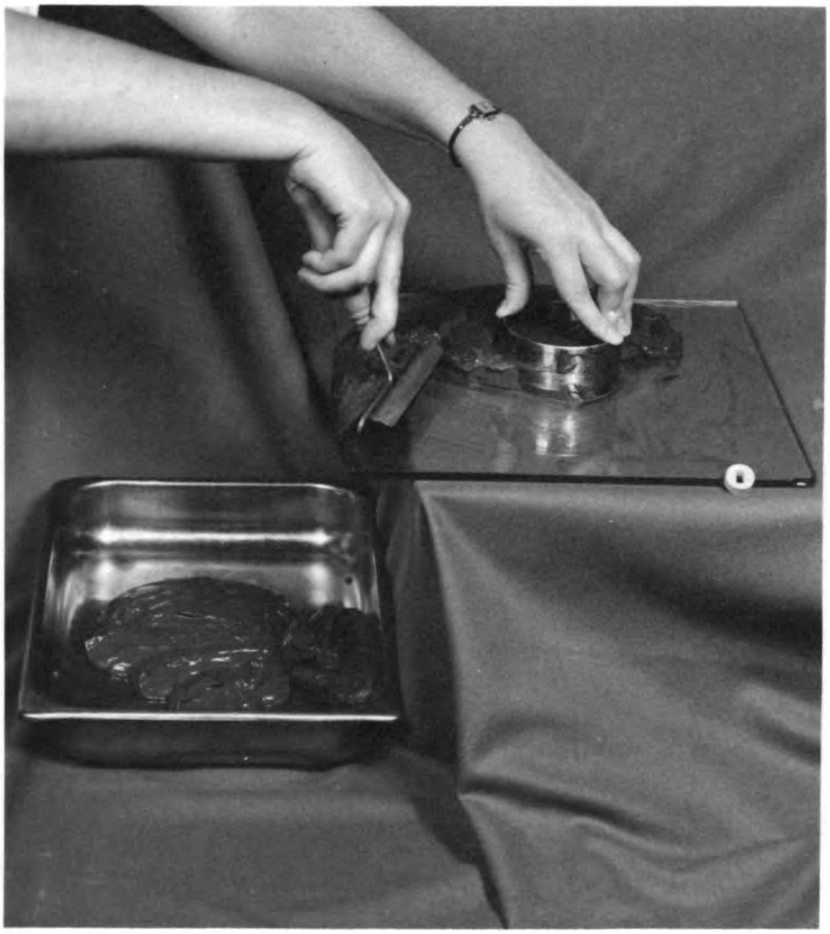

Figure 6. Removing the excess filling from the outer edge of the sample cutter.

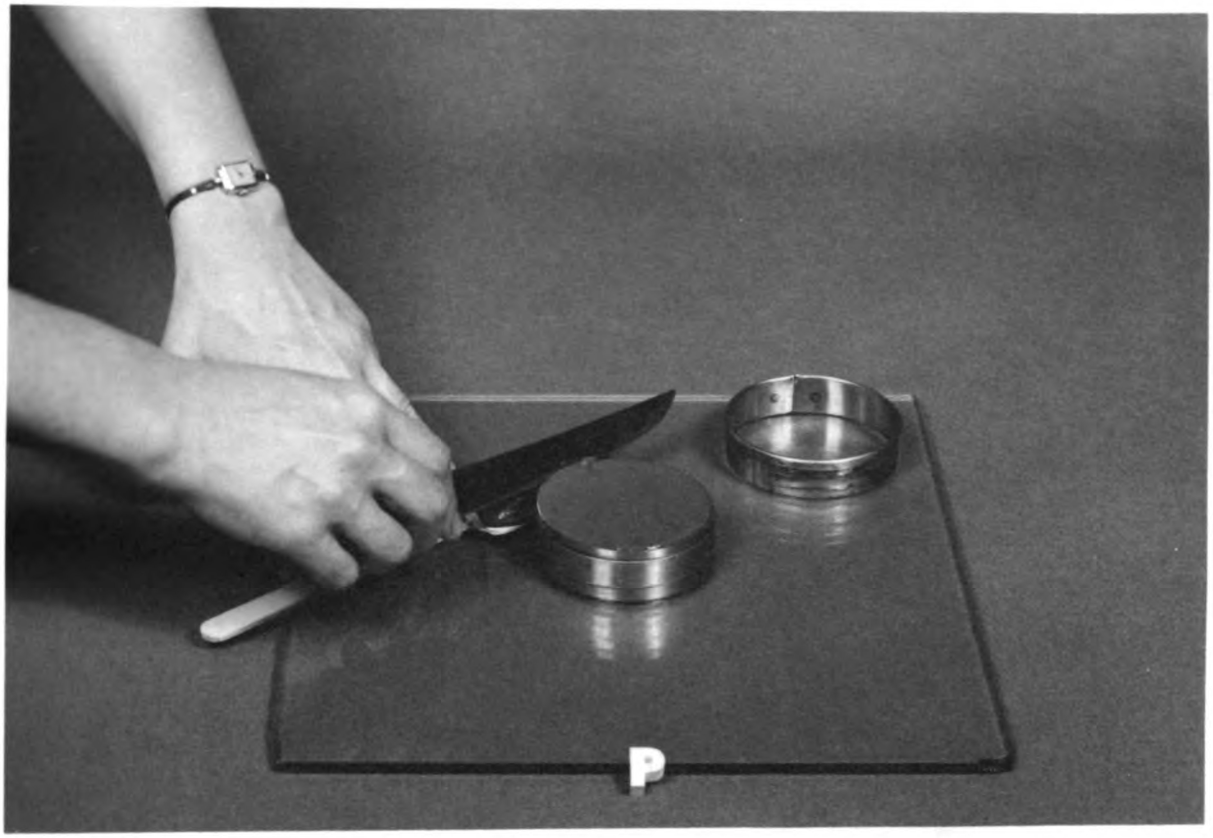

Figure 7. Leveling the cut sample.

