1946

# Some factors affecting the functional properties of liquid egg albumen

Harry Marshall Slosberg
*Iowa State College*

14

# SOME FACTORS AFFECTING THE FUNCTIONAL PROPERTIES OF LIQUID EGG ALBUMEN

by

Harry Marshall Slosberg

A Thesis Submitted to the Graduate Faculty
for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: Food Technology

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

Head of Major Department

Signature was redacted for privacy.

Dean of Graduate College

Iowa State College
1946

TABLE OF CONTENTS

# I. INTRODUCTION

Egg albumen as a fresh liquid, in the frozen state or in the form of a dried product, finds wide applications in the food industries, as well as in other industries for use such as sizing material, an emulsifying agent, an adhesive and a body for pigments. When used as a fresh liquid or when frozen and thawed for use, little difficulty is encountered with this product. Also large quantities of dried whites are successfully used in certain food products such as cake frostings, meringue powders, and in such candies as creams, nougats, and marshmallow whips. To a very limited extent, dried egg whites are used also in the preparation of angel cakes. However, when used for angel cake, the product does not compare favorably with fresh or frozen egg white probably due to the loss of some property during the drying process.

At present insufficient attention is paid to the production of a dried egg white particularly suited to a given purpose. It is evident also that the requirements for a good product vary with its application.

The use of dried egg white for commercial use is retarded by a lack of uniformity in the properties of different products. Large variations in foaming capacity and other properties which determine the actual usage of the product are encountered and are largely due to a lack of fundamental knowledge of the changes occurring in commercial processing of the albumen.

Since dried yolk is the most important dried egg product, being used in large quantities in ready-mix flours for doughnuts, cakes and pancakes and in mayonnaise and noodles, the albumen can be considered as a by-product and up to the present time, has more or less been treated as such. Because of the great demand for dried yolk, large quantities of eggs must be broken and separated, resulting in a large supply of albumen. Since the demand for whites is normally not as great as that for yolks, the price of the albumen has a tendency to be quite low. If technological progress resulting in an improvement of the quality and uniformity of egg albumen products were advanced so that the present uses of the product were extended and new uses found, a more favorable price situation might result.

Since dried egg albumen is considered to perform fairly satisfactorily for use in prepared meringue mixes, candy and certain industrial applications but not to perform satisfactorily in the preparation of angel cake, it is desirable that information be obtained with regard to the factors which affect the functional properties of egg albumen. Unquestionably, information which may be obtained regarding these factors would be of great value in the preparation of dried or concentrated egg white products for many of the present uses for the liquid product as well as extending its use for numerous other products.

Certain information is already available which, when properly integrated, should give us some knowledge as to the direction in which we should look or could direct our efforts with regard to determining the effect of present processing methods on the functional properties of egg albumen.

Liquid egg albumen from fresh or frozen stocks can be whipped, blended with sugar and flour and baked into an angel cake which is very satisfactory. A dried egg white, prepared by the usual spray-dry or pan-dried process, has lost some of its functional properties so that it does not produce an angel cake of satisfactory quality. Although the dried product may have satisfactory foaming properties, it has lost the ability to hold sugar and flour so that in baking, a cake lacking volume and texture results. The cake is not at all comparable to that obtained when fresh or frozen liquid whites are used.

There is some indication that an egg albumen dried as a foam results in a product which performs satisfactorily in angel cakes. In addition, certain other data indicate that egg whites dried from the frozen state and under high vacuum or by the use of low air temperatures and comparatively thin films of liquid result in products which retain most of the properties essential for proper performance in angel cake. These data also indicate that some change in the functional properties of egg white occurs during the drying operation, especially when artificial heat is used. The earlier observation, that when whites are dried from the foam state less destruction of the functional properties occurs, may be due to the fact that less heat and time are required for drying a foam than the liquid. It is also possible that some change occurs in the structure of the egg white during the foaming process which aids in retaining the desired qualities that are reflected in angel cake performance.

Other tests have indicated that the protein, mucin, plays an important role in the retention of the desirable properties of egg albumen for performance in angel cake. Therefore, it is important to obtain more information regarding the role of this protein and to determine the effect of various treatments given egg albumen on the mucin fraction during processing. In the commercial handling and drying of egg albumen certain procedures such as acidification, neutralization, fermentation, homogenization and application of heat are used. The effect of these treatments on the functional properties of the egg albumen has been given little attention. It is believed more research should be directed toward the fundamental changes occurring in the egg albumen as a whole and in the various protein fractions during the processes involved in commercial drying operations.

It is the purpose of these experiments to study some of the factors that affect certain functional properties of egg albumen. Initially, it was deemed desirable to determine the time and temperatures to which egg albumen could be subjected without losing the ability to perform in angel cake. This information was desired so that some type of drying process could be designed whereby a concentrated or dried product of the desired properties could be produced.

In order to follow any changes which occur in egg albumen when subjected to the many treatments normally encountered in concentrating and drying processes, a suitable test had to be devised which was simple in operation and yet would actually measure the functional property most desired. In this particular case, since it was desired to measure the ability of the product to perform in angel cake, the method had to have a sufficiently close relationship to the actual performance in cakes without having to go through the entire, complicated procedure of baking angel cakes as well as measuring their volume, texture and flavor characteristics.

