

THE EFFECT OF THE PROPORTION OF
SUCROSE ON THE VISCOSITY OF
CORNSTARCH PASTES MADE WITH
DIFFERENT LIQUID MEDIUMS

Thesis for the Degree of M. S.
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Marie Josephine Ferree
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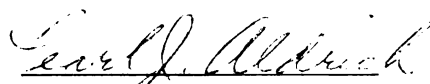
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THE EFFECT OF THE PROPORTION OF SUCROSE ON THE VISCOSITY
OF CORNSTARCH PASTES MADE WITH DIFFERENT LIQUID MEDIUMS

By

Marie Josephine Ferree

A THESIS

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THESIS



A SUMMARY

The primary objective of this study was to determine the effect of the proportion of sucrose on the viscosity of corn-starch pastes made with four different liquid mediums.

Eleven per cent cornstarch, based on the weight of the liquid, was selected for making the slurries in the study. The proportion of cornstarch to water was kept constant in all replications of the starch slurries throughout the study. The sucrose concentrations arbitrarily selected for the investigation were 15, 21, and 27 per cent, based on the weight of the liquid in each formula.

The four liquid mediums used in making the starch slurries were distilled water, unsoftened tap water, a solution of nonfat dry milk solids in distilled water, and a solution of whole dry milk solids in distilled water. The amount of nonfat dry milk solids and the amount of whole dry milk solids, based on the weight of the liquid, was consistent with the amount of solids found in fluid milk milk and whole fluid milk, respectively.

The weights of starch, sucrose, and liquid medium, based on the desired percentage relationships, were calculated to yield a total volume of one liter of each mixture.

The Corn Industries Viscosimeter was used for cooking the starch slurries and for measuring the viscosity of the hot pastes. The temperature of the uncooked starch slurries was 26°C when the slurries were poured into the preheated cooking vessel. The temperature of the cooking

bath was 100° C. All replications of the starch slurries in the investigation were cooked to a final temperature of 95° C.

In this limited study it was found that the maximum viscosity of unsweetened and sweetened pastes made with tap water were higher than were those of similar pastes made with other liquid mediums with the exception of the pastes made with reconstituted whole dry milk solids containing 21 per cent sucrose. The maximum viscosities of the control and all sugar levels of pastes made with reconstituted nonfat dry milk solids were lower than those of similar pastes made with the other liquid mediums. The maximum viscosities of the control and sweetened pastes with all three sugar levels made with reconstituted whole dry milk solids were appreciably higher than were those of similar pastes made with distilled water with the exception of the paste containing 27 per cent sucrose.

In this investigation it was found that the variations of pastes made with tap water were more unstable than were pastes made with the other liquid mediums. The pastes made with reconstituted nonfat dry milk solids were more stable than were other pastes made with other liquid mediums.

From the data of this investigation, it appeared that sucrose, in concentrations from 0 to 21 per cent did not show any consistent effect on the length of cooking time required to reach initial viscosity rise, maximum viscosity, and initial viscosity breakdown of the pastes made with the four liquid mediums. The addition of 27 per cent sucrose to the basic starch slurries made with all liquid mediums increased the length of time required for the pastes to reach maximum viscosity. The

additions of 15 and 21 per cent sucrose did not always alter the cooking time required for the pastes to reach maximum viscosity. However, additions of sucrose to the basic slurries appeared to decrease the breakdown in viscosity of the pastes as cooking time increased.

The temperature at maximum viscosity was appreciably increased by additions of 27 per cent sucrose to the basic slurries made with the four liquid mediums. Pastes made with additions of 15 and 21 per cent sucrose did not show any definite pattern in relation to temperature of pastes at initial viscosity rise or at maximum viscosity.

The data from this limited study suggest that additional investigation needs to be made in order to study more fully the effect of cooking time and paste temperature on the viscosity of sweetened corn-starch pastes made with different liquid mediums.

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INTRODUCTION

Cornstarch is important in quantity food production because of its extensive use as a thickening agent in sauces, gravies, pie fillings, and cream puddings. Preparation of these foods involves relatively simple methods of combining and cooking the ingredients. However, difficulties in the preparation of starch mixtures are encountered frequently enough to suggest the need of study of the behavior of such mixtures during cooking. The final consistency of cooked starch mixtures is not always predictable; this variation in consistency of the cooked product is frequently observed in starch mixtures which contain relatively high percentages of sugar.

In cream pudding the cornstarch may fail to thicken the liquid completely; or, although the desired thickening appears to have occurred, the pudding may become thin during the cooling period. This erratic behavior of cream pudding is usually attributed to careless measuring and handling of the ingredients. However, starch chemists have also suggested that temperature of cooking, rate of heating, the presence of electrolytes, and the proportion of sugar to cornstarch in the mixture may also be contributing factors.

Instructions for making cream puddings and pie fillings presumably consider all of the factors mentioned above. Slow heating of the combined mixture is recommended. The instructions further state that excessive sugar concentrations will prevent thickening of the final product. The exact sugar concentration which may be expected to cause

this lack of thickening is not mentioned in the literature, nor is information available which adequately explains the increased thickening effect of starch in mixtures containing relatively low concentrations of sugar as contrasted with control pastes without sugar.

The purpose of this investigation is to study the effect of the proportion of sucrose on the viscosity of cornstarch pastes made in four different liquid mediums. The sugar concentrations used lie within the lower range of those found in cream type puddings and pie fillings. The liquid medium used in the first study is distilled water. Electrolytes are present in the second medium in the form of the minerals commonly found in unsoftened tap water. The liquid mediums used in the third and fourth series are solutions of dry milk solids in distilled water. These dry milk solids are of the spray dry type most frequently used in quantity food production. It is hoped that the results of this study will be useful to those interested in the preparation of cream type puddings and pie fillings of high quality.

REVIEW OF LITERATURE

Prior to 1900, little was known of the chemistry and production of starch. In a review of the history of starch, Brautlecht (13) stated that starch and starch flour, manufactured exclusively from wheat, was known to the ancient Greeks and Egyptians. Potato starch, first made in Europe during the sixteenth century, was used to stiffen and give finish to linen. Late in the nineteenth century, Frankel (20) observed that commercial starches could be manufactured from potatoes, wheat, maize, and rice. Since that time, carbohydrate chemists have contributed much to the progress in the many phases of the study of starch. Since 1930, starch research has clarified the organization of the starch granule and the structure of the starch molecules and their behavior in uncooked suspensions and cooked pastes.

Chemical Fractions

In 1881, in the earliest record of starch behavior published in English, Frankel (20) stated, "Starch belongs to chemically indifferent substances, i. e., to the so-called hydrates of carbon, or to that group of organic bodies which, besides carbon, contains hydrogen and oxygen in such proportions that they could form water when combined with each other."

Schoch (42), in a review of starch research, reported that as early as 1834, the behavior of starch in warm water was interpreted as evidence that starch was heterogeneous in composition, that it

contained two or more different carbohydrate substances. Frankel (20) indicated that a starch and water mixture, heated to 100° C temperature, contained no starch in solution and that the paste formed in this way should be regarded as a product of the swelling of the separate starch granules.

In 1924, Alsberg and Rask (2) experimented with cereal starches and found that certain varieties of the starches gave a blue color with iodine and that other varieties gave a red color. After treatment of the various starches in a hot water bath, Alsberg and Rask concluded that the starches which gave a red color with iodine produced more viscous pastes than did the starches which gave a blue color. Two years later, Alsberg (1) reported that the power of starch to form pastes might be dependent upon a starch constituent, amylopectin. He attributed this to the ability of the amylopectin to preserve the suspensoid character of the boiled starch.

Brimball and Hixon (15) tested the rigidity of cornstarch pastes made with nine different kinds of cornstarch. Results of the tests showed no definite relationship between the elasticity and the breaking strength of the cooked pastes. Microscopic observations failed to show noticeable change in the granules at the temperature of maximum viscosity of the pastes. Brimball and Hixon concluded that the lack of correlation between rigidity and viscosity values indicated that they measured different properties of the pastes. The findings of Knowles and Harris (33) substantiated this theory. By 1947, other research had given a conclusive answer to the problem of authentic fractions of starch molecules.

According to Schoch (42), the two starch fractions were first isolated by leaching them from a starch solution. The soluble component, called amylose, had a linear structure and gave a brilliant blue color with iodine. The residue from the starch solution was termed amylopectin. This fraction had a branched chain structure and gave only a red or violet color with iodine.

As a result of later research, Schoch (45) proposed that the linear chain fraction be called A-fraction and that the branched chain fraction be called B-fraction. He considered the terms amylose and amylopectin to be too indefinite. Kerr (32) stated that in expressing the components as A- and B- fractions, it would be necessary to denote the starch used, name the alcohol used in fractionation, and to state the conditions under which the fractionation was made. Kerr and other authors (18, 28, 48) refer to Schoch's proposed A-fraction as amylose and to his B-fraction as amylopectin.

The properties of the two starch components have been generally agreed upon by starch chemists. Amylose is a linear polymer which is composed of glucopyranoside units joined at the first and fourth carbons by alpha-glucoside linkages. A solution of amylose in hot water shows an exaggerated tendency to retrograde or revert to an insoluble state on cooling. When a hot solution of 5 per cent amylose from corn is cooled to room temperature, it immediately sets up to a rigid, irreversible gel. At concentrations below 1 per cent, the amylose separates from solution as an insoluble precipitate. This tendency of amylose to retrograde is often an undesirable feature because it impairs the

stability of starch pastes. Examples of this effect can be found in the formation of insoluble skins on the surface of starch pastes and in the tendency of starch adhesives to thicken and become less soluble. The behavior of amylose in solution is of practical value especially in those mixtures where gel formation is desired.

In 1944, Hixon and Rundle (30) reported the amylose content of the common starches as follows:

Tapioca	17%
Rice	17%
Corn	21%
Potato	22%
Wheat	24%

Schoch (43) found that by removing the free fatty acids from cornstarch, the amylose precipitated by fractionation could be increased from 21 per cent to 28 per cent. Schoch concluded that this treatment would produce similar increases of amylose from other starches which contained free fatty acids.

Whistler and Weatherwax (52) presented evidence that the amylose content of 39 different samples of unimproved Indian corn from New Mexico, Arizona, and South America varied from 22.2 to 28.3 per cent. Starches from 7 standard corn belt corns averaged 26 per cent amylose.

Amylopectin is the starch component of most practical value in the common uses of starch as thickening agents, as emulsifying agents, and as sizing materials for paper and textiles. Amylopectin is a branched chain fraction of glucopyranoside linkages, joined at the first and fourth carbons by alpha-glucoside units. In addition, at

frequent intervals throughout the structure, a glucopyranoside unit is joined at the sixth carbon by a glucoside unit. Amylopectin constitutes the major proportion of the common starches, corn, potato, wheat, and rice. Amylopectin is soluble in water at concentrations of 5 and 10 per cent, and such solutions are relatively stable (42). According to Schoch and Elder (46), a 30 per cent cooked paste of the branched fraction will harden to a gel on standing but the gel can be readily dissolved by heating to 60° C temperature.

Schoch and Elder (46) observed that the staling of bread was believed to be due to crystallization of the branched chain fraction. This theory was supported by evidence that staled bread, completely staled by storing for 10 months, could be regenerated to a fresh and edible condition by brief heating to 100° C. Schoch and Elder attributed the regeneration to the properties of amylopectin since amylose has a tendency to retrograde. They stated that the linear starch fraction was almost completely retrograded during the baking and cooling of bread and that the hardening of the bread crumb seemed to represent the slow association of the branched chain fraction. Heating of the stale bread caused disassociation of the branched chain which resulted in the bread returning to its freshly baked state. Kerr (32) attributed the staling of bread to the hydrogen bonding of the hydroxyl groups of both amylose and amylopectin. This related bonding, Kerr commented, probably eliminates water molecules. Kerr pointed out that the physicochemistry of refreshed bread has not been proved to be identical with that of freshly baked bread.

Chemists from the National Starch Products Laboratory (38) reported that a corn known as waxy maize was brought from China to the United States in 1908. Since that time, plant geneticists have reported waxy strains of potato, rice, sorghum, and barley starches. These waxy or glutinous starches are entirely devoid of amylose and consequently give the red iodine color typical of amylopectin. Schoch and Elder (46) stated that a 5 per cent paste of waxy maize starch would remain clear and fluid for long periods of time. Schoch and Elder (46) concluded that the stability of the waxy starches indicated they have specific application where complete freedom from retrogradation is desired.

In 1951, Hanson and co-workers (24) tested starches from various sources for their values in stabilizing precooked frozen gravies and sauces. The investigators found that the mixtures thickened with starch from the waxy cereals remained more stable after frozen storage than the mixtures thickened with starch or flour from other sources. In addition to these findings, Hanson and co-workers discovered that sauces and gravies thickened with waxy rice flour were more stable than those thickened with flours from other waxy cereals. The use of waxy rice flour produced sauces and gravies which remained completely stable for almost a year under commercial frozen storage conditions. In a later study, Hanson and co-workers (25) used waxy rice flour to thicken cornstarch pudding-type desserts for frozen storage. The desserts remained stable after six to nine months of storage at -23.5°C temperature. Hanson and co-workers reported that both plain and chocolate

puddings which were thickened with waxy rice flour showed no visible change in appearance when thawed for one hour at 25° C temperature after 14 months of storage at -23.5° C temperature.

Effect of Swelling on Physical Characteristics

The changes which occur in starch granules during cooking have been the subject of great interest and controversy among starch chemists.

On the basis of microscopic observations, Alsberg and Rask (2) reasoned that each starch granule was enclosed in a membrane or sac and that the granules first swelled and then burst when a suspension of starch granules was heated. Primball and Hixon (15) decided that heat caused starch granules to lose their rigidity and collapse, giving a wrinkled appearance to the granule walls. A few years later, the same investigators (14) presented evidence that cooked starch pastes contained granules which had swollen sufficiently to become deformed under pressure and as a result, the pastes were made up of empty granule sacs and soluble materials which had diffused from the granules and changed the composition of the dispersing medium.

Bear and Samsa (6) explained the changes in potato starch granules during cooking by comparing them with gas bubbles which had swelled rapidly in size and then collapsed. Bear and Samsa reasoned that in the initial stages of heating the starch suspension, the granules expanded more rapidly than fluid could penetrate through them. Therefore, the investigators concluded, a low pressure area developed in

the interior of the granule with the result that the cell walls collapsed. Hixon and Rundle (39) reported that evidence indicated there was no separate membrane or layer surrounding the starch granules. These authors suggested that enormous forces within the granule were released by the swelling of the granule, and the tangled starch molecules, moving outward in the swelling process, created the illusion of the sac or membrane which was observed under the microscope.

In 1950, Bechtel (8) measured the viscosities of different starch pastes. He established the fact that the changes which occurred during the cooking of starch pastes were complex. Bechtel described the changes as swelling of the starch granules, collapse of the cell walls, solution of the constituents, and final disintegration of the granules. The findings of Campbell and co-workers (18) substantiated the conclusions of Bechtel. By means of photomicrographs, Campbell and co-workers showed that little or no change took place in the starch granules prior to a rapid increase in the viscosity of the starch paste. After examining the photomicrographs of the swollen starch granules, the investigators suggested that the rapid rise in viscosity of a starch paste could be attributed to the congestion of the swollen granules. Campbell and co-workers concluded that a decrease in viscosity could be attributed to rupture of the starch granules and dispersion of the starch.

Viscosity

Kerr (32) stated that most starch pastes do not possess viscosity in the sense in which the term is applied to the more perfect fluids such as water; he suggested that instead they possess anomalous viscosity. A number of authors (5, 10, 18) use the term "apparent viscosity" to describe the consistency of starch pastes. Kerr (32) stated that apparent viscosity is shear-dependent viscosity which is established by the ratio of shearing to the rate of shear. Alsberg (1) reported that the viscosity of a starch paste could be attributed to the jostling of the swollen granules. The findings of Schoch (44) substantiated the conclusion of Alsberg. Observations of Sjoström (47) indicated that starch paste is a suspension of whole and disintegrated granules and the degree of viscosity is a measure of the extent to which they crowd each other in passing through a narrow glass tube.

Reports of early starch research were confused by a lack of agreement of descriptive terminology. A survey of the more recent literature shows that much of the confusion has been eliminated. Kerr (32) reported that the terms, viscosity and consistency are used interchangeably by modern starch chemists. In the recent literature, gelatinize is the term used to describe the changes which occur in a suspension of starch as it cooks. The term gelation is used to describe the cooling and solidifying of cooked starch pastes. Gel is defined as the jelly-like material formed by the coagulation of a starch paste when it has cooled.

It has been mentioned previously in this investigation that the final viscosity of a starch paste is affected by the time and temperature of cooking, the presence of an electrolyte, and the presence of materials other than starch. According to Kerr (32), other factors which may affect paste viscosity are inherent starch characteristics, treatment of starches during manufacture, mechanical injury of the particles, concentration of the starch, and pH of the cooking medium.

Inherent Starch Characteristics

Kerr (32) commented that it has long been known that the larger granules of any particular type of starch gelatinize more easily than the smaller granules from the same starch. However, Kerr continued, it now appears that there may be some correlation between the dispersibility of a type of starch and its average granule size.

In a comparison of corn, wheat, tapioca, and potato starches, Caesar (16) found that the pastes made with wheat starch thickened more slowly but were more stable than the pastes made with other starches. After microscopic examination of the starches, Caesar concluded that the stability of the wheat starch could be attributed to the fact that the cell walls of the wheat starch granules were thicker than the cell walls of the other starches.

Mangels and Bailey (34) tested the swelling power of hard spring, hard winter, soft winter, and durum wheats in cold gelatinizing reagents. From the results of the tests, the investigators concluded that the

chemical differences which cause differences in physical properties of starch are complex in nature and may be attributable to morphological differences in the starch granule.

Taylor and Beckman (48) commented that the characteristics of a cornstarch paste are functions of the physical nature of the starch granules rather than functions of the chemical nature of the amyloses. When a starch paste is made in the ordinary way, the investigators commented, a few of the starch granules rupture easily but the majority of them rupture only with great difficulty after maximum viscosity is reached.

In a study of physiochemical properties of unmodified starches, Harris and Jespersen (28) found little difference in the viscosity and swell of wheat, rice, and barley starches. However, they reported that the viscosity and swell of potato starch was higher than that of the cereal starches. Later in the same year, Harris and Jespersen (27) reported data which showed significant differences in granule swelling among commercially prepared wheat, barley, and corn starches.