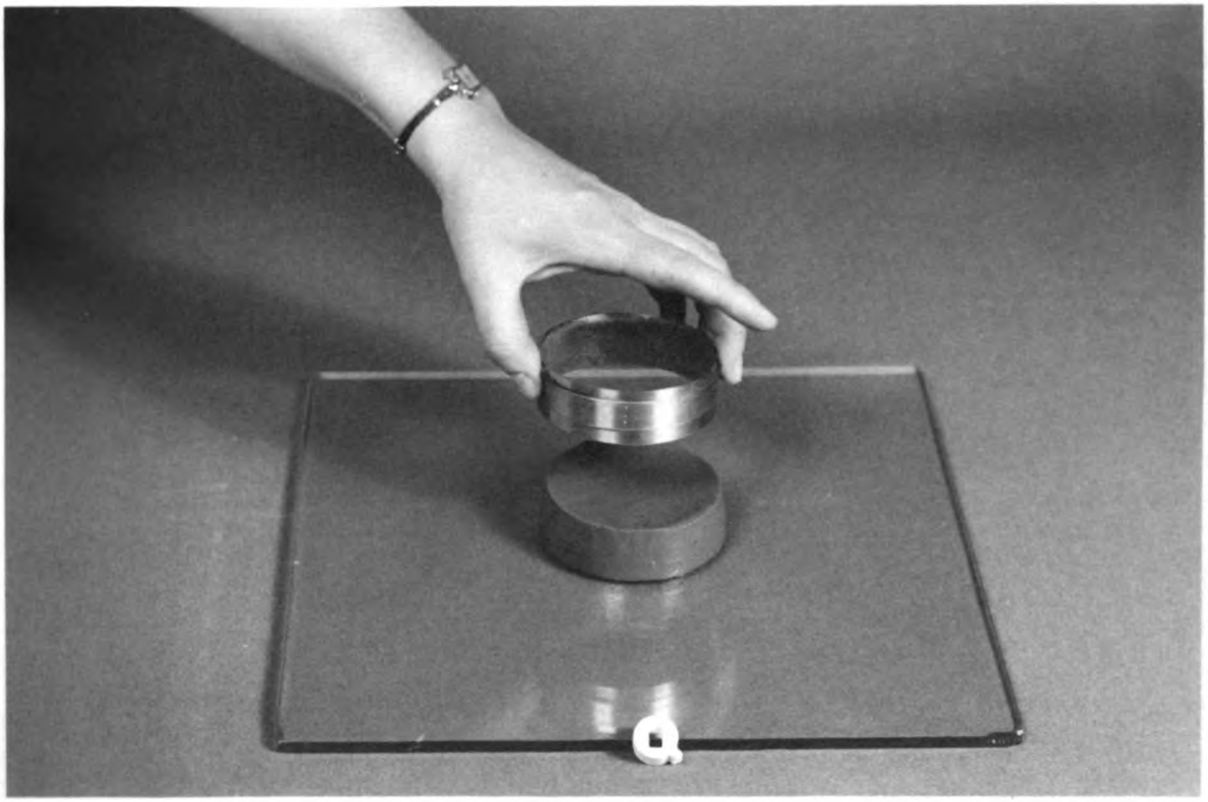

Figure 8. Releasing the cut sample for flow.

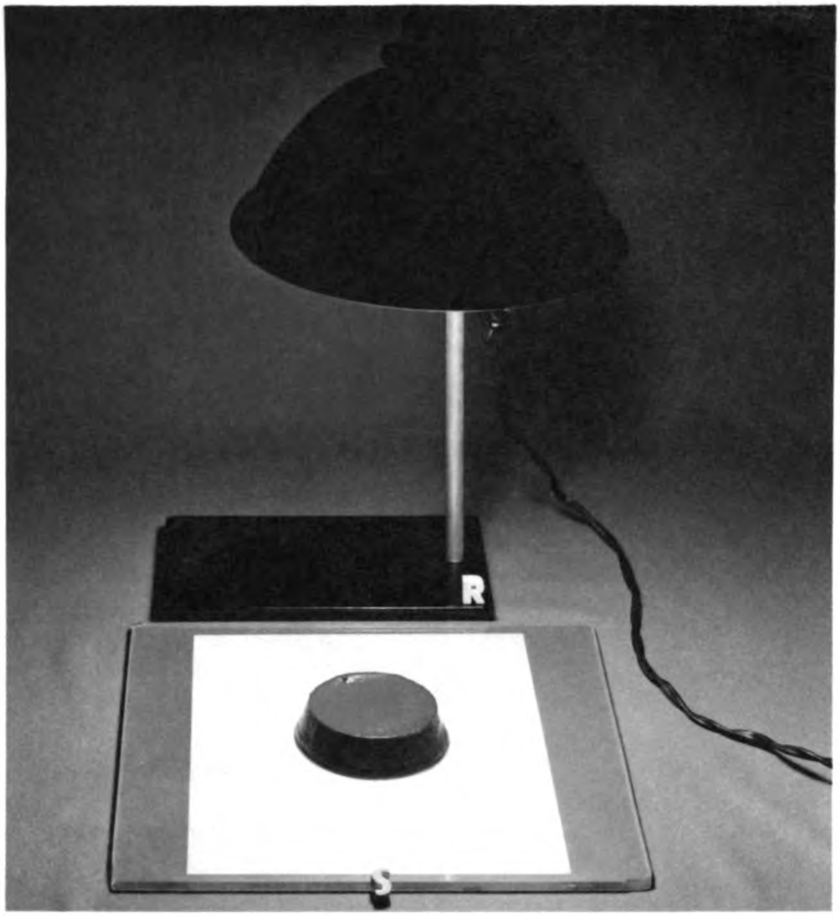

Figure 9. Recording the sample area on Technifax Diazo blue line paper.