A whip test which had been in use and which had been found to be closely related to the actual angel cake-making properties of egg white was studied and finally set up as a criterion for measuring changes occurring in the egg white when subjected to various treatments. This method is quite sensitive, being capable of measuring changes occurring in egg albumen which would be difficult or practically impossible to measure by any other known means.

In this study the effect of time, temperature, pH, homogenization and added substances on the functional properties of egg albumen was studied. It is realized that similar studies on the several protein fractions of the albumen would have been desirable also and are necessary for a full understanding of the problems involved. The work covered in this thesis is quite preliminary and for obvious reasons, it is limited to the behavior of egg albumen as a whole. It was hoped sufficient information would be gained explaining at least some of the difficulties encountered in commercial processing of egg albumen, and perhaps pointing out additional avenues of research which would aid in solving certain of the many other problems of processing this product.

# II. REVIEW OF LITERATURE

## A. Foaming Property of Egg White

The criterion used in this study to determine the effect of various treatments on the ability of egg albumen to retain its functional property in angel cake performance is the rate of foaming when combined with a certain quantity of sugar and whipped to within a given range of specific gravity. Accordingly, it seems essential to know some of the factors affecting the foaming properties of egg white.

It is obvious that the initial physical and chemical condition of the egg white might play an important role in its ability to perform in foaming. Numerous investigators (67-72, 40, 41) have reported on the condition of egg white as affected by storage. These investigators have shown that the pH of newly laid whites is about 7.6 and in storage the pH increases to about 9.5 within a few days due to loss of carbon dioxide by diffusion from the egg to the atmosphere (69). In addition as the storage period increases, the firmness of the whites decrease, a process known as liquefaction (1). There is a decrease in the percentage of thick white and a corresponding increase in percentage of thin white. Almquist and Lorenz (1) showed that the firm white was composed of a fine fiber net-work of pure ovomucin, which entrapped the ordinary thin white.

A number of studies have shown that thick and thin white, when whipped, give different whipping volumes and result in angel cakes of different quality. St. John and Flor (74) found on whipping the thick and thin portions of egg white under the particular conditions of their experiment, that the thin white gave a larger foam volume than thick white. Hunt and St. John (42) confirmed these results and indicated that thin white gave a larger volume angel cake than that made from thick white. Henry and Barbour (39) noted that although the initial beating properties of thin white were superior to those of thick white, on continued beating foam volume decreased. Bailey (3) found that thick white beat up into a greater foam volume than thin white and suggested that the differences in the results reported by various investigators could be caused by the type of beater used. Pyke and Johnson (63) reported that poor quality eggs whipped more rapidly than high quality eggs, but this difference in volume was not reflected in the finished cake. Cakes made from the high quality eggs were considered superior in volume, texture and quality to those made from low quality eggs. Hedstrom (36) reported decreased cake volume with increased age of eggs. Careful control of the initial quality of the eggs used was an essential factor in obtaining reproducible results.

Barmore (10) in studies on the influence of chemical and physical factors on egg white foams measured the stability of the foams produced under various conditions. He concluded that the foam stability was directly proportional to the viscosity of the liquid medium and inversely proportional to the specific gravity of the foam. Neither $Ca(OH)_2$, NaOH, $Na_2SO_3$ nor heat treatment had any apparent effect on foam characteristics, but acids and acid salts increased foam stability considerably. Beating time was found to greatly affect the stability of the foam. When beating periods longer than one minute were used, the stability decreased with increase in beating time. The age of the eggs also influenced the foam stability. Although the specific gravity of the foam produced on beating for any given period was progressively lighter the older the eggs, foam stability was less with short periods of beating. As the beating periods increased, there was less difference between the foams from eggs of different ages. No apparent difference in foam stability was observed when the temperature of the egg was held within the range of $70^{\circ}$F. to $93^{\circ}$F.

Peter and Bell (61) indicated that in foams produced from milk and whey proteins, a marked increase in stability of the foams was produced by heating previous to beating. This improvement in foaming was thought to be due to changes in viscosity, peptization and, in particular, to an accelerated denaturation of the protein, resulting in a gelatinized or semi-solid protein. Samples of egg white were heat treated by Barmore (10) for 30 minutes at 113-140°F. and 15 minutes at 150°F. No effect was observed on the foams produced from the egg white heated up to 122°F. for 30 minutes but treatments at higher temperatures decidedly decreased the stability.

Most of the work with the foaming of egg white has been done on the basis that the stability and volume of the foam are of prime importance. Little has been done to correlate these results with the ultimate performance of the product in cakes. Pyke and Johnson (63) reported the necessity for beating foams to a constant specific gravity to compensate for the different quality eggs being used for test. Barmore (10) found that with foams beaten to the same specific gravity, the foams from different egg whites vary in stiffness and size of bubbles. Henry and Barbour (39) King et al (44) and Glabau (31) indicated that specific gravity was an important factor to be controlled in beating tests for egg products.

Hanson (33) reported, "after a study of the relationship between the beating time of the meringue, cake volume, tensile strength, and palatability scores, it is apparent that for some purposes there is no need of baking angel cakes to determine the performance ability of the egg whites. The time required to beat the meringue to within a certain specific gravity range bears a direct relation to cake volume, tensile strength, and palatability scores - - - -. The longer the time required for beating the meringue, the lower the volume, the higher the tensile strength and the lower were the palatability scores."

Bennion et al (14) after many tests conducted with dried whole eggs to evaluate their baking quality found that the volume of foam obtained by beating together the egg and sugar under specified conditions, was an indication of the baking quality of the egg product. The correlation between foam volume and baking quality was very excellent.