Campbell and co-workers (18) gave an account of methods of evaluating starch for specific uses. They stated that the importance of starch for practical application is closely related to water absorption, swelling, and rupture of the granules. Viscosity and gel formation are characteristics which affect the practical use of starch pastes, according to Campbell and co-workers.

Treatment of Starch During Manufacture

During the manufacturing process, native starches are frequently modified or altered in some way to make them suitable for particular uses. According to Kerr (32), the modification of starch may be a relatively simple process of bleaching, or it may involve extreme alteration of the chemical and physical properties of the starch granules. Alteration of the physical characteristics is the most common modification of starch for food use. Starches which have been subjected to this type of modification are classified as heavy boiling, thin boiling, and mobile starches.

Mobile or dry starch is sold for use as a dusting agent for pastries and confections. It is characterized by its ability to create dust, the ability to spread evenly, and great volume per unit weight. Kerr (32) reported that it is not clearly understood why some starches possess mobility and others do not. Heavy boiling starches possess unusually high viscosity. Kerr (32) mentioned that treatment with chlorine gas is one of the most acceptable methods of increasing the viscosity of native starch. According to Kerr (32), most of the modified starches which are marketed have a reduced viscosity below that of native starch. These are called thin boiling starches. The amount of thin boiling starch required to thicken a unit volume of liquid must be increased beyond the amount of native starch needed to thicken the same volume of liquid. This is an important factor because the binding power and other desirable characteristics of starch increase as the amount of starch per unit of volume of liquid increases.

Caesar and Moore (17) tested the consistency changes of pastes thickened with commercially prepared chlorinated and acid-treated thin boiling starches. They found that the acid-treated thin boiling starch produced heavy, plastic pastes. As heating was continued beyond the temperature of maximum viscosity, thinning of the pastes and dispersion of the starch appeared to occur simultaneously. The investigators also heated the pastes of the chlorinated starch beyond the temperature of maximum viscosity. They reported that in these pastes, the physical effect of starch dispersion appeared to be more pronounced than did the chemical effect of degeneration of the pastes.

Sjostrom (47) commented that the space occupied by the suspended granules of a thin boiling starch was smaller than the space occupied by granules of heavy boiling starch. Sjostrom reasoned that other factors affected the difference in fluidity of pastes of heavy and thin boiling starches; but he suggested that this relation in volume was, without doubt, the most important.

Campbell and co-workers (18) reported that chemical and heat treatment during manufacture affected the characteristics of starch. They pointed out that starch which had been dried by heat had gelatinized slightly. The gelatinization increased the power of the starch to absorb water and also increased the viscosity of the pastes made with the starch.

The findings of Campbell and co-workers were substantiated by Bechtel (8). In addition, Bechtel stated, "With increasing modification of the starch, the consistency of the hot pastes of acid-modified corn-starches decreases to a greater extent than do the rigidity and breaking

strength of their gels." Alsberg (1) reported that grinding natural, untreated starch granules in a pebble mill decreased their power to produce pastes when they were mixed with water in normal concentrations. Reports of other starch chemists (44, 32) substantiated the findings of Alsberg. Harris and Jespersen (28) studied the effect of various factors on the swelling of laboratory-extracted cereal starches. They concluded that data on starch research was of no value unless the method of starch manufacture was reported also.

Concentration of Starch

Anker and Geddes (5) experimented with starch pastes thickened with different concentrations of corn, wheat, and potato starches. They found that an increase in the concentration of starch resulted in an initial rise in viscosity at a lower temperature, a more rapid rise in viscosity, and a more extensive breakdown in the body of the paste after maximum viscosity was reached.

The observations of Bechtel and Fischer (10) substantiated the findings of Anker and Geddes. In addition, Bechtel and Fischer found that increased concentrations of tapioca and acid-modified cornstarch produced the same effects as increased concentrations of unmodified corn, wheat, and potato starches. Brimball and Hixon (15) established the fact that each increase beyond the point of a critical concentration of starch produced enormous increases in viscosity and rigidity of the resulting pastes.

Presence of Electrolytes

The presence of ingredients other than starch and liquid medium affect the behavior of starch granules during cooking. Gelatinization and subsequent viscosity breakdown during prolonged cooking of starch pastes are accelerated by the addition of some ingredients and retarded by the addition of others.

Kerr (32) demonstrated the effect of salts on the sedimentation of starch granules. He washed a starch sample thoroughly with distilled water and then used the washed sample to prepare a starch suspension to which he added a few drops of a strong solution of sodium chloride. Kerr reported that the starch from this sample settled more rapidly than did the starch from an identical suspension which contained no sodium chloride. He concluded that the rate of starch sedimentation is increased by the presence of an electrolyte. Richardson and Higgenbotham (41) reported that starch had greater swelling power in the presence of any salt.

Harris and Banasik (26) investigated the effect of electrolytes on the swelling of cereal starches. One commercial wheat starch and several laboratory-extracted wheat starches were studied. The starches were treated with H_2SO_3 , NaOH , and HCl . The investigators found that NaOH raised the pH of the dry starch and greatly increased the swelling of the starch granules during cooking. Treatment with H_2SO_3 lowered the pH of the starch and increased the swelling very slightly. Cooking in the presence of an acid markedly increased the swelling of the

starch at 90° C temperature and above. Harris and Banasik also tested the swelling power of starch in a solution of water, NaOH, and acid. They found that the two variables tended to counteract each other and the swelling of the starch during cooking was decreased. They concluded that the problems of cooking starch in the presence of electrolytes are complex and that the results are not always predictable.

Bechtel (9) adjusted the pH of modified and unmodified starch slurries with HCl and NaOH. He found that differences in pH altered the temperature of initial viscosity rise and the temperature at maximum viscosity. He stated that the pastes with pH value which fell within the range of 4 and 7 showed no breakdown after maximum viscosity was reached but the pastes made from alkaline solutions showed a definite tendency to break. Bechtel used distilled water in the experiments which he conducted because he found that tap water produced unreliable results. Schoch (44) stated that the solubility of starch could be raised by certain chemical modifiers. He mentioned that the peptizing of starches by alkalies or salts resulted in mushy pastes.

Anker and Geddes (5) reported that maximum paste viscosity decreased with an increase in pH value of 5.2 to 6.8. Chapman and Buchanan (19) found that inorganic acids hasten syneresis of starch gels. They stated that the inorganic acids caused a decrease in the viscosity of starch pastes after maximum viscosity had been reached and that the gels formed from these pastes showed definite syneresis.

White (51) presented evidence that starch gelatinized quickly in suspensions of pH value below 4 or above 7. He said that both

gelatinization and paste breakdown took place more slowly in pastes of pH value which fell within the range of 4 to 7.

According to Bisno (12), variations in the water supply used in making pie fillings altered the viscosity of the fillings. He stated that a change from tap water to softened water frequently produced visible changes in the consistency of pie fillings. Bisno observed that pie fillings made with tap water were more viscous than were the fillings made with softened water. Hains (23) reported that the addition of a solution of citric acid at the beginning of the cooking of sweetened cornstarch pastes made it possible to obtain maximum viscosity in an appreciably shorter time than was required for similar sugar-starch pastes without acid. Hains further reported that additions of citric acid to cornstarch pastes decreased the viscosity of the pastes containing 20 per cent sucrose and of the control pastes made without sucrose. However, citric acid solution did not alter the viscosity of the cornstarch pastes which contained 40 and 60 per cent sucrose. According to Hains, there was no decrease in gel strength of any of the pastes to which citric acid solution was added.

Effect of Time and Temperature

The chemists from the National Starch Products Laboratory (36) reported that the gelatinization temperatures of starches are not physical constants. The gelatinization process takes place gradually over a wide range of temperatures. The chemists attributed the lack

of definite gelatinization temperatures to the fact that starch granules differ in size. In general, the chemists stated, the large granules start to swell at a lower temperature than do the small granules. When the temperature of maximum viscosity has been reached, White (51) stated, further cooking, even at a constant temperature will result in a breakdown in the viscosity of the paste.

Alsberg and Rask (2) used the Stormer viscometer to test the consistency of 4.5 and 5 per cent concentrations of wheat and corn starches. The starch suspensions were cooked in a water bath which was heated at such a rate that the temperature of the suspensions was raised from 25° C to above 30° C in the course of 40 to 45 minutes. The investigators reported no change in the viscosities of the suspensions below 65° C. The viscosities of the pastes began to rise at 65° C to 68° C and continued to rise until the temperature of maximum viscosity was reached. Temperature of maximum viscosity was 91° C for cornstarch and 95° C for wheat starch, according to Alsberg and Rask. The investigators concluded that the viscosity changes were caused by gradual changes in the starch granules which took place over a temperature range of 20° C to 30° C. From the results of their experiments, Alsberg and Rask concluded also that the gelatinization process of suspended starch granules is a gradual one. They made the following observations concerning the gelatinization of starch: (1) sharply drying or thoroughly wetting the starch granules altered the gelatinization temperature, (2) gelatinization was incomplete unless adequate quantities of water were present, (3) the rate of heating had a definite effect on the gelatinization temperature of starch.

The findings of Alsberg (1) indicated that three factors affected the extent to which heat caused starch granules to swell: (1) the ease with which the granules were softened by moist heat, (2) the inherent swelling power of the granules, (3) the surface area of the granules. After considering these factors, Alsberg concluded that different starches would increase their volumes to different degrees when boiled and that individual granules, even in the same sample, would swell to a different extent.

Beckford and Sandstedt (11) used a spectrophotometer to study the gelatinization properties of starch granules. Their findings confirmed the observations of Alsberg. In addition, they stated that within the limits of 2.5°C , the rate of heating had no effect on the viscosity rise of corn and wheat starch suspensions.

Bechtel and Fischer (10) reported that most types of starch appeared to attain a plateau in viscosity after one hour of cooking at 90°C to 92°C . Vigorous agitation produced a rapid decrease in viscosity but differences in the rate of agitation did not appear to alter the pasting process of the starch.

Bechtel (9) used the Corn Industries viscometer to measure the pasting characteristics of different starches. He found that both time and temperature affected the viscosity of starch pastes. Rapid heating of the paste lowered the temperature of initial viscosity rise, decreased the length of time the starch pastes needed to be held at 90°C to reach maximum viscosity, and increased the viscosity of the pastes. Bechtel concluded that there appeared to be a definite

temperature at which each type of starch gelatinized at a uniform rate and at which the paste could be held for a reasonable length of time without excessive breakdown of paste viscosity. For unmodified cornstarch, this temperature was 90° C, according to Bechtel. The findings of Bechtel have been confirmed by other investigators (17, 16, 6).

The Effect of Fatty Acids and Glycerides

It has been known for many years that some starches contain fatty acids (32). During purification, rice, tapioca, and corn starches yield relatively large amounts of combined fatty acids. However, the tuber starches appear to have no fatty acids associated with them. Schoch (44) stated that the short, opaque characteristics of the pastes made from cereal starches are attributable to the presence of fatty acids. Schoch (44) found that the pasting characteristics of starch from which the fatty acids had been extracted were different from the pasting characteristics of natural starch. He reported that defatting unmodified cornstarch lowered the maximum viscosity to about one-half that of the original starch. Later research by Bechtel (9) substantiated the findings of Schoch.

Mitchell and Zillman (35) studied the effect of fatty acids on the viscosity of nonwaxy starches. Among the factors which influenced the physical properties of the starch and fatty acid mixtures were the proportion of starch to water and the amount of fatty acids present. The investigators concluded that soaps, fatty acids, and perhaps natural fats increased the viscosity of starch pastes.

In practical usage, glycerides in the form of milk fats are frequently present in starch pastes. The Brookfield viscosimeter was used by Jordan and co-workers (31) to measure the viscosity of cornstarch puddings made with homogenized and nonhomogenized milk. Nine different levels of cornstarch were used to thicken puddings made with each type of milk. The levels of cornstarch ranged from 2.41 to 5.63 per cent, based on the weight of the milk. The puddings were cooked over boiling water to 91.5°C temperature. Analysis of variance for the puddings showed no significant difference in the consistencies of the puddings which contained less than 3 per cent cornstarch. However, the analysis of variance for all the puddings containing more than 3 per cent cornstarch showed that those made with homogenized milk were significantly thicker than were those made with nonhomogenized milk. The investigators suggested that the differences in viscosities might be attributable to the relative surface area of the fat globules in the two kinds of milk. They reasoned that the increased surface area of the fat globules in homogenized milk increased the amount of fat exposed for colloidal reaction. They further reasoned that the increased availability of the fat in homogenized milk might be considered equivalent to an increase in the amount of fat in the starch paste.

In a second part of the study, Jordan and co-workers prepared cornstarch puddings with skim milk to which they added varying amounts of clarified butterfat and refined cottonseed oil. Jordan and co-workers stated that the results of the second group of tests supported the belief that the higher viscosity and greater firmness of puddings

made with homogenized milk were associated with the greater surface area of the fat globules.

Morse and associates (36) tested the effect of nonfat dry milk solids on the viscosity and gel strength of starch pastes. In the first part of the tests, slurries were made of flour, nonfat dry milk solids, and water. The amount of flour was kept constant and the amount of nonfat dry milk solids was varied. The investigators discovered that increased amounts of nonfat dry milk solids increased the viscosity and gel strength of the starch pastes.

Morse and associates also studied the effect of fat and salt on the viscosity and gel strength of starch pastes made with additions of nonfat dry milk solids. They reported that additions of fat appeared to have no effect on the viscosity of thin pastes. However, additions of fat caused significant decreases in the viscosity of the thick pastes. Increases in the amount of salt only slightly decreased the gel strength of any of the pastes, according to Morse and associates.

In a report on the use of starch in pie fillings, Trempel (50) stated that large amounts of eggs, fat, dry milk solids, and sugar interfered with the swelling of starch granules during the pasting process.

The Effect of Sucrose

Nevenzel (39) used the Stormer viscometer to study the effect of varying concentrations of sugar on starch gels. She found that the cold gel of a 5 per cent cornstarch paste containing 5 per cent sugar

concentration did not hold its shape when turned out of the mold. With additions of 15 and 30 per cent sugar, the gel strength of the corn-starch pastes gradually increased. However, Nevenzel reported that the cold gel from the paste containing 30 per cent sugar was weaker than the gel from the paste containing 15 per cent sugar. When the sugar concentrations were increased to 50 and 60 per cent, the resulting gels were soft or liquid. From the studies of photomicrographs of the starch pastes, Nevenzel concluded that, at a specific temperature, the starch granules in the pastes containing sugar had swelled less than the starch granules in the pastes without sugar.

Woodruff and Nicoli (53) cooked 5 per cent slurries of corn, wheat, rice, potato, and cassava starches with four different concentrations of sucrose. The samples were cooked, poured into molds, and allowed to stand for 24 hours before they were tested for firmness. With additions of 10 and 30 per cent sucrose, the root starches formed increasingly softer gels. The additions of 50 and 60 per cent concentrations of sucrose produced syrups instead of gels. The same percentages of sucrose were added to 5 per cent slurries of cereal starches. ~~X~~ Each addition of sucrose produced an increase in transparency and tenderness of the cold gels. The addition of 50 per cent sucrose formed a gel which would not hold the shape of the mold and the addition of 60 per cent sucrose to the cereal starch slurry produced a syrup.

Trempel (50) stated that sugar raised the gelatinization temperature of starch and interfered with the swelling of the starch granules. For making pie fillings, Trempel suggested that the amount of sugar in

the mixture should not be more than three and one-half times the amount of starch in the mixture during the pasting process. If increased sugar is needed for palatability, it should be added after the pasting of the starch is completed.

The findings of Morse and associates (36) indicated that the viscosity of thin starch pastes was increased by additions of sucrose. However, the investigators stated that pastes made from flour and water were proportionately more viscous with added sugar than were pastes containing flour, water, nonfat dry milk solids, and sugar.

Hester (29) reported the effects of increasing concentrations of sucrose on the paste and gel strength of several types of starches. She stated that a paste containing 6.5 grams of cornstarch and 100 grams of water formed a paste which was considered standard. The additions of 15.9 grams of sucrose to the standard paste produced an increase in viscosity. However, further increases in the level of sucrose progressively decreased the maximum viscosity of the pastes. Increases in the level of sucrose also increased the temperature of the initial viscosity rise and the temperature of maximum viscosity of the pastes. Hester found that the gels of the standard pastes containing 15.9 grams of sucrose were slightly less firm than those of the standard paste without sucrose. Further increases in sucrose concentrations produced gels which would not hold the shape of the molds. The highest sucrose concentrations, 31.6 grams and 39.5 grams, formed thin pastes.

Hains (23) tested the maximum viscosity of 12 per cent cornstarch pastes in which sucrose constituted 20, 40, and 60 per cent of the weight of the liquid. She found that the pastes containing 20 per cent sucrose were thicker than were the control pastes without sucrose. With additions of 40 and 60 per cent sucrose, the maximum viscosity of the pastes progressively decreased. Hains stated that higher temperatures and much longer cooking periods were required to obtain maximum viscosity of starch pastes when increased proportions of sucrose were added.

Gel Properties

It has been mentioned that Brimball and Hixon (15) reported differences in the properties of hot and cold starch pastes. Further studies by other investigators have emphasized these differences.

In experiments with various root and cereal starches, Woodruff and Nicoli (53) reported that maximum gel strength was obtained from the starches which had been cooked to a temperature of 90° C or above. The report of Bisno (12) confirmed the findings of Woodruff and Nicoli. Maximum gel strength, Bisno reported, was produced by rapidly heating the starch paste to 90° C and then removing it immediately from the cooking container. The findings of Bechtel (8) indicated that the effect of temperature of cooking on the gel properties of starch pastes varied with the degree of modification of the starch. The rigidity and breaking strength of the starch increased with increased

modification of the starch, according to Bechtel. These conclusions were supported by the evidence that acid-modified starches which had been cooked to 91° C and then cooled to room temperature showed greater increase in rigidity and breaking strength than did the unmodified starches which had been given the same treatment. Bechtel (8) cooked other pastes to temperatures of 94° C and above. He found that gel strength of pastes cooked to 94° C was greater than the gel strength of pastes cooked to lower temperatures but gel strength decreased if the pastes were cooked to temperatures above 94° C.