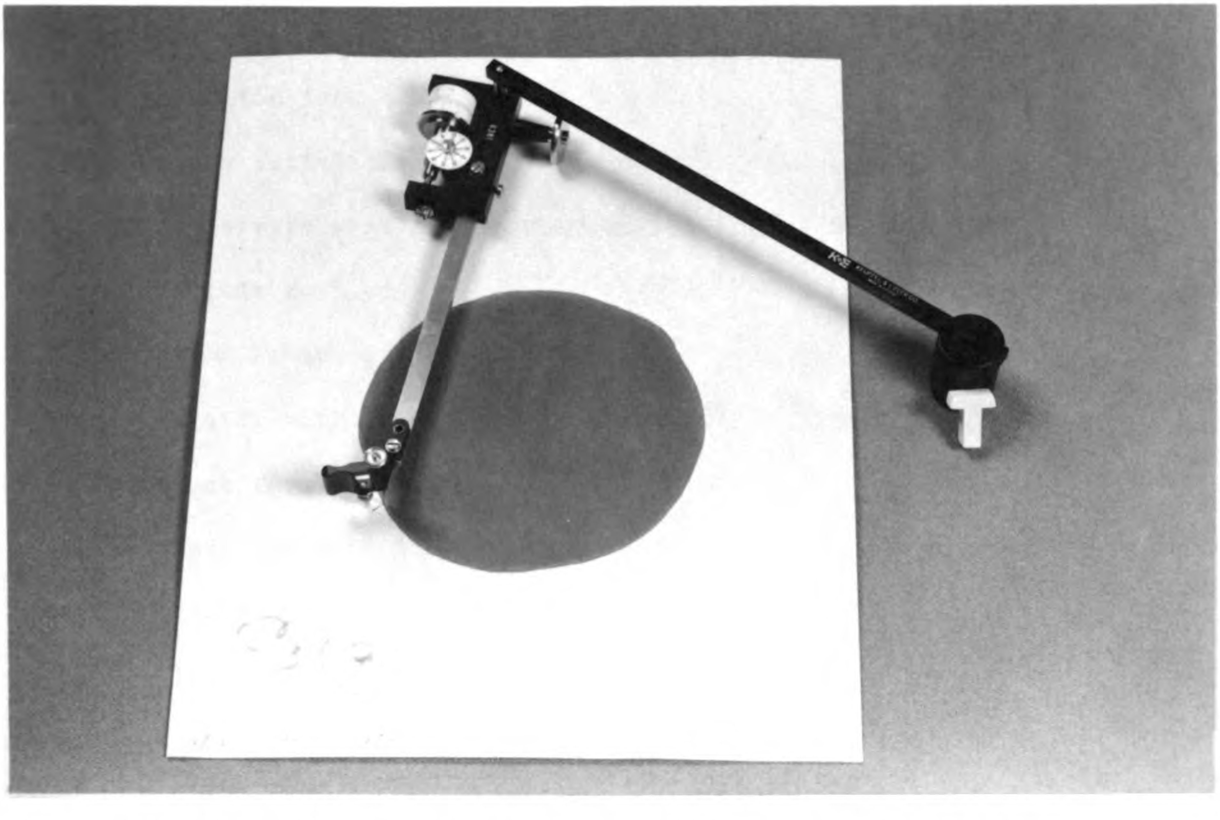

Figure 10. Measuring the sample area with the compensating polar planimeter.

DISCUSSION AND RESULTS

Control of techniques used in the execution of this project were as complete as possible in the production center in which the testing was done. However, these physical limitations were taken into consideration in interpreting the findings of the study.

The steam-jacketed kettle was a part of a battery consisting of one 3-compartment steamer, one braiser, and three large steam-jacketed kettles. The source of steam was also connected to the pot and pan sink in addition to this cooking battery. The steam pressure for the kettle used throughout this study was not thermostatically controlled. Constancy of steam pressure was dependent upon manual adjustment as indicated by a gauge located near the point at which the steam entered the base of the kettle. Mechanically controlled agitation would have measurably decreased the variables introduced by manual stirring. The proximity of the kettle to an entrance of the building complicated control of heat loss and evaporation from the surface of the mass.

Production activities which were necessary for the operation of dormitory food service were in progress during the cooking periods of this experiment and made complete control of physical factors extremely difficult. Production scheduling and the details of procedure were planned by the investigator with the dormitory food service personnel in an attempt to reduce physical and operational variables to a minimum.

This study was directed primarily toward the objective measurement of flow of cooled, cut samples of the starch-thickened mixture prepared in 6, 8, 10, 12, and 14-gallon batch sizes. The treatment variable was introduced at the end of the cooking process and concerned the length of time the mass was held in the kettle after it had reached a temperature of 82° C. Three samples were taken from each replication at the end of the specified holding periods of 0, 30, and 60 minutes. Treatments, based on the length of the holding period, were designated as Series A, Series B, and Series C.

Cold Paste Viscosity Tests

The measurement of flow for samples, expressed in terms of square centimeters, was determined by measuring Technifax prints of the samples with a compensating polar planimeter. Averages for three readings for each treatment within each replication are shown in Table 1.

Two samples in two different replications of the 8-gallon batch were lost through breakage of the lower glass plate during the cooling process. These values were statistically estimated and inserted in the data (4). Replication three of the 8-gallon batch size showed flow readings for all nine samples which were relative within the replication but were not comparable to the flow readings of replication 1, 2, or 3. The investigator felt that this extreme variability might have been attributable to an error in the liquid measurement of the formula. These flow readings were not discarded but were statistically modified by the application of the least square method (4). The insertion of these eleven estimated values affected five of the treatment averages.