## B. The Effect of Heat on Egg Albumen

### 1. <u>General</u>

In this study, the thermal stability of egg white proteins as a whole was of major interest since it is essential that the egg be dried or concentrated at the highest, practical temperature if economy of operations is to be maintained. There are numerous references in the literature which relate to the effect of heat on egg albumin. This fraction makes up approximately 70 percent of the total egg white proteins. Although for the purpose of this study, interest is centered chiefly on the egg white per se, it is essential that the behavior of the individual proteins constituting the egg white be studied.

It is well known that protein solutions are easily denatured and coagulated by heat. Chick and Martin (23) found by using crystallized egg albumin and other proteins that, "heat coagulation is a reaction with a high temperature coefficient, the reaction velocity of which varies considerably with different proteins and according to the acidity and saline content of the solution." Lepeschkin (49) working along similar lines confirmed the data of Chick and Martin indicating the effects of acid, alkali and salt concentration on rate of heat coagulation. Kruyt and DeJong (46) followed the rate of heat coagulation of ovalbumin by viscosity measurements. Anson and Mirsky (2) Loughlin and Lewis (51) and Bull (21) also used viscosity as an index of the heat denaturation of egg albumin. Ruprecht (65) indicated that in the concentration or drying of egg white temperatures not exceeding 122-125°F. should be used; it would be more desirable to carry out the process at temperatures as low as 104-115°F. He observed that a much higher quality product was obtained at drying temperatures of 104-115°F. as compared to 122°F.

Payawal (60) reported "In liquid egg white, denaturation occurs in the temperature range 136-144.5°F. As in whole egg, the irregular character of the viscosity temperature relationship above 144.5°F. indicates the region at which fractional precipitation of the protein occurs. A linear viscosity-time relationship is shown by liquid egg white at 136°F. and at

140°F. but at 144.5°F. the region of denaturation is very short. Beyond a certain period of heating (46 seconds) at 144.5°F., the fractional precipitation of the proteins is indicated by a drop in viscosity of the liquid white."

A number of chemical and physical changes occur in native proteins as a result of denaturation and these may be used as criteria to determine the degree of denaturation due to any specific treatment. Among these are: (1) decreased solubility, (2) increased viscosity of solution, (3) exposure of certain chemically reactive groups such as sulphydryl and disulfide linkages, (4) loss of specific biological properties such as loss or change of immunological and enzymatic properties and, (5) loss of crystallizability. All of these criteria have been used to measure the degree of denaturation caused by heat, especially with egg albumin. However only a few have been used in measuring the heat denaturation occurring in egg white.

Harris (34) showed that a feeble nitroprusside test developed in egg white foam on drying. Hanning (32) reported that neither of the chemical methods used in her study were satisfactory in measuring the degree of denaturation produced by beating (iodosobenzoate and ferricyanide methods for detecting active sulphydryl groups were used). Payawal (60) used viscosity as a measurement of protein denaturation in heated liquid whole eggs, yolks and whites. Barmore (10) used the stability of egg white foam as a measure of heat damage to liquid egg white.

Funk (29, 30), in attempting to reduce the degree of deterioration occurring in storage eggs due to embryo development, bacteria and other agents subjected shell eggs to heat treatment by submerging them in water or oil held at temperatures of 130°F. to 150°F. for varying lengths of time. It was found that embryonic development was arrested in 8-12 minutes at 140°F. At the same time, storage tests indicated that the egg albumen was stabilized. However some difficulty was encountered with coagulation. Some occurred when eggs were immersed in still water for 15 minutes at 138°F. and 40 minutes at 135°F. Although the method indicates a definite stabilizing effect on the keeping quality of the shell egg in storage, no work was done to determine the effect of thermal stabilizing on the functional property of the albumen as regards foam formation and performance in food products. Barott and McNally (12) heat treated shell eggs at temperatures of 125°F. and 144°F. and determined the rate of heat penetration and the effect of time and temperature on the egg albumen. The opacity of the egg albumen was used as a criterion.

Romanoff (64) studied the effect of short heat treatments on shell eggs at temperatures above the coagulation temperature for albumen. He found that a five second exposure of fresh shell eggs to boiling water formed a thin film of coagulated albumen, adherent to the shell membrane. He indicated that the treatment did not show any noticeable denaturation of the egg contents since the beating power of albumen and natural biological qualities of yolk remained unchanged. Lowered beating properties for albumen from eggs treated by holding shell eggs for 10 minutes at 140°F. was noted. This may be attributed to a partial coagulation of the albumen. No data was available concerning the actual temperatures reached in the various layers of albumen when subjected to the heat treatment.

At the present time large quantities of liquid whole egg are pasteurized to lower the number of micro-organisms present in the final product. Pasteurization times vary from 135°F. to 160°F. for a few seconds to several minutes (79, 80). Experimental work at present indicates that this process may be carried out without noticeably affecting the property of the eggs for use in cakes and other baked goods. Epstein (28) reported that it was not commercially practical to pasteurize egg whites because of the low temperature 127°F. at which they were coagulated.

LeClerk and Bailey (47) reported that egg albumen cannot be spray-dried economically, the temperature being too high for the delicate character of the albumen and the whipping quality of the product being thereby seriously impaired. However, there is at least one commercial operator spray drying egg albumen and obtaining a product suitable for a number of uses.