According to Knowles and Harris (33), environmental conditions during growth of wheat affected the gel strength of pastes made from hard and soft wheat starches. Knowles and Harris also indicated that the stage of maturity of the wheat affected the gel strength of the starch pastes.

Objective Tests for Cooked Starch Pastes

The characteristics which determine the usefulness of starches for practical application are viscosity, plasticity, gel strength, and rigidity (32). Measurements of these characteristics are made in terms of hot paste viscosity and cold paste body.

Viscosity measurements

Objective measurements of viscosity are made on both hot and cold pastes. Several accepted tests of this kind are described on the following pages.

Scott test for hot paste viscosity (32). The Scott test is widely used for determining hot paste viscosity. A slurry is made of 280 cubic centimeters of distilled water and a quantity of starch of known pH value. The slurry is mixed in a German-silver beaker and then the beaker and contents are placed in a boiling water bath. The starch mixture is heated for 15 minutes with constant stirring. Two minutes prior to the end of the cooking period, 200 cubic centimeters of the paste are transferred to a Scott viscosity cup which is also in the water bath. At the end of the 15 minute cooking period, 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 time, in seconds, is the specific Scott viscosity value of the starch.

The viscosity may also be considered as relative viscosity in the sense that standard starches are used to set up permissible limits of variation in the viscosity of other starches to be tested by this method.

Stormer viscosimeter (32). This instrument is used to measure cold paste body. The viscosimeter consists of a cylinder immersed in the test paste which is held 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. For the test, the starch is gelatinized in the manner described for the Scott viscosity test. Heating is continued for the full 15 minute cooking period without transferring the paste to the Scott viscosity cup. Instead, the paste is placed in

a closed container and immediately put into a 25° C constant temperature bath. At the end of a definite aging period, the surface skin on the paste is carefully removed. The remaining paste is gently stirred with a spatula and then transferred to the cup of the Stormer viscometer. The viscosity of the paste is noted at 25° C temperature.

Brookfield viscosimeter (32). This torsional viscometer contains spindles of various capacities which are driven by a synchronous motor. Viscosity, in terms of poises, is recorded as the force which the thickening paste exerts on the spindles.

Caesar consistometer (16). This continuous recording instrument gives a complete history of the consistency changes of starch pastes. The recorded changes include the gelatinization temperature of the starch, peak viscosity which is obtained with a definite cooking procedure, specific viscosity after a prescribed cooking operation, rate of increase in paste body with decreased temperatures, and cold paste body after a specified cooling period. For the test, the starch suspension is poured into a cooking beaker which is surrounded by a heating bath. As the temperature of the heating bath is raised at a regular rate, the starch suspension is stirred by a paddle. The paddle is connected by a shaft to a constant speed electric motor. Changes in viscosity or paste body are indicated by the difference in the electrical input needed to maintain a constant motor speed. When the cooking of the starch paste is completed, cold water may be put into the bath to cool the paste. To obtain significant differences in observed viscosity values, it is recommended that relatively high starch concentrations be used.

Brabender amylograph (32). The Brabender amylograph is used to measure the pasting characteristics of starches. With this instrument, the paste is held in a cup surrounded by an air bath for temperature control. The cup is revolved at a constant speed. The measuring device consists of a disc to which are attached several short rods extending into the paste. This mechanism serves as a stirring unit also. The torque impressed on the measuring unit is transmitted to a torsion balance. A continuous, graphical record is traced by the instrument over the entire period of the test. The temperature may be increased at a fixed rate and may be held at any level by a thermostatic control. By switching off the heating unit, the paste may be cooled to any desired temperature. A cooling coil is provided for circulating cold water and accelerating the cooling of the paste.

Corn Industries viscometer. Bechtel (7) tested various cornstarches with this instrument and showed its suitability for research. The Corn Industries viscometer measures and records the viscosity of starch pastes for any desired cooking period. The slurry to be tested is poured into a stainless steel cooking beaker which is set in a thermostatically controlled liquid bath. The operating temperature of the liquid bath is usually 92° C to 96° C. The cooking paste is stirred at a constant rate by electrically driven paddles which remove the layer of pasted starch from the walls of the cooking beaker. This constant removal of the pasted layer improves the efficiency of the heat transfer to the body of the paste and results in a nearly uniform paste

temperature. A separately mounted propeller, driven through the gear differential, stirs the center of the paste and also serves as a means of measuring 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. Attached to the dynamometer is a pen which automatically records the continuous viscosity changes of the paste. Evaporation of moisture from the cooking paste is prevented by the cover of the beaker which acts as a condenser. 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 thickening paste. The apparatus can be adjusted for a cooling period if desired.

Line spread tests

Grawemeyer and Pfund (22) have developed an objective test for measuring the flow characteristics of hot or cold starch pastes. This method, or its modification, is often used to determine the spread of cream pudding or pie filling.

Grawemeyer and Pfund test (22). In this test, a flat glass plate is placed on a surface which has been checked for evenness with a spirit level. A diagram of concentric circles is placed beneath the glass. The smallest circle has a diameter of two inches and the surrounding

circles are graduated at intervals of one-eighth inch. A hollow cylinder, the exact diameter of the innermost circle, is put in place over the center circle and filled with the material to be tested. The material in the cylinder is leveled with a spatula and the cylinder is carefully lifted. The product is allowed to spread for two minutes and readings are taken at 4 widely separated points which mark the limits reached by the product. The average of the four readings is recorded as the line-spread of the sample.

Gel strength tests

The gel strength of starch pastes has been measured by a variety of instruments embodying different principles. Kerr (32) reported that several of the instruments are the rigidometer, Tarr-Baker jelly tester, blunt plunger type penetrometer, and the tube type penetrometer. The rigidometer measures the rigidity of a gel or its lack of elasticity; the Tarr-Baker jelly tester gives a value which is proportional to the force necessary to rupture the gel. The results of tests with the blunt plunger type penetrometer are a combination of plastic and elastic effects. The tube type of plunger measures the resistance of gels to cutting action.

Exchange Ridgelimeter (29). For this test, the starch pastes are stored in jelly glasses provided with sideboards. At the end of a specific aging period, the sideboards are removed and the excess gel is sliced off even with the rim of the glass. Each gel is removed from the glass by inverting it on a glass plate. The gel is allowed

to stand on the plate for two minutes and then a micrometer screw is adjusted and the per cent of sag is read. The rigidity of the gel is interpreted in terms of the per cent of sag.

Tarr-Baker jelly tester (32). For this test, the starch suspension is placed in a porcelain cup and cooked in a boiling water bath for 30 minutes. The cooked paste is cooled and immediately covered with a film of mineral oil. After the paste has aged in a water bath at 25° C for one hour, the mineral oil is poured from the paste and the paste is then placed under the plunger of the tester. With 500 cubic centimeters of water in the jelly tester, the flow of water is adjusted so that it raises in the manometer column at the rate of 60 centimeters per minute. The manometer is read when the gel breaks. The gel strength is recorded as the height in centimeters reached by the water column in the manometer at the breaking point of the gel.

Fuchs penetrometer. Kerr (52) stated that the Fuchs penetrometer provided a sensitive and accurate method of determining the gel strength of a starch paste. For this test, the cooked starch paste is aged for a definite period of time and then the surface skin of the gel is removed. The plunger of the penetrometer is adjusted so that it rests on the top surface of the prepared gel. A weight is imposed on the plunger in a receptacle on top of a vertical rod which is attached to the top of the plunger. The plunger consists of a sharpened, hollow tube that is highly polished. This tube resembles a large cork borer. The plunger is released, and the time, in seconds, required for the hollow tube to cut into the gel up to a certain depth is noted.

PROCEDURE

Ingredients

Four different liquid mediums were used in making the starch slurries in this study. The four mediums were distilled water, a single sample of tap water with a value of 16 grains hardness, a solution of nonfat dry milk solids in distilled water, and a solution of whole dry milk solids in distilled water.

The cornstarch for this project was supplied by the Corn Products Refining Company of Argo, Illinois. The lot used was taken from a regular run of their commercial starch prepared for food uses. According to Bechtel (8) the standard Scott viscosity for this type of starch is 76.

The entire lot of cornstarch, packaged in polyethylene bags, was stored in a covered, stainless steel bin at room temperature.

Superfine granulated sugar was obtained from the College Food Stores. The sugar was kept at room temperature in a covered, water-tight container.

The supply of nonfat dry milk solids for this investigation was obtained from the Michigan Milk Producers Association of Adrian, Michigan. The nonfat dry milk solids were manufactured by the spray dry process and were sold for home and institution food preparation. Composition of the nonfat dry milk solids was as follows (3):

Butterfat	1.00%
Minerals	8.00%
Moisture	3.00%
Protein	37.00%
Lactose	51.00%

The supply of whole dry milk solids was purchased from the Borden Company of New York City, New York. These dry milk solids were manufactured by the spray dry process and sold under the trade name, Parlac. Composition of the whole dry milk solids was as follows (40):

Butterfat	28.00%
Minerals	5.80%
Moisture	2.00%
Protein	26.50%
Lactose	37.70%

Because the mineral content of tap water varies from day to day, the entire volume of tap water used in this study was drawn from the faucet at one time. The water was stored at room temperature for a period of two days in a covered glass bottle. A sample of the tap water was analyzed for hardness by the college sanitarian.

The distilled water used in this investigation was freshly distilled and stored at room temperature in a covered glass bottle for a period of not more than three days.

Formulas

Starch concentration

As a preliminary step in this study, cream pudding recipes for home and institution use were checked. The percentage of cornstarch

in these recipes was found to vary from 8.3 to 13 per cent of the weight of the liquid (4, 21, 49). Eleven per cent cornstarch was selected for this study after tests with 11 and 12 per cent cornstarch pastes. In these tests, it was found that 12 per cent cornstarch pastes made with the solutions of dry milk solids in distilled water were too viscous to be handled by the instrument used to record viscosity. The proportion of cornstarch to water was kept constant in all replications of the starch slurries in this study.

Sucrose concentration

In the cream pudding recipes which were checked, sugar content varied from 25 to 55 per cent of the weight of the liquid. Sucrose concentrations of 15, 21, and 27 per cent of the weight of the liquid were arbitrarily selected for this study. These low ranges of sucrose were chosen because information concerning the effect of the proportion of sucrose on the thickening of starch pastes is limited and because the increased thickening effect of starch in mixtures containing relatively low concentrations of sucrose has not been adequately explained. A basic starch paste without sucrose was used as the control for each liquid medium. Because the beaker of the viscometer was designed to cook and stir a total volume of one liter, the weights of starch, sucrose, and liquid medium, based on the desired percentage relationships, were calculated to yield a total volume of one liter of each mixture. Allowance for the displacement of the dry ingredients in the liquid medium of each replication was based on actual measurement of the starch slurries in a preliminary step in the investigation.

Liquid mediums

Series A. The purpose of this series was to determine the effect of the proportion of sucrose on the viscosity of cornstarch pastes made with distilled water. Table 1 lists the ingredients and the quantities of each used for Series A of the study.

Series B. To study the effect of the proportion of sucrose on the viscosity of cornstarch pastes made with tap water, Series A was repeated with tap water substituted for the distilled water. Table 2 lists the ingredients and the quantities of each used for Series B.

Series C. Series A was repeated with addition of 8.52 per cent nonfat dry milk solids, based on the weight of the liquid. The purpose of this study was to determine the effect of the proportion of sucrose on the viscosity of cornstarch pastes made with a solution of nonfat dry milk solids in distilled water. The percentage of nonfat dry milk solids was consistent with the amount of nonfat dry milk solids found in fluid skim milk. The formulas for Series C are listed in Table 3. Allowance for the displacement of the dry milk solids in distilled water was based on actual measurement of the dry ingredients and the solution of nonfat dry milk solids in distilled water.

Series D. To study the effect of the proportion of sucrose on the viscosity of cornstarch pastes made with a solution of whole dry milk solids in distilled water, Series A was repeated with addition of

12.01 per cent whole dry milk solids, based on the weight of the liquid in the formula. The concentration of whole dry milk solids used in the liquid medium for this series was consistent with the whole dry milk solids found in whole fluid milk. Table 4 lists the ingredients and quantities of each which were used in Series D. Allowance for the displacement of the whole dry milk solids in distilled water was based on actual measurement of the dry ingredients and the solution of whole dry milk solids in distilled water.

Table 1. Formulas for Series A, distilled water medium.

Variation	Cornstarch		Sucrose		Distilled Water
	Gm.	%	Gm.	%	Ml.
I	106.7	11	0	0	970
II	100.3	11	136.8	15	912
III	97.5	11	186.1	21	886
IV	94.6	11	232.2	27	860

Table 2. Formulas for Series B, tap water medium.

Variation	Cornstarch		Sucrose		Tap Water
	Gm.	%	Gm.	%	Ml.
I	106.7	11	0	0	970
II	100.3	11	136.8	15	912
III	97.5	11	186.1	21	886
IV	94.6	11	232.2	27	860

Table 3. Formulas for Series C, nonfat dry milk solids plus distilled water medium.

Variation	Cornstarch		Sucrose		Distilled Water	Nonfat dry milk solids	
	Gm.	%	Gm.	%	Ml.	Gm.	%
I	102.1	11	0	0	927.8	79.0	8.52
II	95.6	11	130.4	15	869	74.0	8.52
III	92.1	11	175.8	21	837	71.3	8.52
IV	89.5	11	219.6	27	813.3	69.3	8.52

Table 4. Formulas for Series D, whole dry milk solids plus distilled water medium.

Variation	Cornstarch		Sucrose		Distilled Water	Whole dry milk solids	
	Gm.	%	Gm.	%	Ml.	Gm.	%
I	100.7	11	0	0	915	109.9	12.01
II	94.3	11	128.6	15	857	102.9	12.01
III	90.8	11	173.3	21	825	99.1	12.01
IV	88.2	11	216.5	27	802	96.3	12.01

Treatment

Preparation of the slurries. All the ingredients for the starch slurries were weighed on a Torsion balance. Glazed weighing paper was used to line the balance pans for weighing the starch, sucrose, and dry milk solids to minimize losses in transferring materials to beakers for blending the ingredients. The water was weighed in a 1-liter glass beaker. A narrow rubber scraper was used to remove the residue of the dry ingredients from the weighing papers. The quantities of ingredients needed for the three replications of each starch slurry were weighed at the beginning of each testing period but were not mixed together until immediately before starting the testing procedure.

Because investigators have established that maximum viscosity of cooked starch pastes is affected by the length of time the starch slurry stands before cooking, care was taken to mix the slurries quickly and to keep the mixing time constant for each replication. In the preliminary tests, technique was developed so that total mixing time approximated one and one-half minutes.

Temperature of the ingredients is another factor which has been found to affect the maximum viscosity of a cooked starch paste. The temperature of the uncooked starch slurries in this study was 26°C , $\pm 1^{\circ}\text{C}$ when the slurries were poured into the preheated, steel cooking beaker.

Series A. For the control slurry, without sucrose, the starch was placed in a 1-liter glass beaker. One-third of the distilled water was added to the starch, and the mixture was stirred with a narrow rubber scraper until it was free from lumps; then half of the remaining water was added to the slurry. The slurry was then poured quickly into the cooking beaker of the viscometer. The remaining one-third of the liquid was used to rinse the glass beaker, and this rinse was added immediately to the mixture in the cooking container.

The addition of sucrose to the starch made it more difficult to produce a slurry which was free from lumps. For the variations with sucrose, the starch and sucrose were placed in the glass beaker and were thoroughly blended in the dry form. Only enough distilled water to moisten the ingredients was added and the mixture was stirred vigorously to produce a smooth paste. With increase in the level of sucrose, the first liquid addition was gradually decreased to produce a smooth slurry. When the slurry was free from lumps, all but one-third of the remaining water was added. The remainder of the water was used to rinse the beaker and this rinse was then added to the slurry in the cooking beaker.

Series B. Tap water at 26° C temperature was substituted for the distilled water in the uncooked starch slurry. Proportion of ingredients and mixing procedure was the same as described for Series A.

Series C. Series A was repeated with the addition of 8.52 per cent nonfat dry milk solids, based on the weight of the water. In the

trial studies the starch, sucrose, and nonfat dry milk solids were placed in a glass beaker and thoroughly mixed in the dry state. The water was added to the dry ingredients and the slurry was mixed in the manner described for Series A. It was found that this method of combining and mixing the ingredients did not produce a smooth slurry within the time limit established for total mixing in Series A and B. Therefore, the investigator decided to reconstitute the nonfat dry milk solids for use in the replications in this series instead of combining the milk solids with the other dry ingredients.

The nonfat dry milk solids were reconstituted in individual solutions immediately before the mixing time of each slurry. One-third of the distilled water needed for each replication was set aside for use in the final rinsing procedure. The remaining two-thirds of the distilled water was used to reconstitute the nonfat dry milk solids. Because dry milk solids dissolve much more easily in warm water, the distilled water was heated to a 45°C temperature in a hot water bath. When the desired temperature was reached, the distilled water was removed from the heat and the nonfat dry milk solids were sprinkled over the surface of the water. The mixture was stirred with a narrow rubber scraper only enough to moisten all the dry milk solids and was then allowed to stand for 20 minutes. During the standing period, the solution was stirred occasionally with a narrow rubber scraper.

At the end of the 20-minute period, the solution of nonfat dry milk solids in distilled water was placed in a cold water bath and cooled to a temperature of 26°C , $\pm 1^{\circ}\text{C}$. Total cooling time was

approximately 10 minutes. In the replications in this series, treatment of the other dry ingredients and mixing of the slurries were the same as described for Series A except that the solution of reconstituted milk solids replaced distilled water.

The beaker which had held the solution of dry milk solids in distilled water was rinsed with the water set aside earlier for this purpose. The rinsings were poured into the beaker in which the starch slurry had been mixed and these total rinsings were added immediately to the mixture in the cooking container.

Series D. Series A was repeated with addition of 12.01 per cent whole dry milk solids, based on the weight of the water. Heating of the distilled water and reconstitution of the whole dry milk solids were the same as described for Series C. Treatment of the other dry ingredients and mixing of the slurries were the same as described for Series A except that the solution of reconstituted dry milk solids replaced the distilled water. Rinsing of the beakers was the same as described for Series C.