An adjustment for total degrees of freedom was made in the analysis of variance to correspond to the missing values shown in Table 1. The analysis of variance of the data, including three treatment averages for four replications of each of the five batch sizes, is shown in Table 2.

Table 1. Summary of treatment averages of batch sizes tested. (square centimeters)

Batch Size	Replication	Treatment A	Treatment B	Treatment C
14 gallon	1	122.5	78.4	57.0
	2	92.3	73.3	61.0
	3	79.1	59.7	46.6
	4	80.4	62.5	55.5
12 gallon	1	50.0	41.6	51.4
	2	63.4	32.1	25.2
	3	72.5	47.9	43.2
	4	91.1	68.2	54.8
10 gallon	1	72.9	51.0	35.8
	2	69.3	43.8	31.6
	3	57.1	57.8	27.7
	4	74.2	47.8	41.4
8 gallon	1	62.4	38.4	28.0
	2	62.4[1]	39.9	31.5
	3	57.4[2]	34.2[2]	26.7[2]
	4	75.8	41.3	33.2[1]
6 gallon	1	79.2	50.6	44.0
	2	65.1	45.5	33.5
	3	59.3	39.4	30.7
	4	49.3	27.9	22.3

[1] Missing value for lost sample.

[2] Modified values.

Table 2. Analysis of variance for flow.

Source of variance	D.F.	M.S.	F.
Total	54		
Replications	3	243.4	7.6**
Treatment	2	6146.2	191.2**
Replication x Treatment	6	21.6	.7
Batch Size	4	1567.5	48.8**
Replication x Batch Size	12	292.4	9.1**
Treatment x Batch Size	8	9.9	.3
Error	19	32.1	

This analysis showed that there were highly significant differences in flow attributable to replication, treatment, and batch size.

Production technique. The effect of variance due to replication was analyzed within each batch size. A summary of these analyses is shown in Table 3.

These analyses indicated that variance due to replication was significant in the 6, 8, 10, and 12-gallon batch sizes but showed no significance in the 14-gallon batch size. Inspection of the original data indicated that the flow readings for four of the nine poured samples of replication one in the 14-gallon batch were extremely high in relation to comparable samples of replication 2, 3, or 4. Failure to level samples 1, 2, 3 of Series A and sample 1 of Series B to a constant depth before releasing them for flow resulted in unusually large flow readings. This factor may have been great enough to affect the mean square value of the error term in the analysis for replication for the 14-gallon batch. (Table 7, Appendix).

**Significant at 1% level of probability.

Table 3. Summary of analyses of variance within 4 replications, for 3 treatments for each of 5 batch sizes.

Source of Variance	D.F.	Mean Square				
		14 gal.	12 gal.	10 gal.	8 gal.	6 gal.
Total	11					
Treatment	2	1531.4**	1175.7**	1208.5**	1302.1**	968.1**
Replication	3	345.5	577.2**	117.6**	59.3*	315.7**
Error	6	88.4	11.1	5.9	10.8	7.2

Time and Temperature. The end cooking temperature of the starch pastes was arbitrarily set at 82° C for all batch sizes tested. The temperature of the mass was recorded at two minute intervals throughout the cooking period for all batches. These temperatures were averaged for replications within each batch size and arranged as time-temperature curves. The average time-temperature relationship of each batch size during the cooking process is illustrated in Figure 11.

These cooking curves indicated that the 6 and 8-gallon batch sizes showed little difference in the time required for the mass to reach 82° C. In these data the average beginning temperature for cooking in the 8-gallon batch size was slightly higher than the initial temperature average for the 6-gallon batch size. However, the end cooking temperature was reached in the same number of minutes. If the beginning cooking temperatures had been identical, it is possible that the average time required for the

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*Significant at 5% level of probability
**Significant at 1% level of probability