Mulvany (58) reported that dried albumen, untreated or unfermented will not whip when reconstituted. He did not indicate what temperatures or methods of dehydration were used. Dried albumen prepared by low temperature dehydration without previous treatment had been found to perform, for many purposes, in a superior manner to treated albumen dried by the normal method. He also reported a process wherein fresh liquid albumen was acidified to pH 5.8, then agitated at elevated temperature in a vacuum, the pH returned to neutral in about one hour. This product when spray dried had good color and excellent whipping properties which were retained after several years storage at room temperature.

2. Effect of pH and added substances

Chick and Martin (23) reported "the effect of acid upon coagulation rate is considerable. The addition to a solution of egg albumin crystals of 4 c.c. tenth normal alkali per gram protein (i. e. the amount necessary to neutralize) reduced the reaction rate to one-sixtieth. The influence of acid in accelerating the coagulation rate of a neutral solution of egg albumin is at first relatively small, with each successive addition of acid its influence becomes disproportional to the hydrogen concentration." Lepeschkin (49) found that an increase in salt concentration accelerated the denaturation of albumin when the salt concentration was small, diminished it when the salt concentration was great, and left it unaltered if the salt concentration was intermediate. Acid strongly increased, and alkali strongly diminished the coagulation rate of denatured albumin. Bovie and Woolpert (17) indicated that solutions of egg albumin with the H ion concentration adjusted to the alkaline side of the isoelectric point ($5x10^{-7}$) at which they may be completely coagulated by heat, if irradiated for a sufficient period of time did not coagulate upon heating to 212°F.

Lewis (50) confirmed the results obtained by Chick and Lepeschkin showing the effect of variation in the H ion concentration on the velocity of the heat denaturation of egg albumin. Hendrix and Wharton (38) reported similar results. Beilinsson (13) showed that sucrose and glycerol exerted a protective action on the stabilization of the proteins of rabbit serum and egg albumin to heat. Rabbit serum with sufficient concentration of sucrose was made completely thermostable at 144°F. and egg albumin under similar conditions attained thermostability at 167°F. Bancroft and Rutzler (8) claimed heat coagulated egg white solutions were peptized by KI, KSCN, $NH_4SCN$, Urea, $NaHCO_3$, formaldehyde and cane sugar. They also indicated that ether extracted a substance from egg white solution that acted like crude lecithin. After this substance was extracted, immersion in boiling water for 15-20 minutes failed to produce coagulation or cloudiness in a 10 percent solution of egg white.

Barker (9) observed the relation between the temperature of denaturation of dried albumin and relative humidity. He found the rate of denaturation at any temperature was an exponential function of the relative humidity. Iwanowsky (43) reported that the formation of alkali albuminates by heating egg white in an alkaline medium was not prevented by glycerol, which, however, stabilized the protein solution toward such precipitating agents as ammonium sulfate.

Von Przylecki and Cichocka (62) formed compounds with proteins and maltose which they called "symplexes". These "symplexes" which formed at pH values between 7 and 10, were believed to involve the lysine residues of the proteins and the sugar. No such compound was found with sucrose. Markevich (55) studied the effect of sucrose on the temperature coagulation curve of ovalbumin in the presence of alcohol. A stabilization action of the sucrose was established.

Pauli and Weissbrod (59) reported that with ovalbumin the temperature of coagulation was raised only at very low salt concentrations ($10^{-3}$N), then was lowered by increasing concentration of salt. Sulfate and thiocyanate favored coagulation most strongly and stood at the same end of the ion series. Sucrose and urea retarded coagulation of ovalbumin and serum albumin. Salicylate ion favored coagulation in low concentrations but in high concentrations, it had a specific inhibiting effect. Heidelberger et al (37) reported a loss of heat coagulability of egg albumin when 20-30 phosphoryl groups were introduced into the molecule by action of $POCl_3$ at 27 to 29°F. His work however was mainly concerned with the change in the immunological properties of treated albumin.

Ball, Hardt and Duddles (4) reported that d-glucose, d-fructose, d-mannose, l-arabinose, d-xylose, and d-mannitol inhibited the formation of sulphydryl groups when egg albumin was heat-denatured under specified conditions. These substances, and also sucrose increased the amount of noncoagulable nitrogen when egg albumin was heated. The inhibiting influence toward heat coagulation did not increase with increases in time of contact of the agent with the egg albumin, even at a high pH. Egg albumin coagulated in the presence of glucose did not contain significantly more readily hydrolyzable reducing substances than did egg albumin coagulated in the absence of glucose.

Leighton and Mudge (48) indicated that the maximum heat stability of milk secured by heating to 203°F. was delayed by the presence of 20 percent sugar. Duddles (27) determined the coagulation of egg albumin at pH 4.6 when held at 158°F. for 10 minutes and found glucose and fructose to exert progressive protective action against coagulation at increasing concentrations of the sugars. Sucrose and mannose exerted some protective action, but were less effective than glucose and fructose.

Townley and Gould (76) reported that "in general, it appears that there is a relationship between heat denaturation and coagulation of serum proteins and the liberation of sulfides. Sulfide liberation from milk is decreased either by low pH values or pH values above 9, by sugars, formaldehyde, cystine, sodium chloride, hydrogen peroxide, iodine, and the following metals: copper, silver, mercury and iron." These workers also indicated that the following factors had no apparent effect on sulfide liberation from milk proteins; homogenization, sunlight and the addition of salts of nickel, tin, aluminum and manganese.