Cooking procedure and viscosity tests. The Corn Industries Viscometer, described in the review of literature, was used for cooking the starch slurries and for measuring the viscosity of the hot pastes. Figure 1 shows a cross section diagram of the viscometer. Pechtel (7) recommends that the stirrer of the viscometer be operated at standard speed during general laboratory testing of starch pastes. For this reason, standard speed was used throughout the investigation.

When highly viscous mixtures are tested in the viscometer, it is necessary to extend the range of the weight arm of the dynamometer. For testing 11 per cent starch mixtures, Bechtel (7) suggests that the 1800 gram-centimeter weight be used. This supplementary weight was placed on the weight arm and was kept there for the duration of the study.

The viscometer has a hot water bath (Fig. 1) which is thermostatically controlled. Distilled water is used as the bath liquid unless a cooking temperature of 100°C is desired. When the bath is used at boiling temperature, steaming may cause excessive evaporation from the bath which makes it advisable to use antifreeze or glycerol heating mediums with boiling points above 100°C . Because the investigator wished to cook the starch slurries at the boiling temperature of water in this study, a glycerol-type permanent antifreeze was used as the bath liquid. Before starting the tests described in this investigation, the temperature of the bath was adjusted. A thermometer was inserted into the liquid, the heating element was turned on, and the thermostat was adjusted to hold the bath at a constant temperature of $100^{\circ}\text{C} \pm 1^{\circ}\text{C}$. The temperature of the bath was kept constant throughout the investigation.

When the bath temperature had been adjusted, the stainless steel beaker and the stirrer were placed in position (Fig. 1). The condenser cover (Fig. 1) was put on the beaker and the air inside the beaker was heated to 70°C temperature. Then the motor which controlled the stirrer was started and the slurry was mixed. The front half of the

Figure 1. Sectional drawing of the Corn Industries Viscometer (7)

1. Recorder and dynamometer (Dynamometer not shown)
2. Cable from viscometer to recorder
3. Cable drum
- 4, 5, 6, 7. Gears of sun and planet differential
8. Worm, turned by synchronous motor (not shown)
9. Worm gear
10. Spring pins for holding center shaft
11. Coupling to attach stirrer
12. Condenser cover
13. Liquid bath
14. Overflow
15. Drain cock
16. Starch beaker
17. Electric heater, thermostatically controlled
18. Scraper blades
19. Propeller
20. Thermometer in paste
21. Thermometer in bath

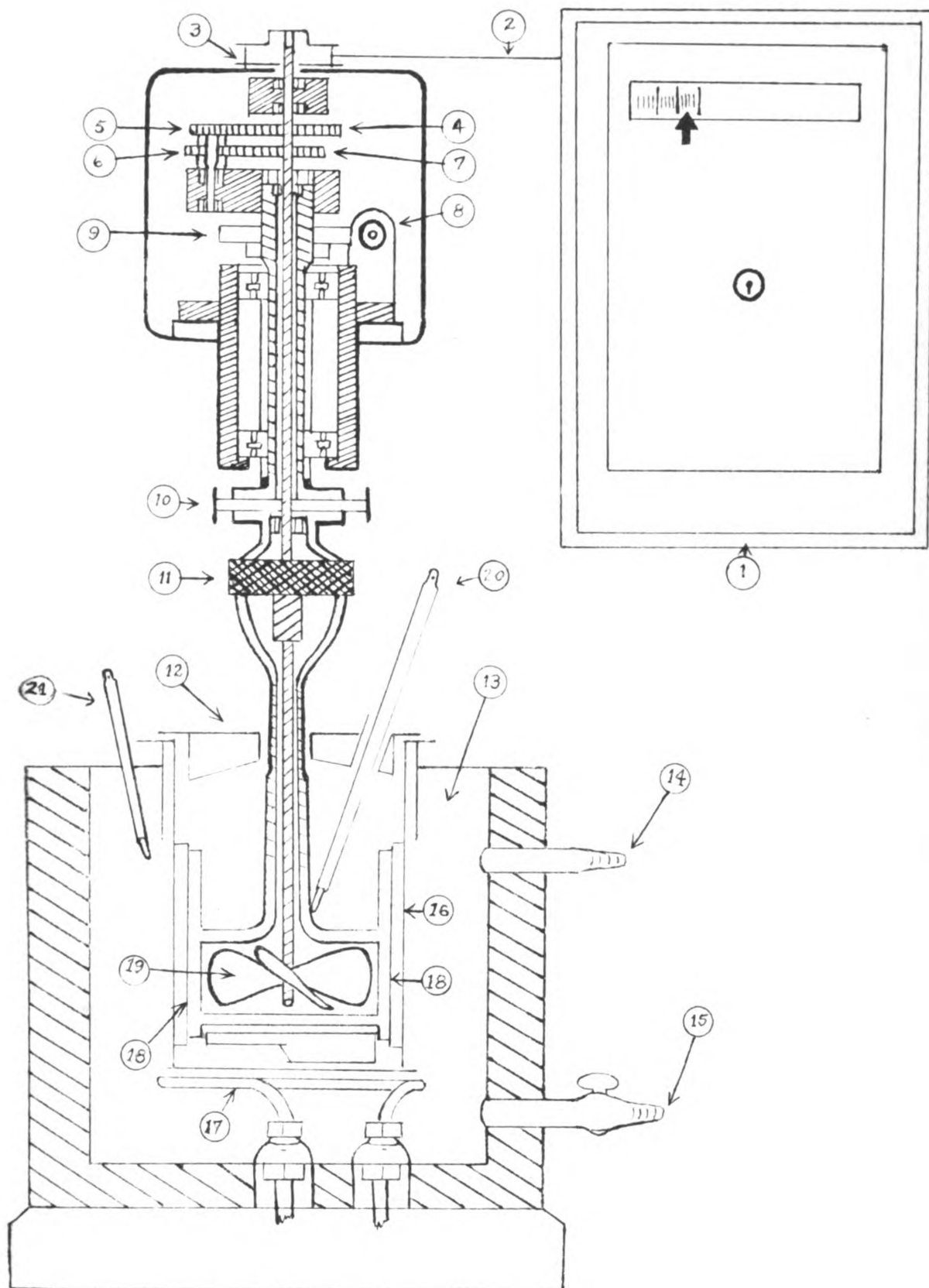


Figure 1. Sectional Drawing of the Corn Industries Viscometer.

condenser cover was removed and the slurry was poured into the cooking container. The condenser cover was replaced immediately. Simultaneously with the start of the pouring procedure, the chart recorder (Fig. 1) was started. On the chart of the viscometer, the continuous viscosity changes during the cooking of the starch pastes were automatically recorded. The measurement of viscosity with the Corn Industries Viscometer is made on the basis of force which the propeller encounters as it turns in the paste. This force on the propeller is transmitted by a cable to the recorder pen which moves from left to right across the chart as the viscosity of the paste increases. The force or torque can be calculated, or Bechtel's tables (7) can be used for transposing chart readings into torque values. Bechtel's tables were used for determining the torque values in this study.

Figure 2 shows a sample chart with a record of a viscosity curve of a starch paste. In this study, the chart was operated at rapid speed. At this speed, the chart moves downward at the rate of one horizontal arc per minute.

Because the rate of temperature rise is a factor which may affect the rate of thickening and the final viscosity of a cornstarch paste, the investigator decided to cook all the pastes in this study to a temperature of 95° C. Paste temperatures were recorded at 1-minute intervals throughout the cooking period from a thermometer inserted into the starch paste through the cover of the cooking container.

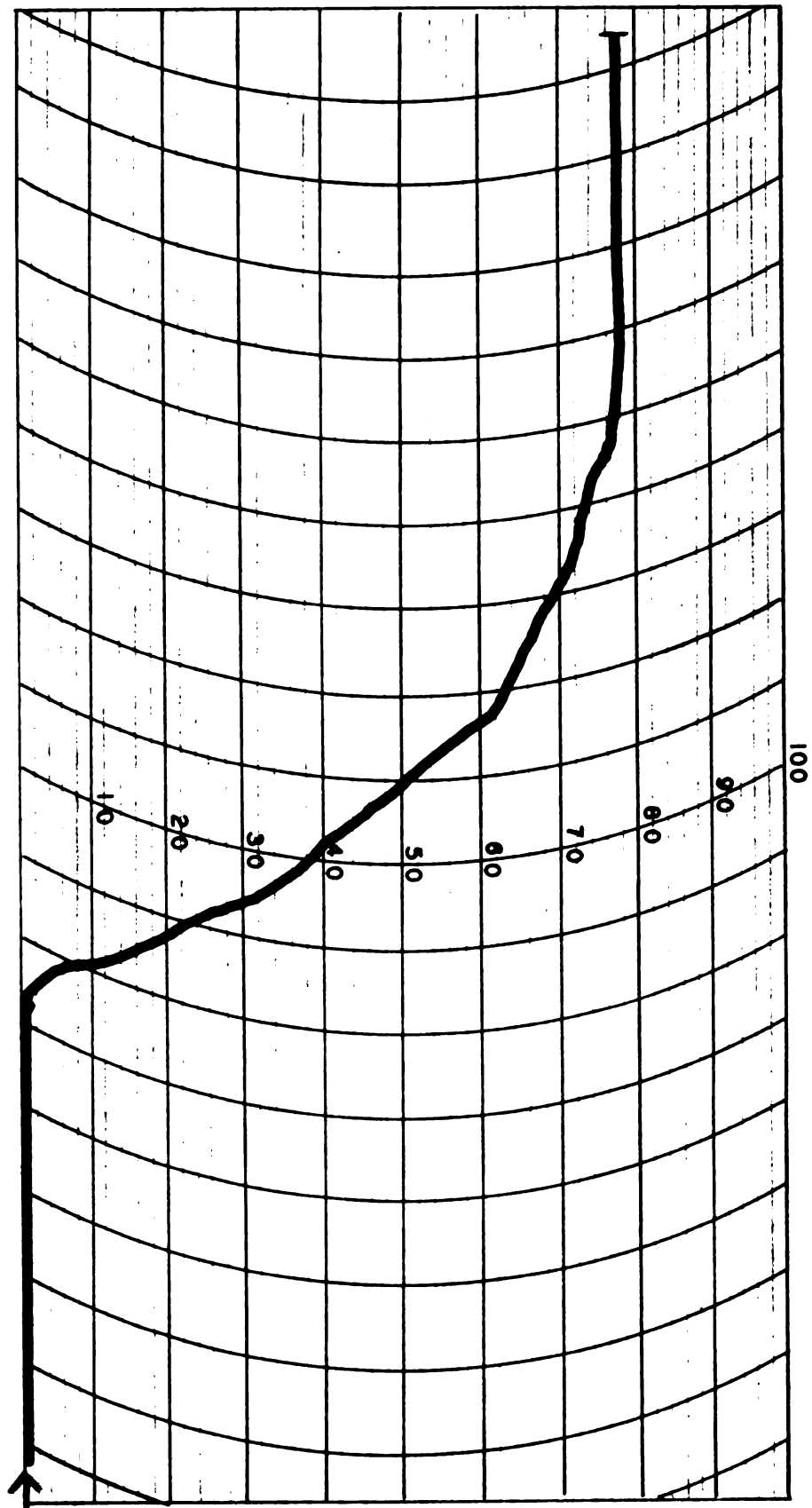


Figure 2. Sample chart with record of a viscosity curve of a starch paste.

DISCUSSION AND RESULTS

Viscosity Tests

Torque values

The torque values of the three replications of each starch paste in this investigation did not vary more than 35 gram-centimeters at maximum viscosity. The range in torque values in the viscosity tests of the three replications of each variation is shown in Table 5. The averages of the torque values at maximum viscosity for the three replications in each series are shown in Table 6.

Table 5. Range in torque values in the three replications of each series.

Series	Liquid Medium	Sugar level in terms of percentage of total liquid			
		0	15	21	27
A	distilled water	1324-1358	1358-1391	1358-1391	1306-1341
B	tap water	1454-1485	1454-1470	1391-1407	1407-1439
C	nonfat dry milk solids in distilled water	1222-1257	1257-1391	1222-1257	1222-1257
D	whole dry milk solids in distilled water	1407-1439	1357-1407	1407-1423	1291

Table 6. Summary of average torque readings of the three replications of each series at maximum viscosity.

Series	Liquid Medium	Sugar Concentrations			
		0	15	21	27
A	distilled water	1335	1374	1374	1329
B	tap water	1464	1464	1396	1428
C	nonfat dry milk solids in distilled water	1239	1274	1233	1239
D	whole dry milk solids in distilled water	1423	1385	1417	1291

Proportion of sucrose

The effect of the proportion of sucrose on the viscosity of cornstarch pastes made with distilled water is shown in Figure 3. Analysis of variance for the starch pastes made with distilled water, Table 7, showed there was no significant difference in maximum viscosity of the control paste and maximum viscosity of the starch paste containing 27 per cent sucrose. However, the maximum viscosities of the pastes which contained 15 and 21 per cent sucrose were significantly higher than the maximum viscosity both of the control and of the paste containing 27 per cent sucrose. This is in agreement with results of other investigators (23, 29, 39) who indicated that additions of relatively low concentrations of sucrose to cornstarch suspensions produced pastes with higher viscosities than obtained from starch and water suspensions alone.

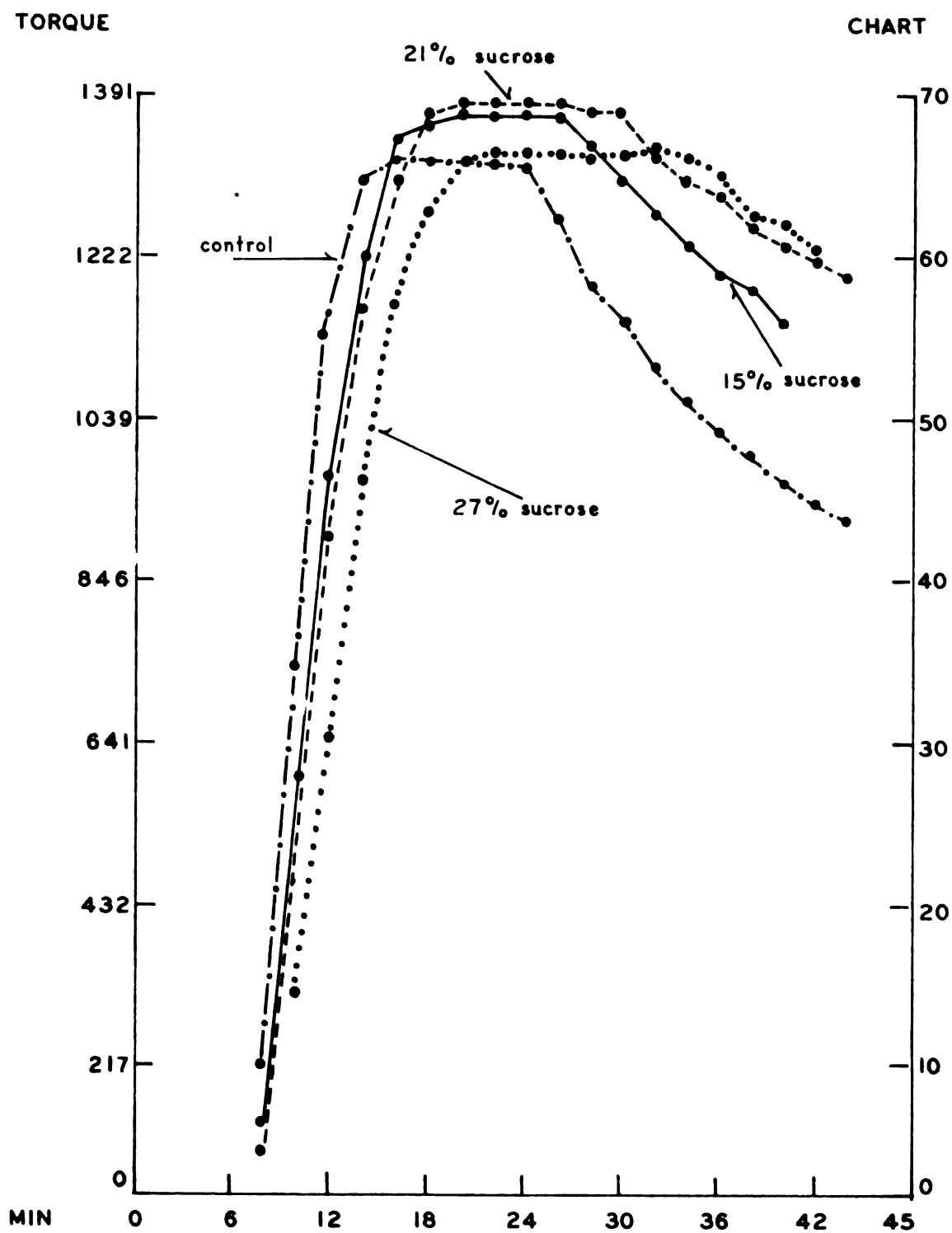


Figure 3. Effect of proportion of sucrose on the initial viscosity rise, maximum viscosity, and final viscosity of cornstarch pastes made with distilled water.

Table 7. Analysis of variance for Series A, distilled water medium, and Series D, reconstituted whole dry milk solids medium.

Source of variance	D. F.	M. S.	F.
Total	23		
Between the series	1	4004.2	4.6*
Between % of sucrose	3	8801.1	10.0**
Interaction: series x sucrose	3	894.6	1.01
Error	16	877.6	

Viscosity curves for the pastes made with tap water are shown in Figure 4. Analysis of variance for the pastes, Table 8, showed there was no significant difference in the maximum viscosity of the control paste and the maximum viscosity of the paste containing 15 per cent sucrose. However, the maximum viscosities of the control paste and the paste containing 15 per cent sucrose were significantly higher than the maximum viscosity of each of the other pastes. There was no significant difference between the maximum viscosities of the pastes containing 21 and 27 per cent sucrose.

Table 8. Analysis of variance for Series B, tap water medium.