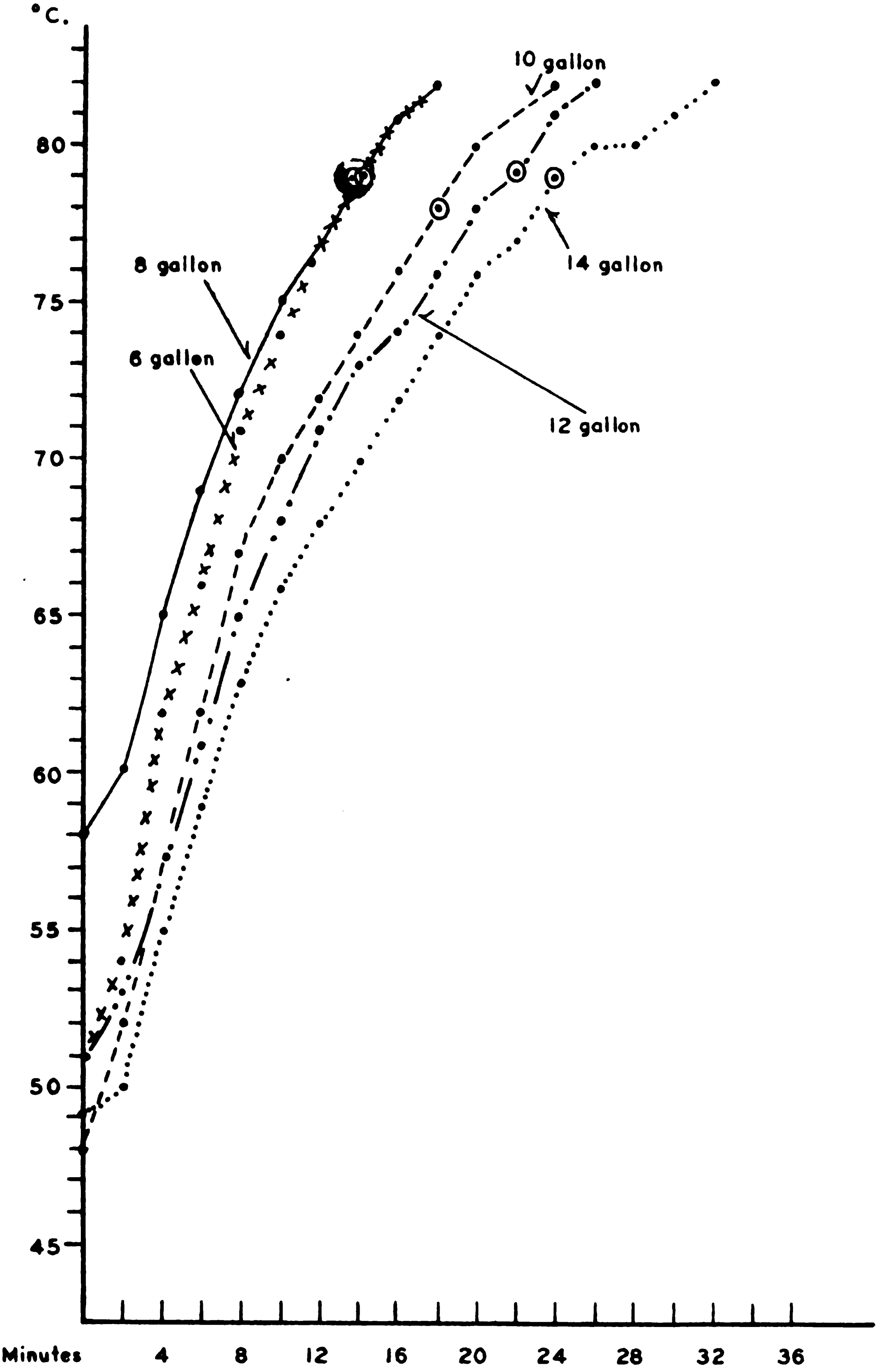

Figure 11. Average time-temperature relationships of batch size during cooking process. ⊙ indicates first visible evidence of thickening.

8-gallon batch sizes to reach the end cooking point might have been increased slightly. The curves of the 10, 12, and 14-gallon amounts indicated an orderly progression of increased time required to reach 82° C for each increment in batch size.

The average temperature at which the first visible evidence of thickening of the mass, subjectively determined, had been noted was 79° C for the 6, 8, 12, and 14-gallon batch sizes, and 78° C for the 10-gallon batch size. Since this decision was purely a subjective one, this temperature discrepancy was deemed negligible. The temperature of initial viscosity rise for all batch sizes tested was considered to be 79° C.

The time-temperature relationship of the cooking curves showed that increase in batch size increased the time required to reach the point of initial viscosity rise as well as the time required for the temperature of the mass to rise from 79° C to the end cooking temperature of 82° C. Preliminary tests had shown that cooled samples made with the same formula cooked to higher temperatures had gel structure with an undesirable degree of rigidity.

Treatment. The analysis of variance of flow, Table 1, indicated that there were highly significant differences attributable to treatment. Further comparison indicated that the difference in flow between Series A and Series B was greater than the difference between Series B and Series C for all batch sizes tested. This observation suggested that the degree of change in consistency was not directly proportional to time. Figure 12 shows the effect of holding time on the average flow of samples from the five batch sizes tested.