Barmore (11) in attempting to clear up a number of points in connection with tenderness of angel cake, studied the effect of temperature, acid, and sucrose content on the properties of coagulating and coagulated egg white. A series of experiments were made using egg white to which had been added varying quantities of sucrose and potassium acid tartrate. These samples were heated in a water bath to temperatures up to 180°F. Observations were made at the first definite appearance of coagulation, an intermediate stage of coagulation, and when the last tube of egg white being tested began showing definite coagulation. The results of these studies indicated that as the sugar content is increased in the absence of acid, the temperature of coagulation was increased. The same result was obtained in the presence of acid, except that the acid lowered the temperature at which coagulation began. The presence of acid alone decreased the temperature of initial coagulation.

Ballou and co-workers (7) investigated the effects of heat on relatively concentrated solutions of human serum albumin. To study the thermal stability of an albumin solution, they followed the rate of cloud formation when albumin solutions containing various added compounds were subjected to heat. The optimun pH for high temperature thermal stability of human serum albumin in 25 percent solution and in 0.3 M NaCl was found to be 6.6, with a secondary optimun at pH 10. Within the protein concentration range, 5 to 45 percent, the cloud point was found to vary inversely with the concentration of protein. The thermal stability of serum albumin solutions was found to increase also with increases in sodium chloride content. If the added electrolyte was a sodium salt of one of the lower fatty acids instead of sodium chloride, the cloud point increased with ascent of the homologous series; i.e., with increase in length of carbon chain. These conclusions applied to systems containing the fatty acid in concentration of 0.15 to 0.3 M.

Brosteaux and Eriksson-Quensel (20) found that when proteins were dried in vacuum the addition of sugars, salt, alanine, glycine or gelatin before drying protected them to some extent from denaturation, the effectiveness of the substances decreasing in the order given. Urea was ineffective and lactose was most effective. The minimum quantities found by experiment to prevent denaturation completely closely approached the quantity calculated necessary to form a unimolecular layer on the surface of the protein micelles.

Quite a bit of work has been done especially by the British on the addition of carbohydrates to egg pulp before drying. Brooks and Hawthorne (19) reported that there was a marked improvement in the aerating power of spray dried whole egg when either lactose or sucrose was added to the pulp before drying. They found that the sucrose exerted a protective effect during the actual drying process. In addition the dried product remained more soluble than a similar product containing no sugar when stored at elevated temperatures for several months. They indicated that there was some evidence that carbohydrate protein complexes existed which may be more stable than the parent proteins. However, it was also probable that the effect may have been due to an alteration in the water relationships within the system, brought about by the presence of sugar. In addition to lactose and sucrose, gelatin, glycerol, and glycerose were tried. The effect of glycerol on the beating power of the reconstituted dried sample was approximately the same as that of the same concentration of lactose; gelatin had no effect and glycerose was detrimental. They also found that the presence of lactose, sucrose, dextrin, and gum arabic retarded denaturation of lyophilized whole egg when stored at 116°F., the effect usually increasing with the concentration of carbohydrate. Sorbitol, glucose, fructose, and arabinose accelerated denaturation, but starch and mannitol had little effect.

Hay and Pierce (35) conducted some tests to determine the stability of dried sugar - egg mixtures at elevated temperatures. Their results indicated that the addition of sugar to egg prior to drying helped to maintain those qualities desirable for baking. They believed some physical or chemical combination may occur between the sugar and components of the egg, and provide protection to the product not only during the drying process but during the subsequent handling.

Bumzahnov (22) pointed out a number of factors affecting the denaturation of egg white proteins. He reported that denaturation of egg white could occur at a temperature considerably lower than the temperature of coagulation depending on the rate at which denaturation takes place. Although albumen may become quickly denatured at 132°F., denaturation still occurred at a much slower rate at 104°F. In addition to temperature and time however acidity had an effect. He pointed out that coagulation of egg albumin would be slower at pH 7.0 than at a lower pH.

## C. Relation of Properties of Thick and Thin Egg White to their Performance in Cakes

Hanson (33) concluded from tests conducted on the preparation of angel cake, that egg white with mucin removed or in the precipitated state does not make an acceptable cake. Egg white with mucin removed required a much longer time to beat to the same specific gravity than did the untreated egg white. Apparently the condition of the mucin is important at least in so far as angel cake making is concerned. In commercial processing of egg white for drying certain treatments are used such as fermentation, acidification and homogenization. It is probable that these processes can cause some change in the mucin fraction of the egg white proteins which is reflected in a poor performance of the finished product in angel cake.

The main difference in thick and thin white is the mucin content. McNally (53) in studying the proteins of egg white found that the thick portion of the white contained a much higher proportion of mucin than the thin white and the volume of thick white varied with changes in hydrogen ion concentration. Schaible (66) by carefully examining freshly broken egg white demonstrated that firm white was of laminated structure, composed of concentric layers containing mucin fibers. The highly swollen mucin fibers form a framework which give to thick white its characteristic appearance (1). Moran (57) reported the mucin content of thick and thin white as follows:

Outer thin white: 0.21 - 0.56 g. per 100 g. dry matter

Middle thick white: 1.49 - 2.45 g. per 100 g. dry matter

Inner thin white: 0.33 - -- g. per 100 g. dry matter

It has been pointed out that the liquefaction of thick egg white is due to a breaking up of mucin fibers. This can be retarded by maintaining the pH at approximately 8 (57). The breakdown of thick white is rapid at high temperatures as shown by Wilhelm and Heiman (77) and confirmed by Balls and Hoover (5) and others.