Source of variance	D. F.	M. S.	F.
Total	11		
Between % of sucrose	3	3586.3	56.8**
Error	8	63.1	

*Significant at 5% level of probability

**Significant at 1% level of probability

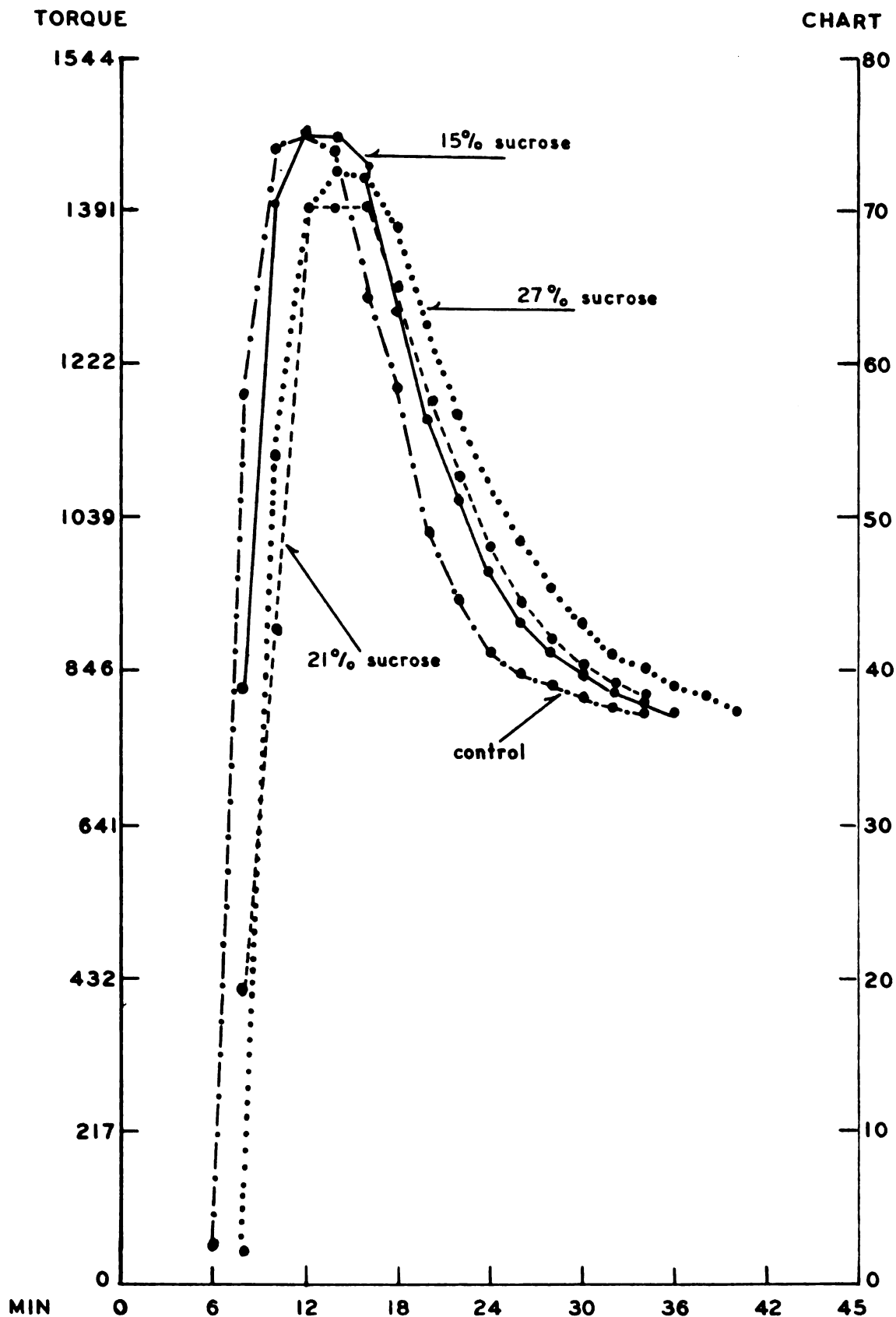


Figure 4. Effect of proportion of sucrose on initial viscosity rise, maximum viscosity, and final viscosity of cornstarch pastes made with tap water.

The effect of the proportion of sucrose on the viscosity of cornstarch pastes made with a solution of nonfat dry milk solids in distilled water is shown in Figure 5. The analysis of variance for the pastes showed that the maximum viscosity of the starch paste containing 15 per cent sucrose was significantly higher than the maximum viscosities of the control and the pastes containing 21 and 27 per cent sucrose.

Table 9. Analysis of variance for Series C, nonfat dry milk solids in distilled water medium.

Source of variance	D. F.	M. S.	F.
Total	11		
Between % of sucrose	3	1023.0	3.68*
Error	8	277.5	

Analysis of variance for the cornstarch pastes made with a solution of whole dry milk solids in distilled water, Table 7, showed there was no significant difference between the maximum viscosity of the control paste and the maximum viscosities of the starch pastes containing 15 and 21 per cent sucrose. However, the maximum viscosity of the paste containing 27 per cent sucrose was significantly lower than the maximum viscosities of all the other pastes. Viscosity curves for the pastes are shown in Figure 6.

Liquid mediums

Although the difference was not calculated statistically, data suggest a probable significant difference between the maximum

*Significant at 5% level of probability, according to Nair (37).

TORQUE

CHART

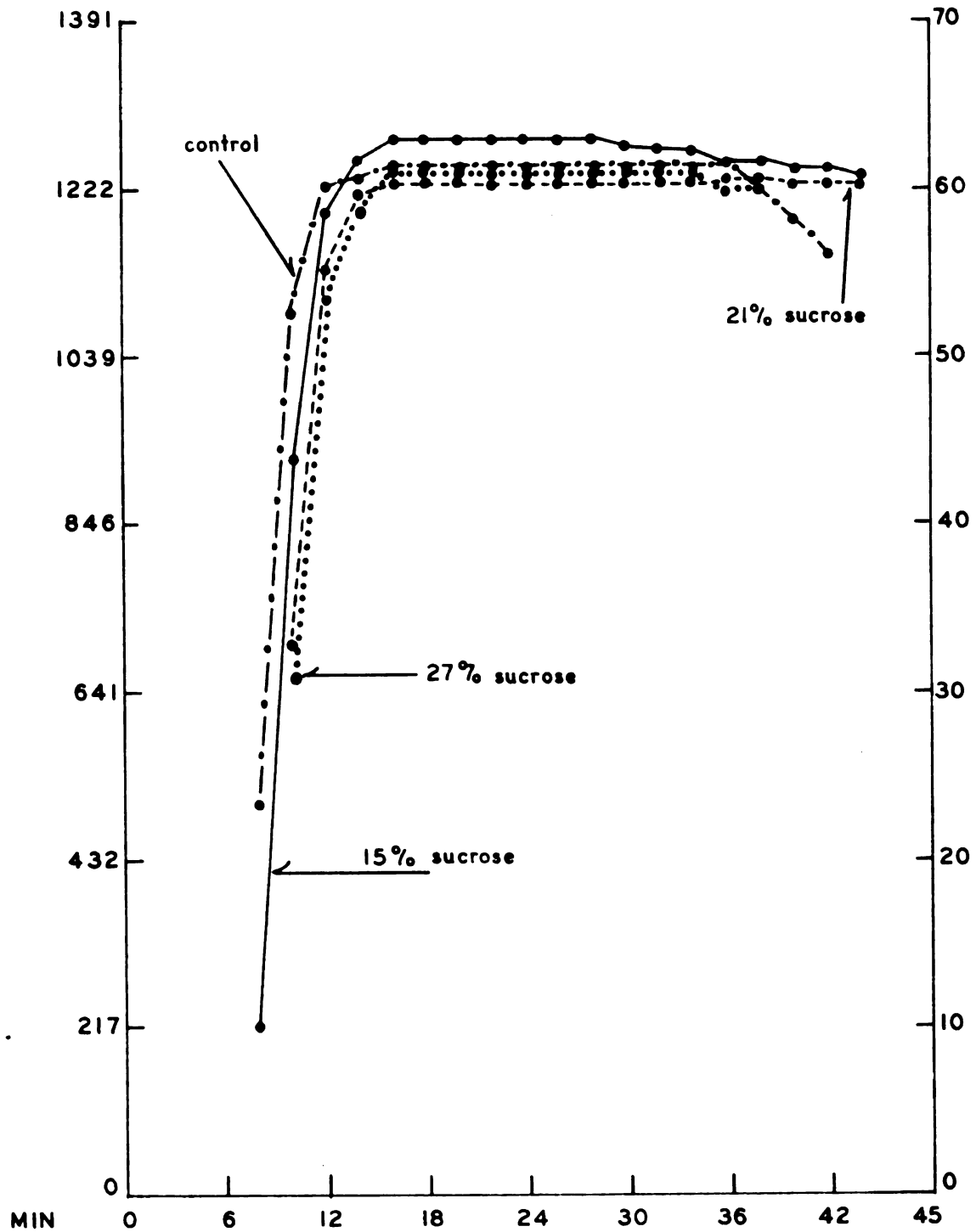


Figure 5. Effect of proportion of sucrose on initial viscosity rise, maximum viscosity, and final viscosity of corn-starch pastes made with a solution of nonfat dry milk solids in distilled water.

TORQUE

CHART

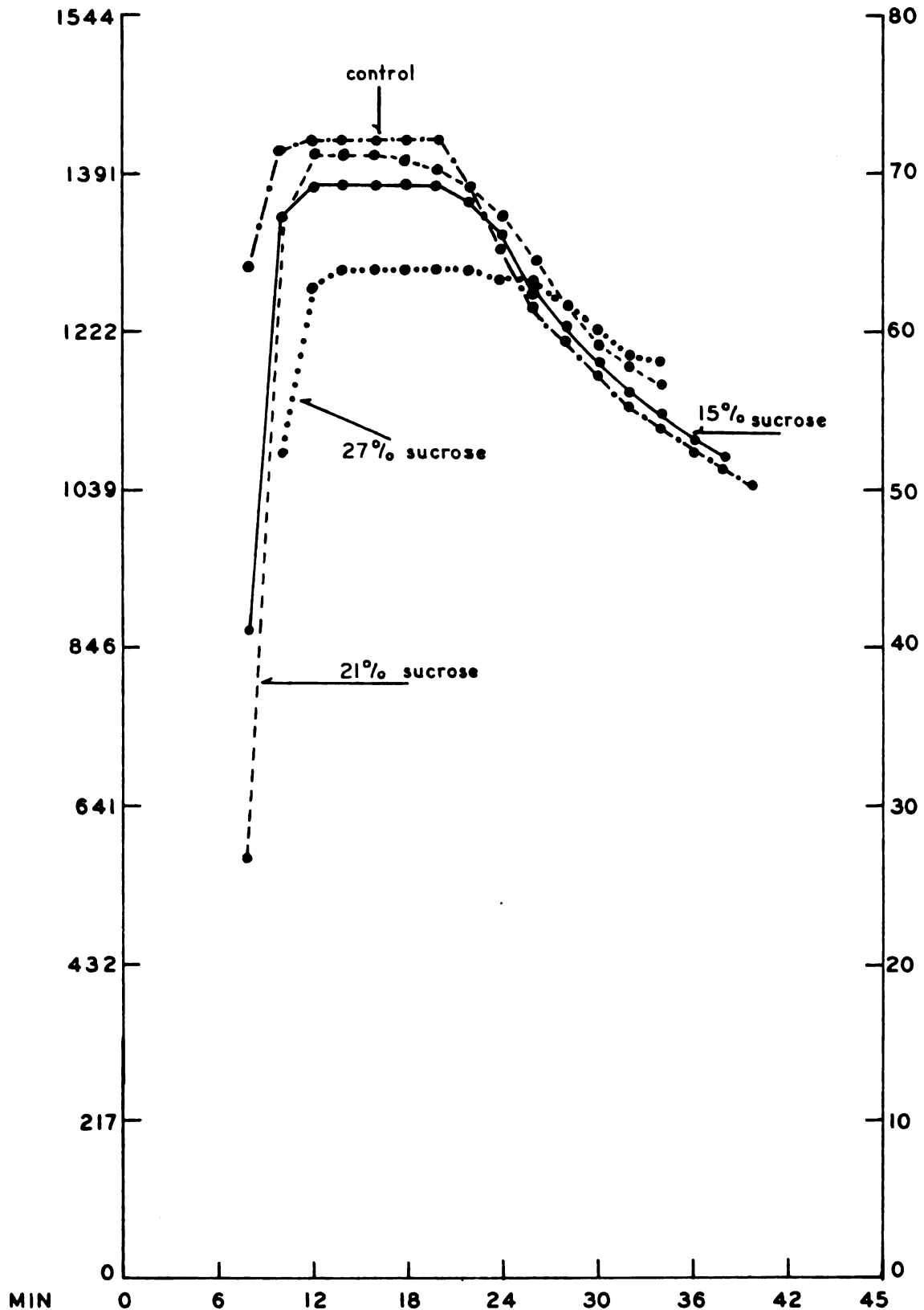


Figure 6. Effect of proportion of sucrose on initial viscosity rise, maximum viscosity, and final viscosity of cornstarch pastes made with a solution of whole dry milk solids in distilled water.

viscosities of the pastes made with tap water and the maximum viscosities of the pastes made with the other liquid mediums. The peak viscosities of the pastes in each variation made with tap water were higher than were the peak viscosities of the comparable pastes made with the other liquid mediums. The exception was the paste made with a solution of whole dry milk solids containing 21 per cent sucrose.

The viscosity curves for the pastes made with tap water indicated that they were more unstable than were the pastes made with the other liquid mediums. According to the findings of this study, cornstarch puddings or fillings made with tap water could be expected to thicken very quickly. However, such mixtures may tend to be unstable and these pastes could be expected to start to show a decrease in viscosity within 2 to 6 minutes after reaching maximum viscosity. From the data of this study, thinning of the pastes, after they have reached maximum viscosity, could be expected to continue as the length of cooking time was increased.

The maximum viscosity of the starch pastes in each variation made with a solution of nonfat dry milk solids in distilled water was lower than that of the comparable pastes made with the other liquid mediums. This is in agreement with the findings of Morse and associates (36) who reported that sweetened flour and water pastes were proportionately more viscous than similar sweetened flour and water pastes to which nonfat dry milk solids were added. The viscosity curves for the pastes made with reconstituted nonfat dry milk solids indicated that they were more stable than were the pastes made with the other liquid mediums.

The analysis of variance for Series A and D showed that there was a significant difference in the maximum viscosities of the pastes attributable to the difference in liquid mediums. The peak viscosities of the pastes made with distilled water were lower than were the peak viscosities of the pastes made with reconstituted whole dry milk solids except for the paste containing 27 per cent sucrose. The peak viscosity of the paste made with distilled water containing 27 per cent sucrose was higher than the peak viscosity of the paste made with reconstituted whole dry milk solids containing 27 per cent sucrose.

The differences between the maximum viscosities of the starch pastes made with solutions of two types of dry milk solids were probably attributable to two factors. First, the total amount of milk solids, including butterfat, in Series D was greater than the total amount of nonfat dry milk solids in Series C, although the total amount of nonfat dry milk solids in each series was calculated to be the same. Second, according to Mitchell and Zillman (35), fatty materials such as soaps, fatty acids, and perhaps natural fats increase the viscosity of starch pastes. The effect of liquid medium on the viscosity of starch pastes is shown graphically in Figures 7, 8, 9, and 10.

Time and paste temperature

The viscosity curves for the cornstarch pastes made with distilled water, Figure 3, showed that the increases in sucrose concentration caused no appreciable difference in the time required for initial viscosity rise. However, as the sucrose concentrations increased, the

TORQUE

CHART

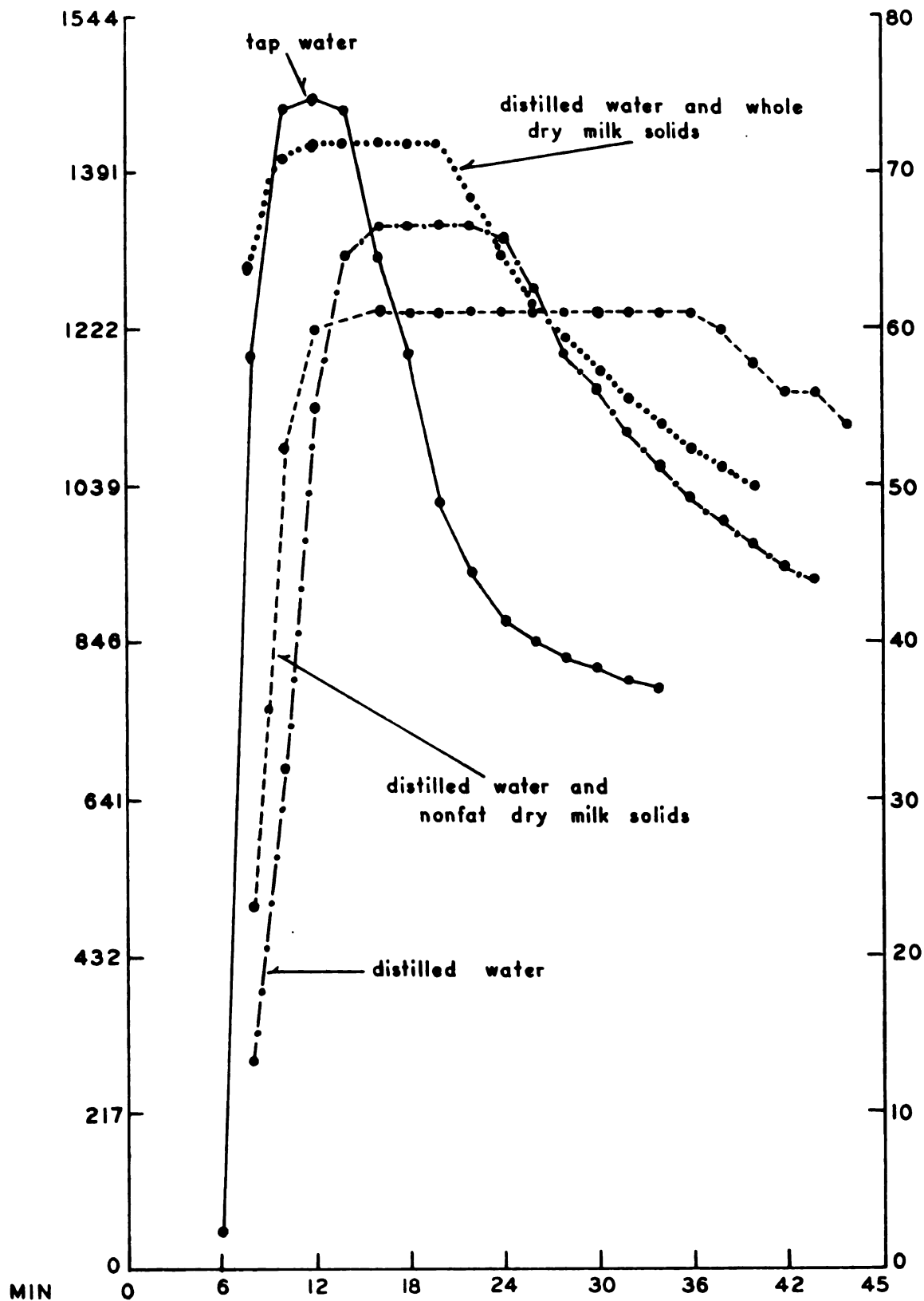


Figure 7. Effect of liquid medium on the initial viscosity rise, maximum viscosity, and final viscosity of cornstarch pastes without sucrose.