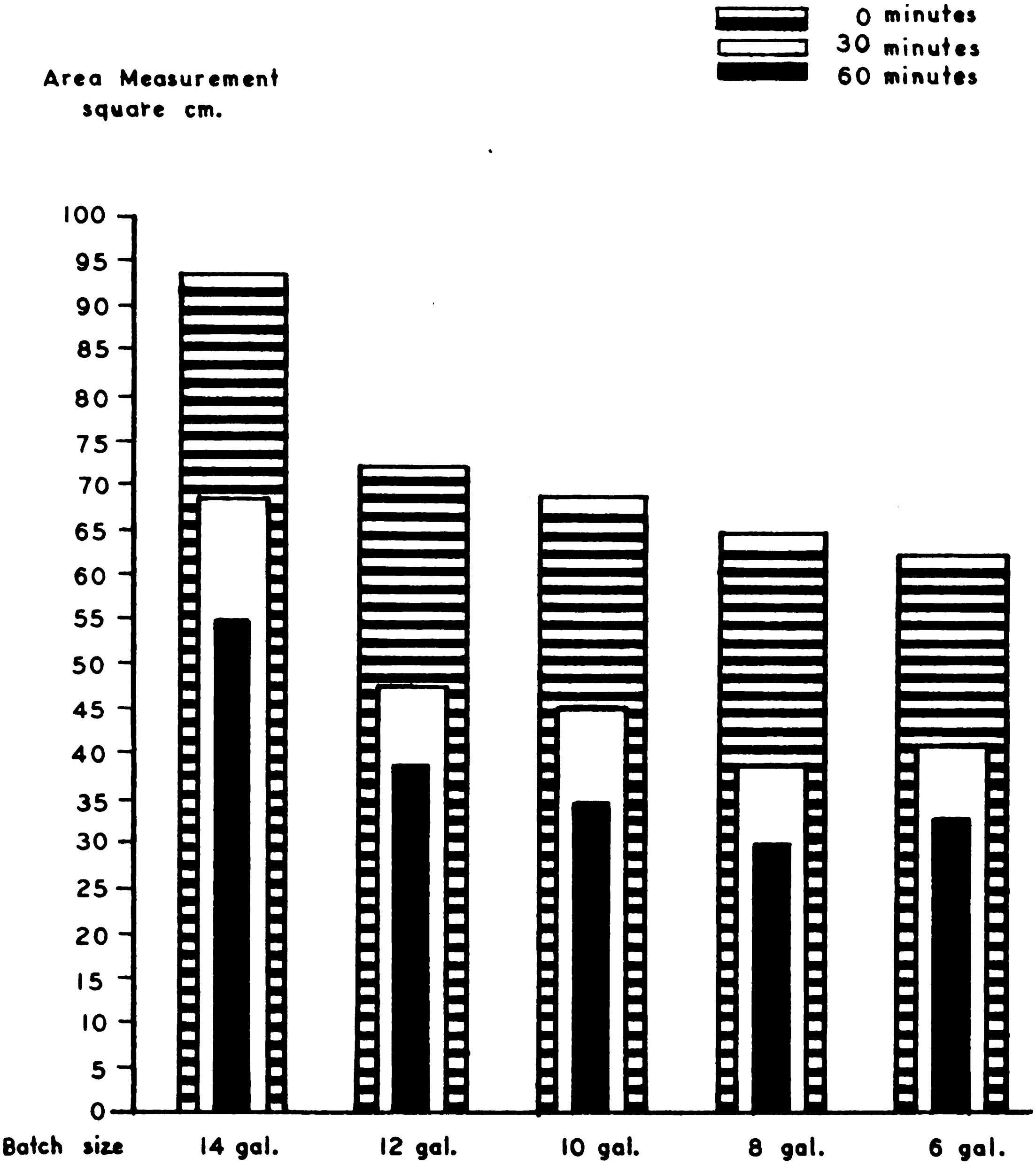

Figure 12. Effect of holding time on the average flow of batch sizes of chocolate pie filling.

The "skin" formation on the mass during the holding periods in the kettle appeared comparable for all batch sizes. It did not seem desirable to include it in the final product. The removal and discarding of this "skin" constituted approximately three quarts of the mass for all batch sizes and had an increased effect on the percentage loss of the finished volume as the batch size decreased. It seems feasible that holding the mass in a covered, steam-jacketed kettle might appreciably decrease the thickness of the "skin" and the percentage loss of the finished volume.

Flow readings for all samples of four replications in each batch size were averaged for Series A, Series B, and Series C. These flow reading averages are listed in Table 4.

Table 4. Summary of average flow readings of four replications of each batch size for each treatment.

Batch Size	Series A	Series B	Series C
6 gallon	62.7	40.6	32.6
8 gallon	64.5	38.5	29.9
10 gallon	68.4	45.1	34.4
12 gallon	71.8	47.5	38.6
14 gallon	93.6	68.5	55.0

A comparison of the average flow measurements of the cooled samples on the basis of batch size indicated that the amount of flow was appreciably greater for each treatment in the 14-gallon batch size than in the 6, 8, 10, and 12-gallon batch sizes. It appeared that the 14-gallon batch would require a longer holding period in the steam-jacketed kettle than would the 6, 8, 10, and 12-gallon batches to produce comparable consistency.

Consideration was given to the variance of flow attributable to batch size within each treatment. These analyses were based upon the average flow value of the three poured samples for each of four replications of the five batch sizes tested.

The analysis of variance of flow readings for Series A, Table 5, showed no significant difference attributable to batch size for 0 minutes of holding time.

The analysis of variance of flow readings for Series B, Table 5, indicated significant difference attributable to batch size for 30 minutes of holding time. In a comparison of the mean flow value for each batch size, no significant difference was established between the 6, 8, 10, and 12-gallon batch sizes. However, significant difference was apparent between the mean flow value of the 14-gallon batch size and that of the other four batch sizes studied.

Table 5. Analyses of variance for treatment with 4 replications and 5 batch sizes.

Source of Variance	Series A			Series B			Series C		
	D.F.	M.S.	F.	D.F.	M.S.	F.	D.F.	M.S.	F.
Total	17[1]			18[1]			17[1]		
Replication	3	184.6	.9	3	62.2	.6	3	41.8	.5
Batch Size	4	620.8	3.0	4	570.1	5.4*	4	398.7	4.6*
Error	10	208.3		11	105.6		10	87.6	

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*Significant difference at the 5% level of probability

[1] Adjusted for sample averages affected by missing values in 8-gallon batch size.

The variance of flow readings for Series C indicated significant difference in flow attributable to batch size for 60 minutes of holding time. This analysis of variance is indicated in Table 5. In the comparison of the mean flow value for each batch size of Series C the trend of significant difference was similar to that of Series B. Significant difference in flow was found between the 14-gallon batch size and the other batch sizes tested. There was no significant difference between the mean flow values for the 6, 8, 10, and 12-gallon amounts.

According to subjective observations of cut samples of cooled filling for Series A in all batch sizes, products obtained by this treatment were considered too fluid for serving. Samples for Series B were judged acceptable for use as pudding, but the consistency was too soft for pie filling of satisfactory consistency. The samples of Series C for the 6, 8, 10, and 12-gallon batch sizes showed dependable stability and gel strength judged necessary for pie filling. Samples of this series from the 14-gallon batches were fairly dependable for use as a pie filling but were softer than those from the other batch sizes. The subjective standard used to determine suitability of the cooled mixture for pie filling was designated as a filling which, after cutting, had sufficient structure to allow a slight degree of bulge but which did not continue to flow during subsequent standing.

SUMMARY

The effect of batch size upon flow was studied by using a basic formula in which the proportion of ingredients was held constant. The end cooking temperature was arbitrarily set at 82° C, and holding periods after this temperature was reached were 0, 30, and 60 minutes.

Significant differences, attributable to replication within a batch size, were found in the 6, 8, 10, and 12-gallon amounts. No significant difference, resulting from replication, was found in the 14-gallon amount. This result may have been attributable to the known error in preparation technique for some of the samples in the first replication of the 14-gallon amount.