In order to process liquid albumen for either spray or pan drying, it is essential that the viscous liquid be treated in some way so as to thin it permitting more easy handling and in order to obtain a more efficient dehydration operation. The thinning process is accomplished in a number of ways, by mechanically pumping through a series of pumps, by acidification, by fermentation, or by enzyme hydrolysis. It is now realized that fermentation not only results in a thin white but also in a removal of free glucose and thus results in a more stable product after drying (45). Just what effect these treatments have on the performance of the egg white is not clear from reports to be gleaned from the literature.

St. John and Flor (74) suggested that firm white took longer to beat because it was apparently necessary to break up the gross colloidal structure before air could be incorporated. Barmore (10) demonstrated that the specific gravity of the foam was directly proportional to the viscosity of the egg white draining from that foam. Balls and Swenson (6) devised a method of enzymatically hydrolyzing thick white by trypsin at low temperatures with the elimination of bacterial action. It was indicated however that this product was much more easily denatured on storage than bacterially fermented egg white.

Because of the many reports indicating the superiority of the foaming property of thin white, Miller and Vail (56) suggested, since they obtained similar results when using either thick and thin frozen whites, that "thin frozen whites resulting from mechanical treatment or from changes brought about by allowing the egg whites to "age" either by natural or artificial methods would beat to a greater volume and in less time than with more viscous whites." Pyke and Johnson (63) pointed out that although storage eggs did become thinner and apparently had better foaming properties they lost their ability to resist the work of leavening agents which is an important factor in contributing to the structural strength of the cake during the baking process. Balls and Hoover (5) pointed out that the mucin content of egg white did not change during the thinning process by normal storage at 86°F. However, approximately 36 percent of the mucin originally present in thick white was digested when thinning was carried out by means of trypsin for 18 hours at 86°F.

Conrad and Scott (24) in following changes in ovomucin during storage concluded that the change in egg white resulting in thin white was not due to an enzymatic hydrolysis of the mucin present. The microscopic structure of the gel from aged eggs was not changed; they therefore believed that the change in properties must be due to a change in the elasticity of the mucin fibers. The increase in pH during storage undoubtedly plays a very important role in the change in elasticity of the fibers, but some other important factor must also influence it.

The role of mucin in egg white foams was pointed out by Epstein (27) who reported that mucin had the unique property of becoming coagulated when beaten, whipped or shaken. According to him mucin is absorbed in the form of films at the surface of air bubbles and coagulated there forming a rigid network in which air cells are embedded. If the mucin is denatured by prolonged freezing or by any other means, the foaming value of the egg white is impaired.

Since, in the normal method of thinning by mechanical means or acidification, apparently no decrease in mucin content of egg white occurs it is likely that there is some change in the physical character of the mucin fibers themselves. McNally (54) indicated that ovomucin while being practically insoluble in distilled water, shows reversible physical changes due to pH and salt concentrations. At a pH of less than 6.0 -

6.4, depending upon salt concentration, the mucin is in a compact, precipitated form. This pH is normally reached during the acidification process and during normal fermentation. From pH 6.0-6.4 to 8.3-8.5, the ovomucin swells to a gel, which on increased alkalimity becomes a viscous solution. He also stated that ovomucin is a gluco-protein, soluble in dilute alkali and precipitated by dilute acids. It may be precipitated by dilution with two or three volumes of water and may be salted out by 0.3 saturation with ammonium sulfate.

D. Effect of Homogenization on Properties of Liquid Egg White

Although there are numerous references in the literature on the variation in foaming property of thick and thin egg white, no direct reference was found to the actual effect of homogenization. Townley and Gould (76) in studying the effect of treatment of milk on the rate of denaturation when subjected to heat, found that homogenization of milk had no significant effect upon the critical temperature nor upon the amount of heat-labile sulfur evolved at various temperatures.

Homogenization of liquid egg white definitely results in a thinning action but the physical action is different than the action normally responsible for the production of thin white during aging. In "Eggs and Egg Products" (26) it is reported that the whipping property of egg white seemed to vary with viscosity and the quality of fluid white it contains. The more viscous the egg white, the longer it takes to form a foam; the resulting foam had less volume but greater stability. This last factor is important, as the foam must be sturdy so that when other ingredients are added the foam structure will be able to support them.

Hanson (33) found that on reconstituting dried albumen, undispersed particles remained in the clear liquid after reconstituting overnight. It was believed that a more thorough blending of the samples might produce more acceptable cakes. However, when samples were blended briefly on the Waring Blendor, she noted an increase in the beating time to obtain the same specific gravity foam and a corresponding decrease in quality of the cakes.

Payawal (60) blended all the egg white which was to be heat treated at various temperatures to determine rate of denaturation as measured by viscosity, but ran no foaming tests to determine the effect of blending on foaming capacity.

Bumzahnov (22) reported that the lowering of the whipping quality of the egg white during the drying process is usually caused by the great viscosity of the liquid and a drying procedure which is not suited for such material. He indicated that the viscosity and general structure of the egg white retards the diffusion of moisture during drying resulting in a rise in temperature, which in turn leads to the destruction of the whipping quality. By lowering the viscosity and destroying the fibrous structure of the egg white pulp, a product which retained high whipping quality was obtained. This was accomplished by acidification or enzyme hydrolysis. He indicated that a product with satisfactory whipping properties could be prepared by spray drying.