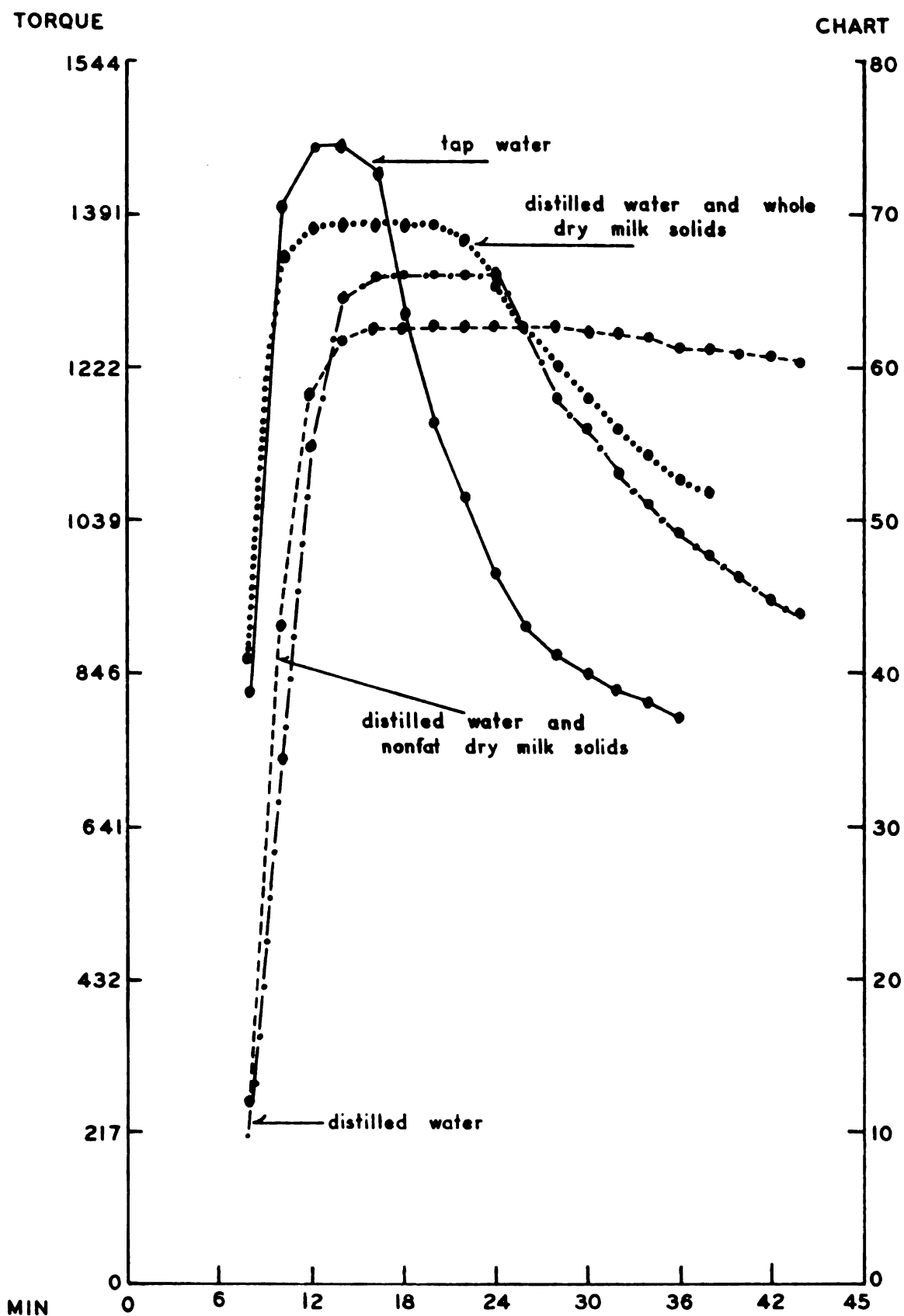


Figure 8. Effect of liquid medium on the initial viscosity rise, maximum viscosity, and final viscosity of cornstarch pastes with addition of 15 per cent sucrose.

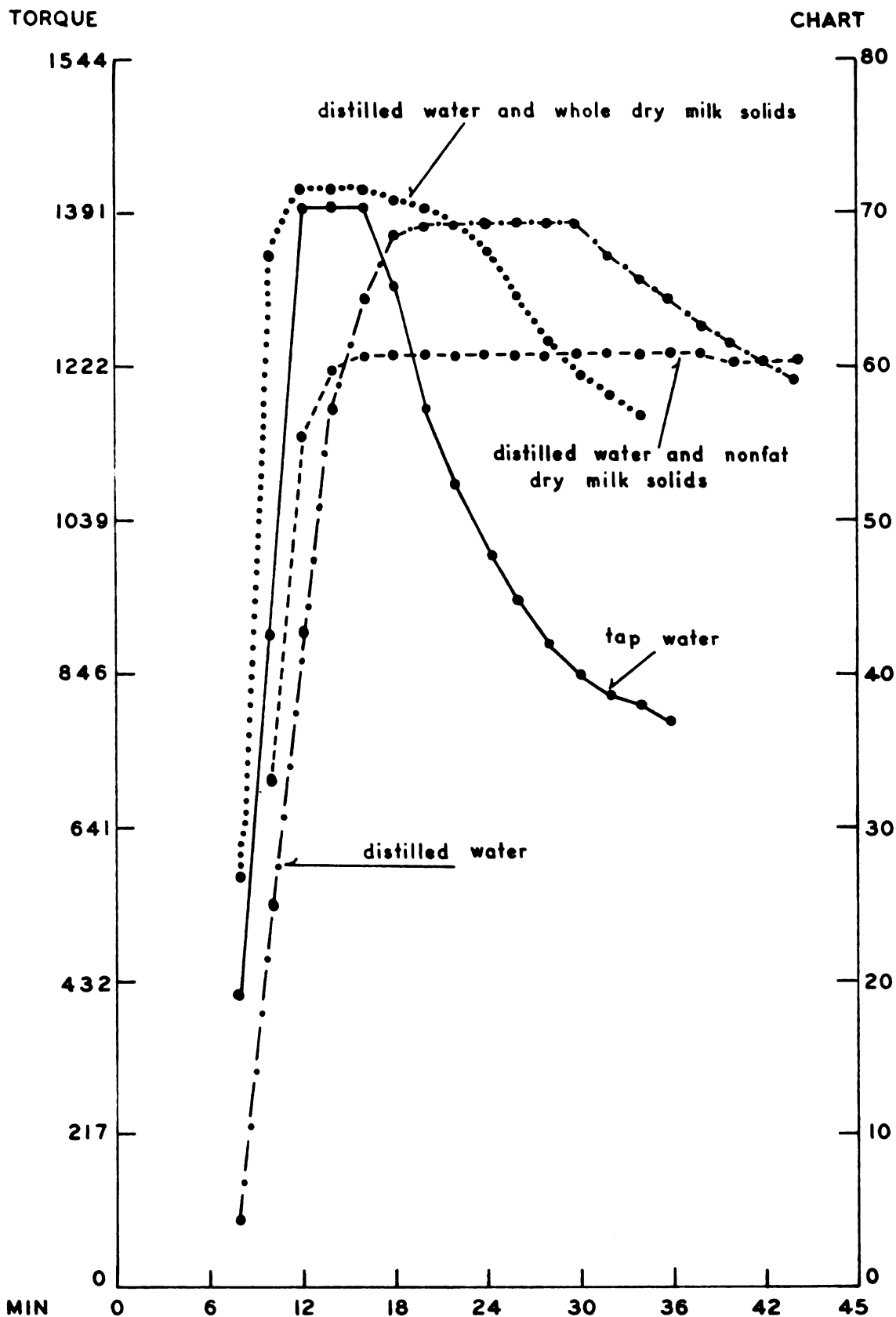


Figure 9. Effect of liquid medium on the initial viscosity rise, maximum viscosity, and final viscosity of cornstarch pastes with addition of 21 per cent sucrose.

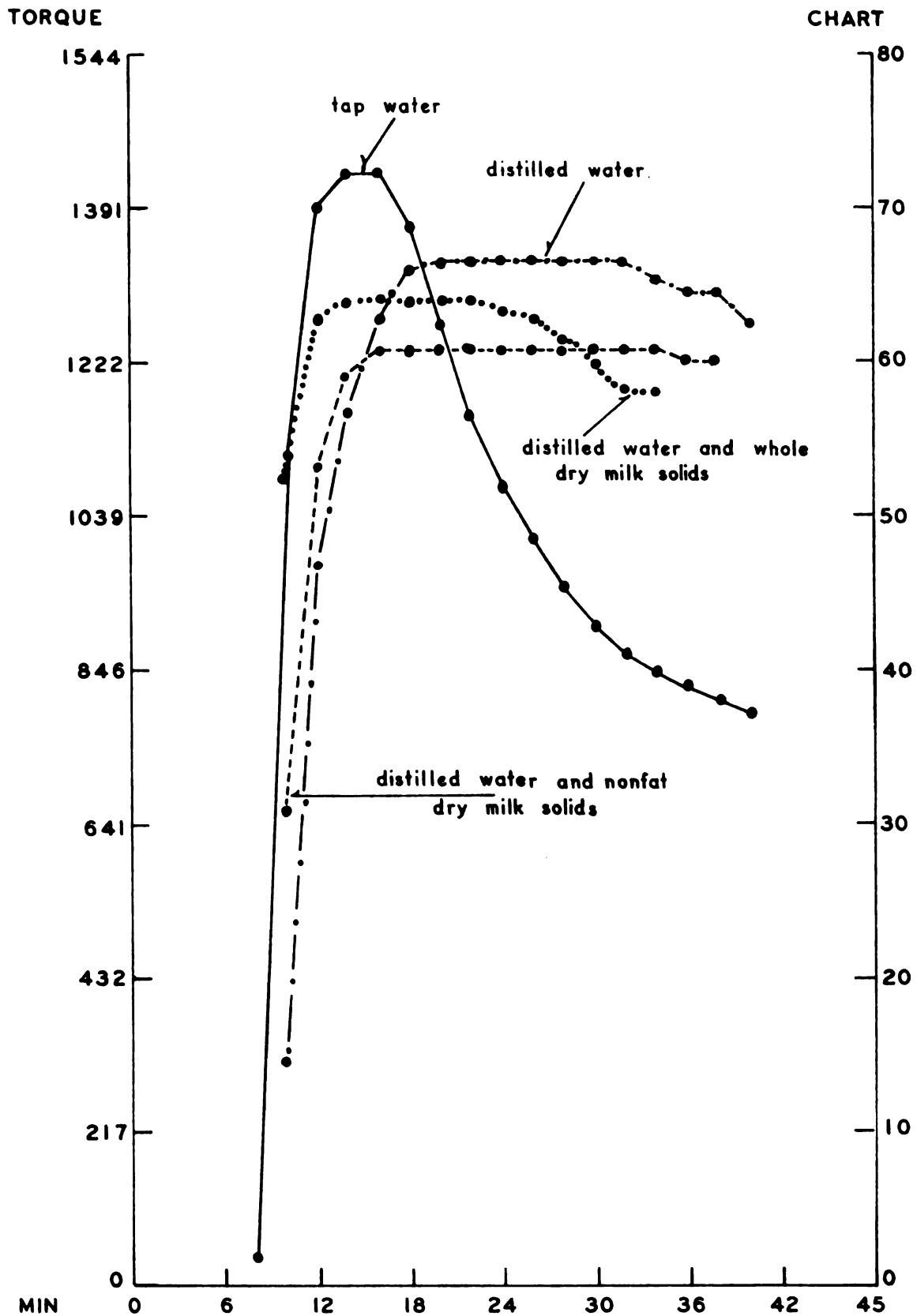


Figure 10. Effect of liquid medium on the initial viscosity rise, maximum viscosity, and final viscosity of cornstarch pastes with addition of 27 per cent sucrose.

time required for the pastes to reach maximum viscosity progressively increased. The exception was the paste containing 21 per cent sucrose which reached maximum viscosity in the same length of cooking time as that required for the paste containing 15 per cent sucrose. The additions of 15, 21, and 27 per cent sucrose to the pastes made with distilled water caused a progressive decrease in breakdown of paste viscosity as the cooking time extended beyond 22 minutes.

The temperature-viscosity curves for the pastes made with distilled water are shown in Figure 11. The curves showed that each increase in the proportion of sucrose caused a progressive increase in the paste temperature at initial viscosity rise and at maximum viscosity. There was also a progressive increase in the temperature at initial viscosity breakdown except in the paste containing 15 per cent sucrose. The control paste without sucrose and the paste containing 15 per cent sucrose showed initial viscosity breakdown at 91° C. It appeared that progressive increases in the concentration of sucrose produced a stabilizing effect on viscosity of the pastes at 95° C.

Viscosity curves for the starch pastes made with tap water, Figure 4, indicated an extremely rapid rise in viscosity of each variation of the series. Maximum viscosity of each variation was maintained for a very short time and a rapid decrease in viscosity followed. The increases in sucrose concentration caused no appreciable difference in the time required for initial viscosity rise in the pastes made with tap water. The control paste without sucrose, the paste containing 15 per cent sucrose, and the paste containing 21 per

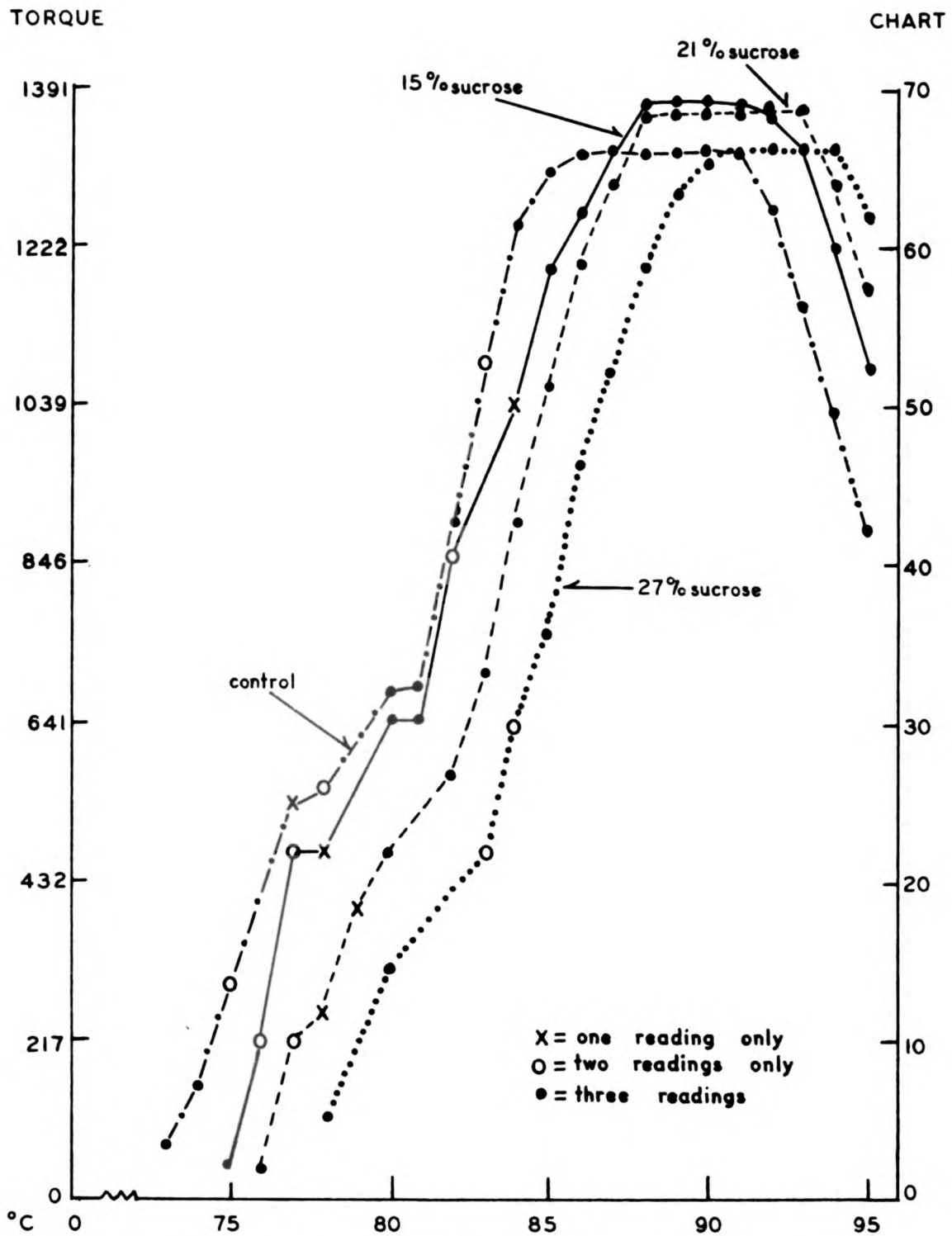


Figure 11. Effect of proportion of sucrose on the temperature rise of cornstarch pastes made with distilled water.

cent sucrose required the same length of cooking time to reach peak viscosity; only the paste containing 27 per cent sucrose required a longer time to reach peak viscosity. The control paste without sucrose showed the greatest breakdown in viscosity after 16 minutes of cooking time. As sucrose concentration increased in the sweetened pastes made with tap water, the rate of paste breakdown progressively decreased.