Time-temperature cooking curves showed no difference between the 6 and 8-gallon amounts in time required for the mass to reach 82° C. The data indicated that the average beginning cooking temperature of the 8-gallon batch size was higher than that of the 6-gallon amount. It is possible that this fact gave a somewhat distorted effect to the average cooking curve for the 8-gallon amount. Average cooking curves indicated that consecutive increases in batch size showed corresponding consecutive increases in the time required for the mass to reach 79° C, the point of visible, initial viscosity, and the additional time required to reach the end cooking temperature of 82° C.

Variance resulting from treatment was found to be significant for all batch sizes. Differences in average flow measurements were greater between Series A and Series B than between Series B and Series C. This result indicated that the degree of change in consistency was not directly proportionate to the length of holding time. The degree of flow for each specific holding period was appreciably greater in the 14-gallon batches than it was in corresponding holding periods for the 6, 8, 10, and 12-gallon batches.

Analysis of the mean flow readings for all batch sizes within each specific treatment showed no significant difference attributable to batch size for Series A. Average flow values analyzed for Series B and Series C indicated no significant difference in flow value within each series attributable to batch size for the 6, 8, 10, and 12-gallon amounts. Significant difference was apparent between the mean flow value for the 14-gallon amount and all other batch sizes both for the 30-minute and for the 60-minute holding periods.

The subjective standard used to determine suitability of the cooled mixture for pie filling was designated as a filling which, after cutting, had sufficient structure to allow a slight degree of bulge but which did not continue to flow during subsequent standing. Subjective observations indicated that all the samples of Series A were too fluid for serving. All samples of Series B were judged to be acceptable for use as pudding but too soft for use as pie filling. In Series C the samples from the 6, 8, 10, and 12-gallon batches were rated as being entirely dependable for use as pie filling. Samples in Series C from the 14-gallon batches proved suitable for use as pie filling but were softer than those from the other batch sizes.

CONCLUSIONS

From this investigation it appears that flow characteristics of cooled, cut samples of starch-thickened pastes are not consistently affected by increases in batch size when procedure and proportion of ingredients remain constant. Within the limits of this study the 6, 8, 10, and 12-gallon batches produced gel structures of similar consistency. Although the 14-gallon amount produced a less stable gel structure than did any of the other batch sizes tested, factors other than batch size may also have influenced the flow of samples.

A progressively longer cooking period is required to reach the points of visible, initial viscosity and end cooking temperature for each consecutive increase in batch size. From the data of this investigation it appeared that the degree of swell of the starch granules is dependent upon batch size, rate of heating, and temperature of the mass during the heating and holding periods.

The length of time that the mass is held in the steam-jacketed kettle, after the temperature of 82° C is attained, appears to affect the stability of the gel structure in all batch sizes. Rigidity of gel structure increased more during the first 30 minutes of holding time than during the following 30 minutes of holding time. As the length of the holding period increased from 0 to 60 minutes, visible increases in hot paste viscosity of the mass were noted. This fact indicated that the starch granules continue to swell after the application of steam is discontinued. In all cases, the temperatures of the mass remained between 79° C and 82° C for the 60 minute holding period. These findings suggest that the rate of heating and the length of the holding period are contributing factors in the final flow of the cooled paste.

Comparison of flow characteristics within each specific batch size indicated that the samples from the 14-gallon amount did not have the same consistency as samples from other batch sizes when all were held for the same length of time under the same conditions. The effect of batch size upon flow for amounts greater than 14 gallons is not predictable from this study.

The gels resulting from the 30-minute holding period were judged suitable for use as pudding for all batch sizes tested; samples from the 60-minute holding period gave gels acceptable for use as pie filling. In all cases gel structure of samples held 60 minutes was tender but stable. These facts suggest the possibility of regulating stability and tenderness of cooled starch-thickened mixtures, for specific batch sizes, by control of time and temperature conditions of the cooking period. It seems feasible that the same formula can be used for the production of pudding and pie filling with the control of the final gel structure being dependent upon the heating and cooling conditions of the mass rather than upon varying concentrations of starch.

Recipes for starch-thickened puddings and pie fillings generally contain two or more ingredients which contribute to the total thickening effect in the finished product. The results of this study, therefore, are only applicable to formulas in which the thickening agents are limited to cornstarch and cocoa powder which, when they are combined in equal concentrations, constitute 7.5 per cent of the total weight of the mixture.

The findings of this study emphasize that accurate prediction of the stability of gel structure of starch-thickened pastes is a complex problem. Additional investigation of the interaction of factors, such as rate of heating, temperature of the mass during the heating period, end cooking temperature, and length of holding period after the application of steam is discontinued, which contribute to the stability of a cooled starch paste needs to be made before the effect of batch size upon flow can be accurately determined.

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APPENDIX

Table 6. Measurement of flow: original data. Planimeter readings in square centimeters.

BATCH SIZE	REPLICATION	SERIES A: 0 MINUTE			
		SAMPLE NUMBERS			
		1	2	3	Mean
14 gallon	1	127.3[3]	118.2[3]	122.0[3]	122.5
	2	97.4	88.0	91.5	92.3
	3	78.9	81.3	77.0	79.1
	4	84.4	79.2	77.7	80.4
	Mean	97.0	91.7	92.1	93.6
12 gallon	1	57.8	61.0	61.1	60.0
	2	79.9	55.9	54.4	63.4
	3	69.0	73.5	75.1	72.5
	4	90.3	91.5	91.5	91.1
	Mean	74.3	70.5	70.5	71.8
10 gallon	1	72.6	72.9	73.2	72.9
	2	68.5	67.8	71.6	69.3
	3	59.3	58.4	53.7	57.1
	4	74.3	76.4	72.0	74.2
	Mean	68.7	68.9	67.6	68.4
8 gallon	1	60.1	64.2	62.8	62.4
	2	61.4	61.9[1]	63.9	62.4
	3	57.4[2]	57.4[2]	57.4[2]	57.4
	4	71.5	77.0	78.9	75.8
	Mean	62.6	65.1	65.8	64.5
6 gallon	1	78.7	82.7	76.1	79.2
	2	64.3	63.0	62.1	63.1
	3	61.0	60.0	56.8	59.3
	4	53.0	48.8	46.1	49.3
	Mean	64.3	63.6	60.3	62.7

[1] Missing value for lost sample.
[2] Modified value.
[3] Sample not leveled.