Homogenization makes use of rather high pressures (usually several thousand pounds per square inch) and the detrimental effect of homogenization of egg albumen might occur due to pressure denaturation. Bridgman (18) observed that albumin may be coagulated by pressure, an observable stiffening occurring at 3000 atmospheres.

Sharp (68) in discussing the relative whipping quality of thick and thin whites reported that the former when homogenized, gave as large a volume as did thin white.

# III. EXPERIMENTAL PROCEDURES

## A. Preparation of Egg White Mixtures

### 1. Whole egg white

The eggs used in these tests were obtained from the Iowa State College poultry farm and were one or two days old before placing them in the laboratory refrigerator held at 35°F. The eggs were used within one to three days from the time they were received from the farm.

The eggs were broken and separated by means of a sliding, hinged separator, which is attached to the breaking knife. The separator is similar to standard equipment available in almost all commercial egg breaking rooms. The whites were then mixed in a Waring Blendor. Approximately 1000 ml. of whites, the equivalent of three dozen eggs, were blended at one time for a period of approximately 30 seconds without incorporating any air. At the end of this period, the liquid white was quite thin and free flowing. When larger volumes than 1000 ml. were necessary for a particular test, the 1000 ml. batches were blended together in a large container before aliquot samples were removed for various treatments. Usually the mixed liquid was given its predesigned treatments the same day the mix was prepared. However, if the tests were to be run the following day, the samples were stored in the refrigerator which was maintained at 35°F.

2. <u>Thick and thin egg white</u>

When tests were to be run on the thick and thin portions of the liquid egg white, the eggs were broken out and separated as usual. Then each egg white was placed on a screen (8 mesh) and the thick and thin separated. With the eggs used, the resulting preparation was usually two parts of thick to one part thin white. If mixing of the fractions was necessary, the thick and thin whites were then separately blended in the Waring Blendor and for purpose of test recombined in the same proportions found when they were separated.

In the preparation of all the egg white mixtures, only eggs of excellent quality as could be judged by appearance and odor of the opened egg were used. All eggs containing blood, meat spots, or other contaminating material were not used.

## B. Whipping Method and Foam Measurement

1. <u>Ingredients and whipping procedure</u>

In all of the whipping tests conducted, a Hobart "Kitchen Aid" Model 4, electric mixer was used. All samples were beaten using third (high) speed.

The following formula was used:

| | |
|---|---|
| Egg white - 61 grams | Cream of Tartar - 0.9 grams |
| Sugar - 47 grams | Salt - 0.3 grams |

This particular formula was used since Hanson (33) found by numerous tests which she performed in her studies on angel cake that whipping this particular formula to a specific gravity range of 0.167-0.190 in 75 seconds or less resulted in angel cakes of satisfactory volume, texture and tensile strength. This formula is a step in the preparation of angel cake since it is only necessary to add the remaining 25 percent sugar and flour to the meringue to obtain the correct batter.

The temperature of the egg white was brought to 70°F. before beating. The following beating procedure was used: the egg whites were beaten for ten seconds, then the salt and cream of tartar were added. Next the sugar was added in four equal portions; after twenty seconds, thirty seconds, thirty-seven seconds and forty-five seconds of beating. Beating was continued for thirty additional seconds so that the total time of beating was one minute and fifteen seconds.

When the egg white containing more than 20 percent sugar already dissolved in the liquid whites was whipped, the time at which the remaining sugar was added, was changed. When greater quantities of sugar were already dissolved in the egg white, the remaining sugar (difference between amount present and that required in formula) was usually added in two portions, at 30 and 45 seconds.

2. Physical measurements on foam

The specific gravity of the meringue was determined by weighing a cup (60 ml.) level full and dividing this weight by the weight of an equal volume of water. When the specific gravity of the foam reached 0.180 heating was stopped. However, if the specific gravity was over 0.180, the foam in the cup was replaced in the beating bowl and whipping continued at high speed for an additional thirty seconds and the specific gravity again recorded. Whipping was continued for thirty second intervals until the specific gravity of the foam fell in the desired range or until a constant specific gravity was reached. Precautions were observed in placing the foam in the measuring cup, a spatula being used, so that pockets of air would not be entrapped. In addition, the foam was carefully placed in the cup so that the foam was not compressed or crushed during filling. The foam was leveled by running the blade of the spatula over it at right angles to the rim of the measuring cup. Only one specific gravity determination of each foam was made since preliminary tests indicated that repeated determinations from the same bowl of foam gave weights of foam within 0.1 gram of each other.

## C. Treatment of Samples

1. Heat treatment

a. Instantaneous heat treatment. The liquid egg white at room temperature (70°F.) was brought up to the desired temperature nearly instantaneously by use of a simple heat exchanger arrangement similar to that used by Winter (79). Water was used for heating and was kept in the bath at a constant temperature (±0.1°F.) by means of a thermo-regulator. The egg sample, in a one liter suction flask, was forced into the glass tube heat exchanger by use of air pressure controlled at varying pressures from 5 to 90 centimeters as registered by a mercury manometer. A copper-constantan thermocouple connected to a Leeds and Northrup potentiometer was inserted by means of a Y-tube at the outlet of the heating tube so that the final temperature reached by the sample during the heat treatment could be measured. It was observed that a temperature differential of 1°F. (between the temperature of the water bath and the final temperature of the liquid white) was required to bring the temperature of the liquid white to the desired temperature in 2.5 to 3 seconds. The heating tube itself was two, four foot lengths of 3mm. soft glass tubing bent in U shape a number of times to allow the entire length of tubing to be completely submerged in the water bath. Arrangement was made so that a bubble of air could be introduced and allowed to flow along with the liquid being heated; thus the heating and holding times could be measured.