The temperature-viscosity curves for the starch pastes made with tap water are shown in Figure 12. The increases in sucrose concentration influenced the temperature at which initial viscosity rise was noted in the pastes. Increases in sucrose concentration also influenced the temperature of the pastes at maximum viscosity except in the paste containing 21 per cent sucrose. At maximum viscosity the temperature of the paste containing 21 per cent sucrose was the same as that of the paste containing 15 per cent sucrose. The additions of sucrose made no appreciable difference in the paste temperature at the initial breakdown of any of the pastes. The breakdown in viscosity of all the pastes took place rapidly after a temperature of 87° C was reached; at a temperature of 94° C there was no apparent difference in the extent to which the pastes had thinned.

The viscosity curves for the pastes made with reconstituted nonfat dry milk solids showed that increases in sucrose concentrations made no appreciable difference in the time required for the initial viscosity rise and the time required for the pastes to reach maximum viscosity. The length of cooking time required for the pastes made with reconstituted nonfat dry milk solids to reach initial viscosity breakdown was as follows:

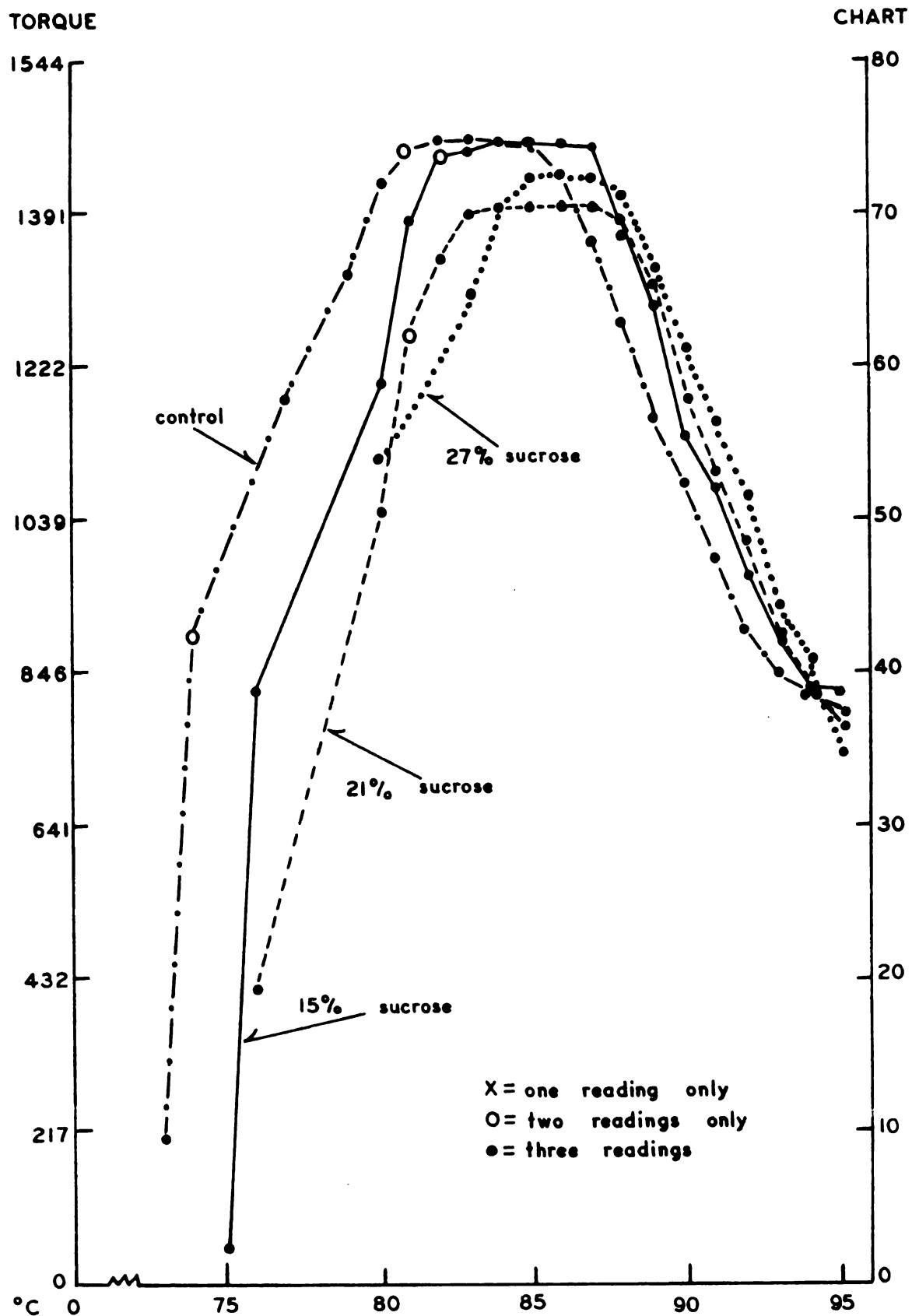


Figure 12. Effect of proportion of sucrose on the temperature rise of cornstarch pastes made with tap water.

control paste without sucrose	36 minutes
paste with addition of 15% sucrose	28 minutes
paste with addition of 21% sucrose	38 minutes
paste with addition of 27% sucrose	34 minutes

The effect of the sucrose concentrations on the time required to reach initial viscosity breakdown was not consistent; but after the initial breakdown, the control paste showed greater decrease in viscosity than the sweetened pastes as cooking time increased.

The temperature-viscosity curves for the pastes made with reconstituted nonfat dry milk solids are shown in Figure 13. The additions of sucrose to the starch suspensions made with a solution of nonfat dry milk solids caused a progressive increase in the temperature of initial viscosity rise and the temperature at maximum viscosity of the pastes. There was no appreciable difference in the temperature at initial viscosity breakdown of the pastes. Breakdown of the pastes did not occur until a temperature of 93° C had been reached.

The viscosity curves for the pastes made with reconstituted whole dry milk solids, Figure 6, showed that the control paste and the pastes containing 15 and 21 per cent sucrose reached maximum viscosity in the same length of cooking time. The paste containing 27 per cent sucrose required a longer cooking period to reach peak viscosity. The increases in sucrose concentration had no consistent effect on the length of cooking time required to reach initial viscosity breakdown. The time required to reach initial viscosity breakdown was as follows:

control paste without sucrose	20 minutes
paste with addition of 15% sucrose	20 minutes
paste with addition of 21% sucrose	16 minutes
paste with addition of 27% sucrose	22 minutes

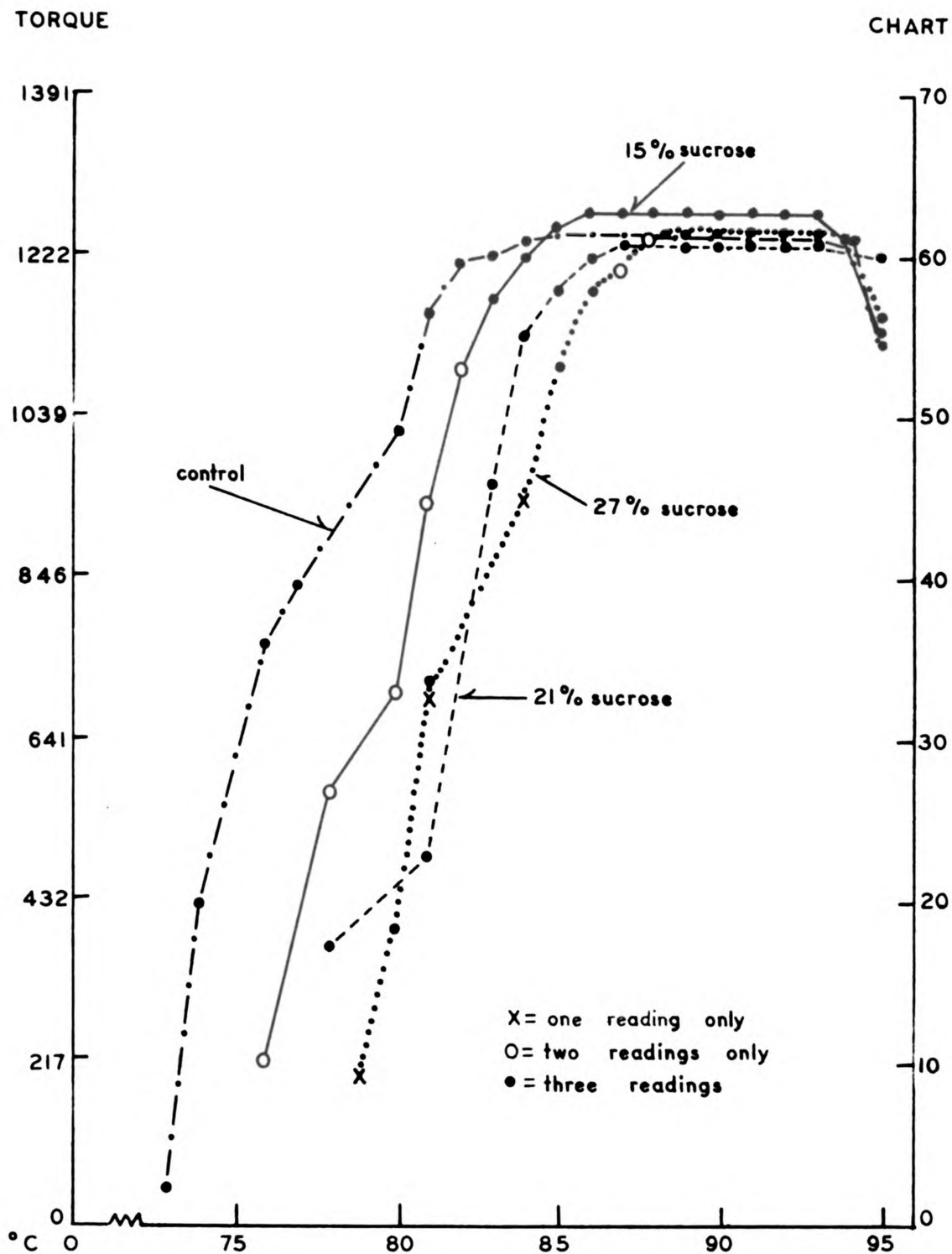


Figure 13. Effect of proportion of sucrose on temperature rise of cornstarch pastes made with a solution of nonfat dry milk solids in distilled water.

The temperature-viscosity curves for the pastes made with reconstituted whole dry milk solids, Figure 14, showed that the increases in sucrose concentrations only slightly increased the temperature at initial viscosity rise. The temperatures at initial viscosity rise were as follows:

control paste without sucrose	75° C
paste with addition of 15% sucrose	76° C
paste with addition of 21% sucrose	77° C
paste with addition of 27% sucrose	77° C

The increases in sucrose concentration had no consistent effect on either the temperature at maximum viscosity or on the temperature at initial breakdown in viscosities of the pastes.

The temperature-viscosity curves for the control pastes made with each of the four liquid mediums is shown in Figure 15. The temperature-viscosity curves for the variations of the starch pastes made with each of the four liquid mediums are shown in Figures 16, 17, and 18.

In the control pastes without sucrose and in all the sweetened pastes, the pastes made with tap water and the pastes made with reconstituted whole dry milk solids showed more rapid increase in viscosity than did the other sweetened and unsweetened pastes. In similar variations of the starch pastes, there was no appreciable difference in the temperature at initial viscosity rise attributable to the different liquid mediums. In similar variations of the pastes, there was no appreciable difference between the temperatures at maximum viscosity of the pastes made with tap water and those made with reconstituted whole dry milk solids. Temperatures at maximum viscosity in the variations of the pastes made with each liquid medium are shown in Table 10.

TORQUE

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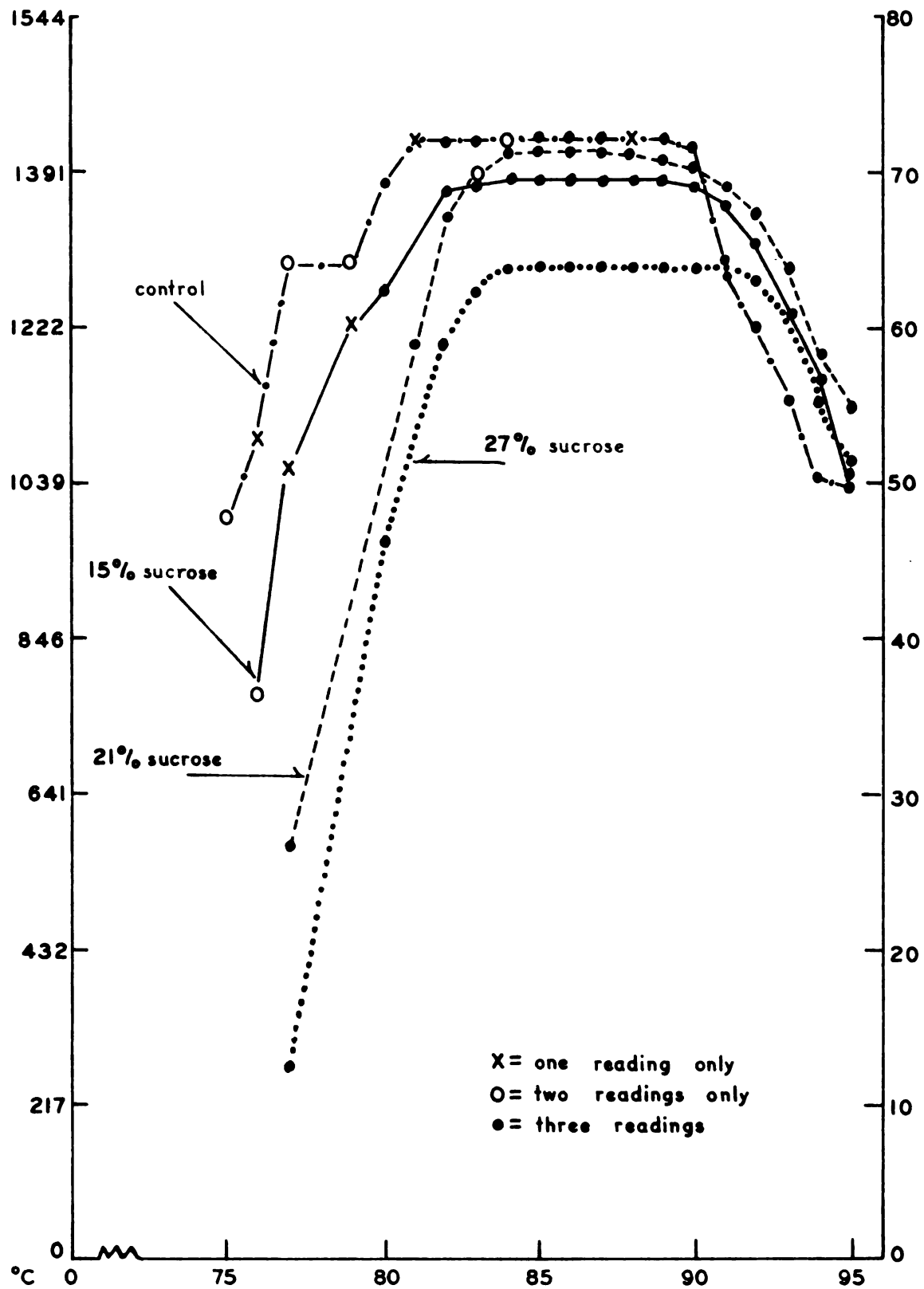


Figure 14. Effect of proportion of sucrose on temperature rise of cornstarch pastes made with a solution of whole dry milk solids in distilled water.

TORQUE

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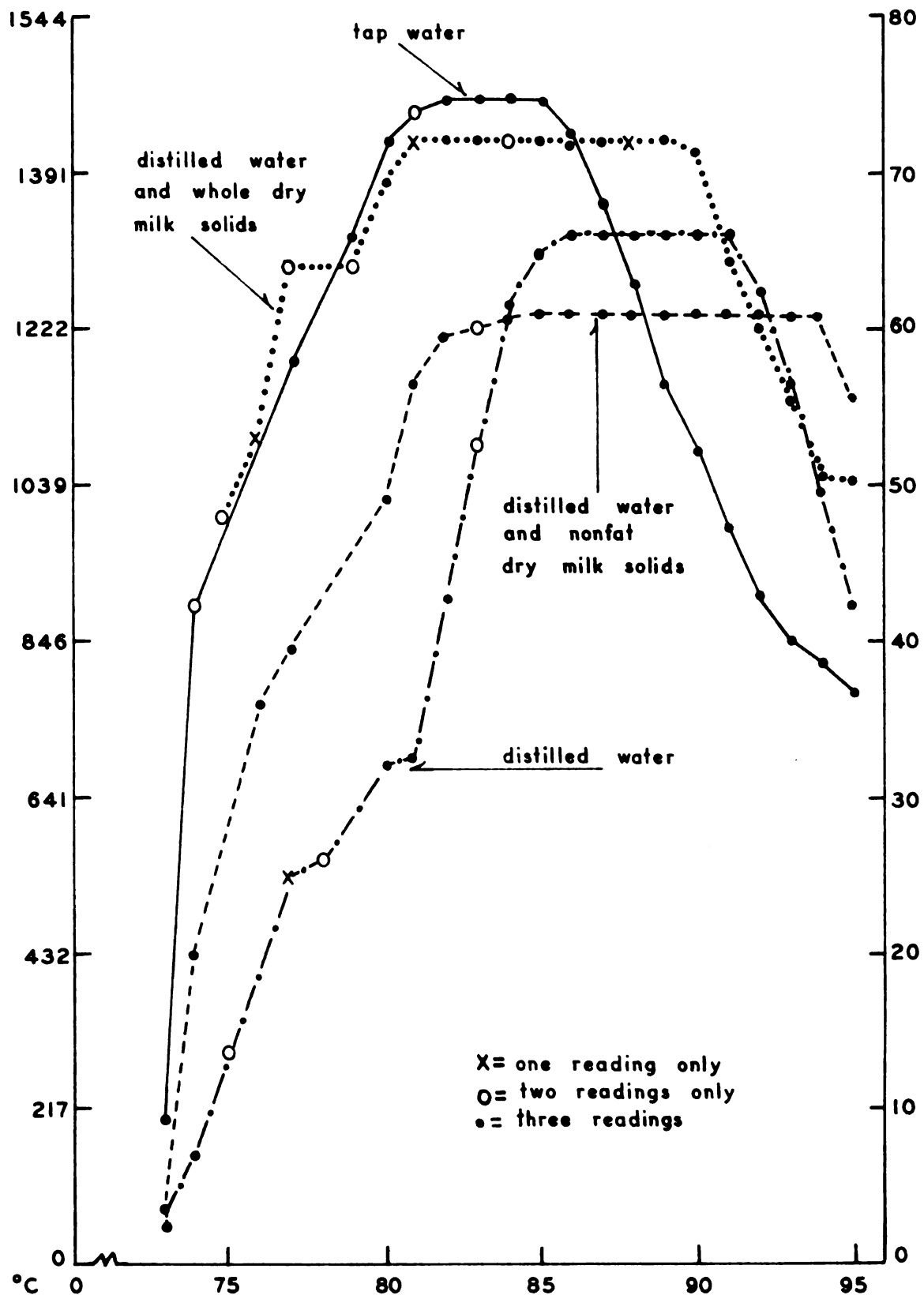


Figure 15. Effect of liquid medium on temperature rise of cornstarch pastes without sucrose.