Table 6. (continued)

SERIES B: 30 MINUTES				SERIES C: 60 MINUTES			
SAMPLE NUMBERS				SAMPLE NUMBERS			
1	2	3	Mean	1	2	3	Mean
98.8[3]	68.8	67.7	78.4	59.8	59.6	51.5	57.0
74.2	73.4	72.4	73.3	67.6	52.7	62.7	61.0
54.8	63.1	61.1	59.7	43.1	46.6	50.2	46.6
60.7	65.5	61.2	62.5	54.2	56.9	55.4	55.5
72.1	67.7	65.6	68.5	56.2	54.0	55.0	55.0
42.1	42.7	40.0	41.6	35.6	28.2	30.4	31.4
35.3	33.0	28.1	32.1	29.3	22.2	24.0	25.2
39.9	52.9	50.8	47.9	47.6	44.3	37.7	43.2
67.0	52.3	85.4[3]	68.2	57.3	55.2	51.8	54.8
46.1	45.0	51.3	47.5	42.5	37.5	36.0	38.6
47.3	54.3	51.7	51.1	39.6	35.8	35.0	36.8
42.0	45.2	44.2	43.8	37.5	28.4	28.9	31.6
39.5	39.4	34.6	37.8	31.0	26.4	25.7	27.7
45.3	52.6	45.4	47.8	41.7	42.5	40.0	41.4
43.5	47.9	44.0	45.1	37.5	33.3	32.4	34.4
42.2	35.4	37.5	38.4	35.7	23.4	24.8	28.0
41.3	39.0	39.5	39.9	38.0	24.5	32.1	31.5
34.2[2]	34.2[2]	34.2[2]	34.2	26.7[2]	26.7[2]	26.7[2]	26.7
46.0	43.9	34.3	41.3	32.3	39.4	27.9	33.2
40.9	38.1	36.4	38.5	33.2	28.5	27.9	29.9
49.0	53.2	49.6	50.6	49.1	40.2	42.8	44.0
49.9	40.1	46.5	45.5	36.3	34.6	29.6	33.5
41.4	38.2	38.7	39.4	34.4	27.5	30.2	30.7
28.3	26.8	28.7	27.9	28.4	19.6	18.9	22.3
42.2	39.6	40.9	40.9	37.1	30.5	30.4	32.6

[1] Missing value for lost sample.
[2] Modified value.
[3] Sample not leveled.

Table 7. Summary of range and mean flow measurements for each batch size. (square centimeters)

Batch Size Gallons	Treatment: Holding Time					
	0 min.		30 min.		60 min.	
	Range	Mean	Range	Mean	Range	Mean
14	127.5 - 77.0	93.6	98.8 - 54.8	68.5	67.6 - 43.1	55.0
12	91.5 - 54.4	71.8	88.4 - 28.1	47.5	57.3 - 22.2	38.6
10	76.4 - 53.7	68.4	54.3 - 34.6	45.1	42.5 - 25.7	34.4
8	78.9 - 57.4	64.5	41.0 - 34.2	38.5	39.4 - 23.4	29.9
6	82.7 - 46.1	62.7	53.2 - 26.8	40.9	49.1 - 18.9	32.6

Table 8. Per cent flow deviation from mean of samples within each batch size.

Batch Size Gallons	Treatment: Holding Time					
	0 min.		30 min.		60 min.	
	+ %	- %	+ %	- %	+ %	- %
14	35.0	17.7	44.2	20.0	22.9	21.6
12	27.4	24.2	81.9	40.8	48.4	42.5
10	11.7	21.5	20.4	23.3	23.5	23.3
8	22.3	11.0	19.5	11.2	31.8	21.7
6	31.9	26.5	30.1	34.5	50.6	42.0

Table 9. Chocolate pie filling formula

Ingredients	% Ingredients[1]	14 gallons	12 gallons	10 gallons	8 gallons	6 gallons
Water (55° C)[2]	63.2	12 1/4 gal.	10 1/2 gal.	8 3/4 gal.	7 gal.	5 1/4 gal.
Whole dried milk solids	9.0	14#	12#	10#	8#	6#
Sugar, granulated	7.3	10# 14 oz.	8# 12 oz.	6# 10 oz.	6# 8 oz.	4# 6 oz.
Cocoa, sifted	3.8	5# 13 1/4 oz.	5#	4# 2 3/4 oz.	3# 5 1/4 oz.	2# 8 oz.
Sugar, granulated	11.3	18#	16#	14#	10#	8#
Cornstarch	3.3	5# 13 1/4 oz.	5#	4# 2 3/4 oz.	3# 5 1/4 oz.	2# 8 oz.
Salt, iodized	0.1	6 T 3/4 t	5 1/3 T	4 1/2 T	3 T 1 3/4 t	2 2/3 T
Butter	0.8	1# 3 oz.	1#	13 oz.	10 oz.	7 oz.
Vanilla	0.8	2c 5 1/3 T	2c	1c 10 2/3 T	1c 5 1/3 T	1c

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[1] Ingredient proportions in terms of percentage of total weight of mixture.

[2] Average hardness 17 grains