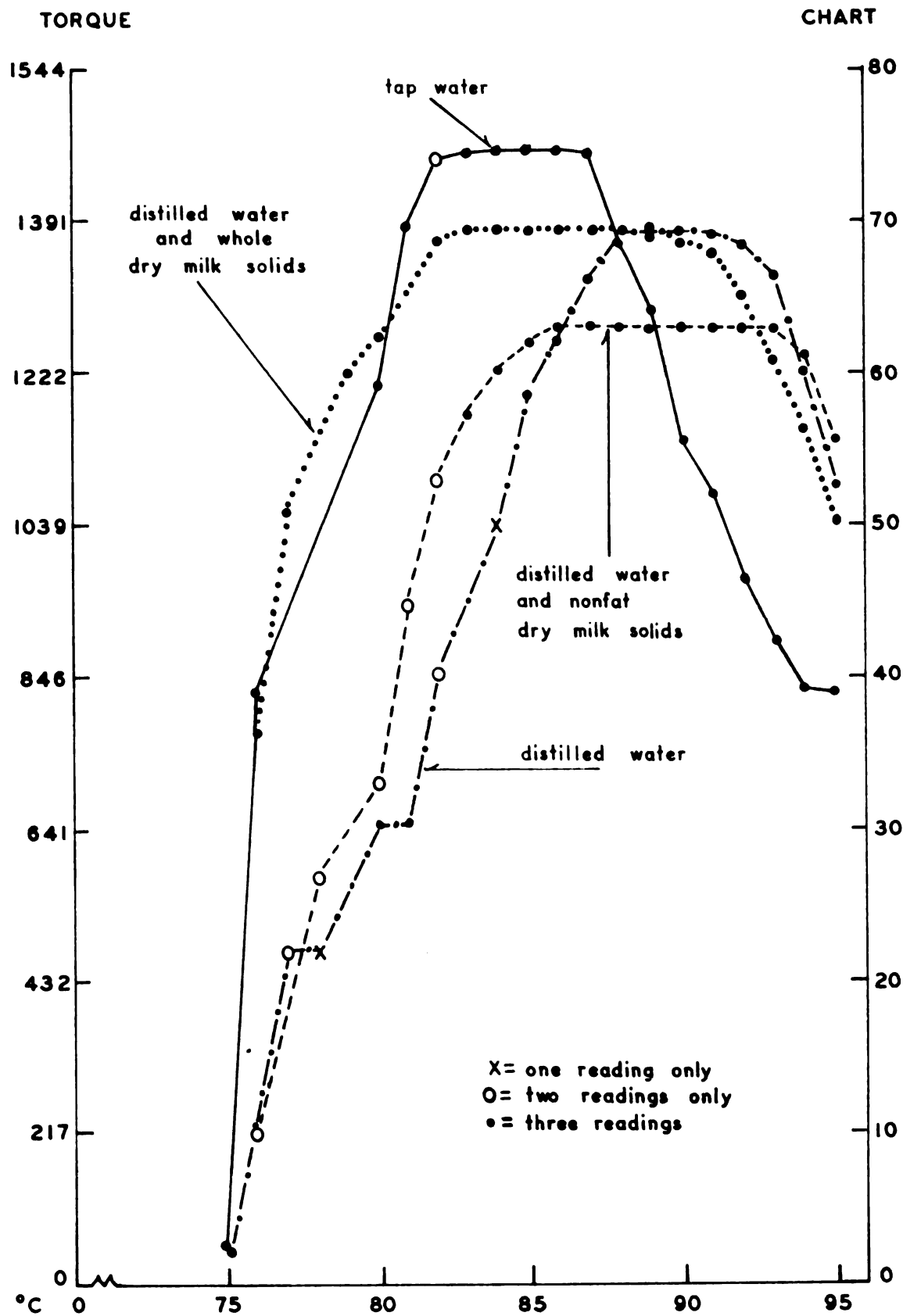


Figure 16. Effect of liquid medium on temperature rise of cornstarch pastes with addition of 15 per cent sucrose.

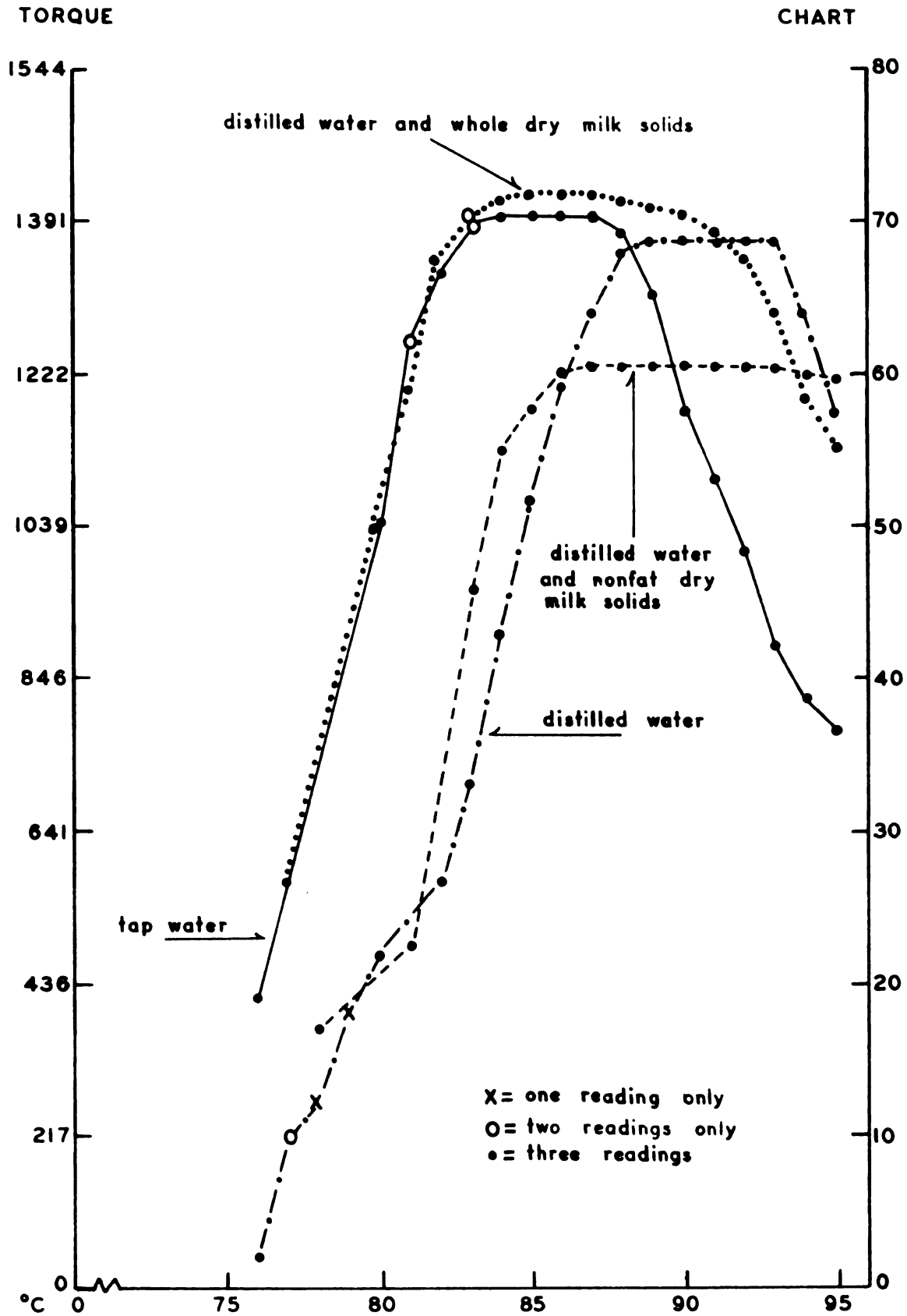


Figure 17. Effect of liquid medium on temperature rise of cornstarch pastes with addition of 21 per cent sucrose.

TORQUE

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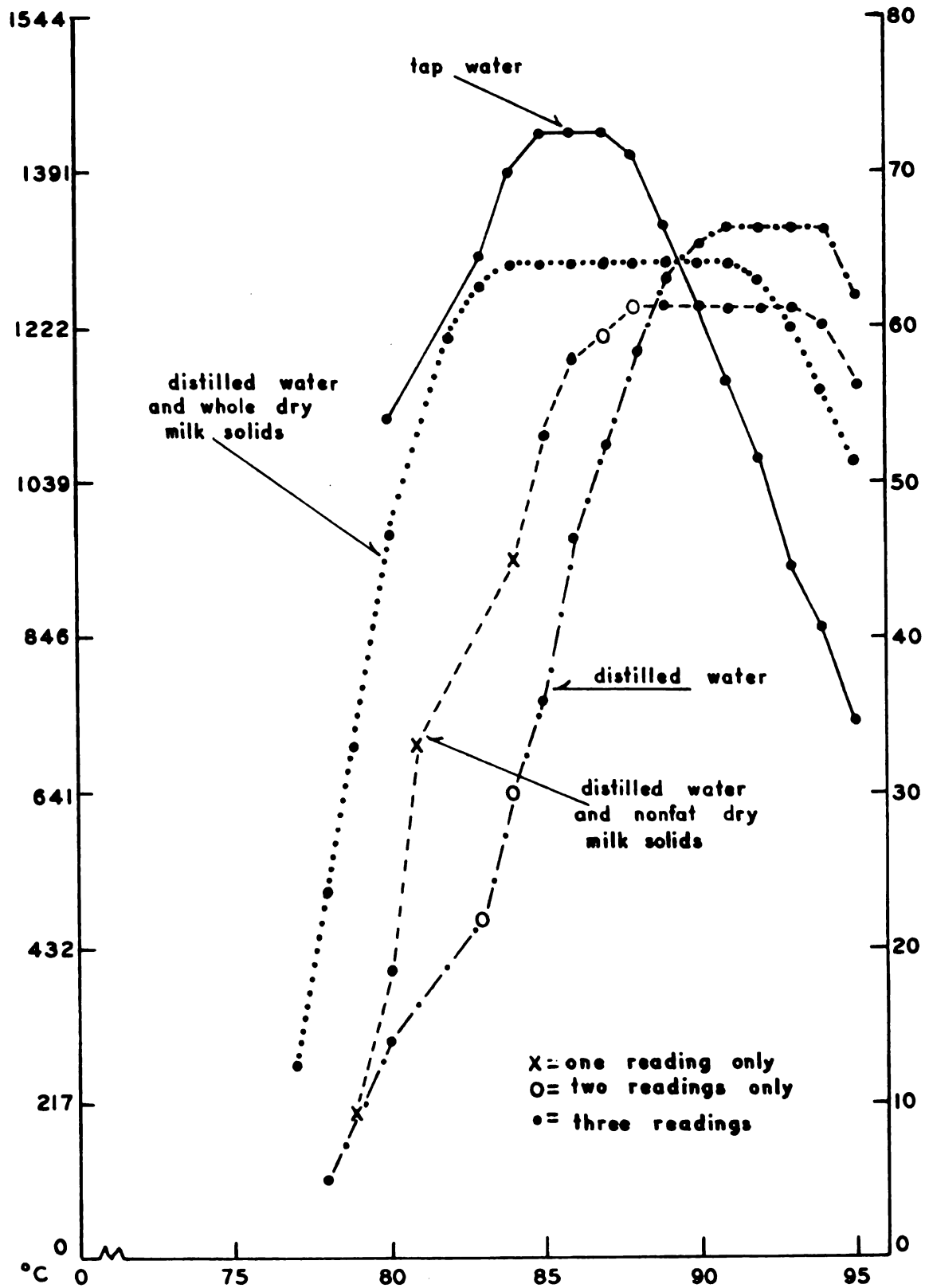


Figure 18. Effect of liquid medium on temperature rise of cornstarch pastes with addition of 27 per cent sucrose.

Table 10. Temperatures at maximum viscosity for pastes made with four different liquid mediums.

Liquid Medium	Control paste no sucrose °C	Paste with 15% sucrose °C	Paste with 21% sucrose °C	Paste with 27% sucrose °C
distilled water	86	87	88	91
tap water	82	84	84	85
reconstituted whole dry milk solids	81	83	85	84
reconstituted nonfat dry milk solids	85	86	87	88

In all liquid mediums the pastes containing 27 per cent sucrose showed higher temperatures at initial viscosity rise than did the control pastes. Temperatures at initial viscosity breakdown in the variations of the pastes made with each liquid medium are shown in Table 11.

Table 11. Temperatures at initial viscosity breakdown for pastes made with four different liquid mediums.

Liquid Medium	Control paste no sucrose °C	Paste with 15% sucrose °C	Paste with 21% sucrose °C	Paste with 27% sucrose °C
distilled water	91	91	93	94
tap water	85	86	87	87
reconstituted whole dry milk solids	89	89	87	91
reconstituted nonfat dry milk solids	94	93	93	93

SUMMARY

The maximum viscosities of 11 per cent cornstarch pastes containing 15 and 21 per cent sucrose made with distilled water were significantly higher than the maximum viscosity of the control paste without sucrose. However, the maximum viscosity of the paste containing 27 per cent sucrose was not significantly different from that of the control paste.

Data on pastes made with tap water showed that addition of 15 per cent sucrose produced a paste with maximum viscosity comparable to the control. However, additions of 21 and 27 per cent sucrose resulted in pastes with maximum viscosities significantly lower than that of the control paste.

Additions of 21 and 27 per cent sucrose to pastes made with reconstituted nonfat dry milk solids resulted in maximum viscosities similar to that of the control paste. However, the additions of 15 per cent sucrose produced a paste with greater maximum viscosity than that of the control paste.

The maximum viscosities of 11 per cent cornstarch pastes, containing 15 and 21 per cent sucrose, made with reconstituted whole dry milk solids were not significantly different from the maximum viscosity of the control paste without sucrose. The maximum viscosity of the paste containing 27 per cent sucrose in this series was significantly lower than that of the control paste.

The maximum viscosities of the control and all sugar levels of cornstarch pastes made with tap water were significantly higher than

those of similar pastes made with the other liquid mediums with the exception of the paste containing 21 per cent sucrose made with reconstituted whole dry milk solids.

The maximum viscosities of the control and pastes with all three sugar levels made with reconstituted nonfat dry milk solids were lower than were those of similar pastes made with other liquid mediums.

The maximum viscosities of the control and pastes with all three sugar levels made with reconstituted whole dry milk solids were significantly higher than were those of similar pastes made with distilled water with the exception of the paste containing 27 per cent sucrose.

The control and pastes with all three sugar levels made with tap water were the most unstable of the comparable pastes made with other liquid mediums in this investigation. The variations of the pastes made with reconstituted nonfat dry milk solids were the most stable pastes in the study.

The control and pastes with all three sugar levels made with tap water and those made with reconstituted whole dry milk solids showed a more rapid rise in viscosity and attained maximum viscosity at lower temperatures than did similar pastes made with other liquid mediums.

At a specific sucrose concentration, the difference in liquid mediums did not appear to influence the paste temperatures at initial viscosity rise of any of the pastes.

There was no consistent effect of time on initial viscosity rise, maximum viscosity, and initial breakdown in paste viscosity attributable to sucrose concentration of the pastes in this investigation.

The addition of 27 per cent sucrose appeared to increase the temperature at initial viscosity rise and the temperature at maximum viscosity of the pastes made with all mediums in this study. Pastes made from the four mediums containing additions of 15 and 21 per cent sucrose did not show any definite pattern in relation to temperature of pastes at initial viscosity rise or at maximum viscosity.

CONCLUSIONS

The effect of the proportion of sucrose on the viscosity of corn-starch thickened mixtures cannot be predicted without taking into consideration the liquid medium in the mixtures.

In this limited study it was found that the maximum viscosity of unsweetened and sweetened pastes made with tap water were higher than were the maximum viscosities of similar pastes made with other liquid mediums with the exception of the paste made with reconstituted whole dry milk solids containing 21 per cent sucrose. The maximum viscosities of the control and all sugar levels of pastes made with reconstituted nonfat dry milk solids were lower than those of similar pastes made with other liquid mediums. The maximum viscosities of the control and pastes with all three sugar levels made with reconstituted whole dry milk solids were appreciably higher than were those of similar pastes made with distilled water with the exception of the paste containing 27 per cent sucrose.

The stability of desserts thickened with starch is frequently an important factor in the quantity preparation of these foods. In this investigation it was found that the variations of pastes made with tap water were more unstable than were pastes made with the other liquid mediums. The pastes made with reconstituted nonfat dry milk solids were more stable than were other pastes made with other liquid mediums.

From the data of this investigation, it appeared that sucrose, in concentrations from 0 to 21 per cent did not show any consistent

effect on the length of cooking time required to reach initial viscosity rise, maximum viscosity, and initial viscosity breakdown of the pastes made with the four liquid mediums. The addition of 27 per cent sucrose to the basic starch slurries made with all liquid mediums increased the length of time required for the pastes to reach maximum viscosity. The additions of 15 and 21 per cent sucrose did not always alter the cooking time required for the pastes to reach maximum viscosity. However, additions of sucrose to the basic slurries appeared to decrease the breakdown in viscosity of the pastes as cooking time increased.

The temperature at maximum viscosity was appreciably increased by additions of 27 per cent sucrose to the basic slurries made with the four liquid mediums. Pastes made with additions of 15 and 21 per cent sucrose did not show any definite pattern in relation to temperature of pastes at initial viscosity rise or at maximum viscosity.

The data from this limited study suggest that additional investigation needs to be made in order to study more fully the effect of cooking time and paste temperature on the viscosity of sweetened cornstarch pastes made with different liquid mediums.

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