A study in which the pressures and temperatures were varied indicated that the final temperature reached was attained at the point of measurement. Slight increases in pressure allowing the liquid to flow through the heating coil more quickly resulted in lower temperatures being recorded by the thermcouple protentiometer arrangement.

b. Holding time. After the desired temperature was reached, the sample was held at that temperature for varying periods of time by continuous flow of the liquid through various lengths of rubber tubing placed in a second bath held at the desired temperature. Varying holding periods were obtained by having a number of 12 foot lengths of the rubber tubing, connected by glass tubing, submerged in the water bath.

When holding periods longer than 30 minutes were desired, a different method was used. In these cases, the liquid egg white to be heated was placed in 8 ounce medicine bottles with screw caps and the bottles submerged (all but the cap) in the water bath. Tests indicated that when 200 ml. of liquid were placed in a bottle approximately 15 minutes were required for the temperature of the egg to reach bath temperature. The water in the bath was kept in constant motion by means of electric stirrer and the temperature was controlled within 0.1°F. by means of a thermo-regulator.

c. Cooling. The liquid egg on emerging from the holder tubing was cooled immediately by running the heated liquid through additional glass tubing placed directly in an ice water bath. The temperature was reduced to 65-70°F. in a matter of seconds. In the case where the 8 oz. bottles were used for the longer heating periods, the bottles containing the heated egg white were cooled by placing them in running tap water and cooled to 70°F. in approximately 5 to 10 minutes.

The cooled samples were then placed in the refrigerator and whip tests run either the same or the following day.

2. pH adjustments

Adjustments in the pH of liquid egg white were made numerous times during this study both in the direction of greater acidity and greater alkalinity. Drops of normal hydrochloric acid or sodium hydroxide were added to the egg white with constant stirring until the desired pH was reached. All pH measurements were made using a Leeds and Northrup Model 7663 A-1 pH assembly. Whenever it was necessary to adjust the pH of a liquid egg white for a particular test a control sample of egg white not adjusted was tested at the same time. In order to compensate for the dilution of the egg white with the alkali or acid added, an equal volume of distilled water was added to the control sample.

3. Homogenization

When homogenizing was desired, the liquid white was prepared as usual and blended on the Waring Blendor. The blended liquid was then homogenized on a hand operated laboratory homogenizer (Central Scientific Co.) by passing through the homogenizer the desired number of times. In addition to this method a number of trials were made using a Mauton-Gaulin motor-driven, laboratory model C.G.B. homogenizer. In this case the egg white which was to be homogenized was first blended and filtered through cheese cloth in order to remove any material which might clog the homogenizer valve.

## D. Incorporation of Added Substances into Liquid Albumen

The sugars, salts, and other compounds which were used in this study were added directly to the liquid albumen with constant stirring.

The sugars and other compounds added to the egg white were dissolved in the liquid white several hours before tests were to be conducted.

## E. Fermentation

To determine the effect of fermentation on the foaming properties of liquid egg albumen, a number of controlled and spontaneous fermentations were made. The latter were obtained by breaking out the eggs, separating the whites without aseptic precautions and allowing the albumen to set at room temperature. The rate of fermentation was followed by changes in pH. The fermentation was considered complete when a five ml. sample of the fermented albumen was heated in an air oven at 250°F. for two hours and no darkening of color of the dried product beyond a pale yellow, was observed. Actual chemical analyses have shown that when no color beyond the pale yellow color develops under these conditions the glucose has been completely removed. Stewart and Kline (73) pointed out the relationship between the decrease in pH of the fermenting liquid and the disappearance of glucose from it. In the controlled fermentations broth cultures of *Aerobacter aerogenes* were used to inoculate samples of liquid albumen broken out in a more aseptic manner than in the uncontrolled fermentations. This egg white culture after attaining active fermentation, was used to inoculate larger volumes of albumen; about a 10 percent to 20 percent inoculum was used. In addition to *Aerobacter* fermentations, yeast and *Streptococcus* fermentations were also carried out.

### F. Drying and Concentrating

#### 1. Pan drying

Several lots of liquid albumen were concentrated and dried by air-film drying. Approximately 300 ml. of albumen were placed in a 10-inch Pyrex glass pie plate and heated by radiation from several infra-red bulbs placed about one foot from the surface of the liquid. An electric fan was used to keep an air current flowing over the surface of the liquid. The temperature of the liquid was kept below 105°F. When drying was almost complete, the surface layer became quite rubbery and drying was completed by inverting the dry skin and finishing the process without heat. The dry material was ground in a mortar prior to testing.

2. Drying from the frozen state

In order to prepare concentrated and dried samples for test without subjecting the albumen to heat, the following method was used: The whites were placed in round bottom, one liter flasks and frozen in an even film approximately 1/8" thick on the inside of the flask (by twirling the flask in an alcohol bath held at -40°F.). The flask was then attached by means of a standard taper joint to an iron condenser immersed in an alcohol bath held at -40°F. The vacuum in the system was obtained by means of a Kinney VSD 556 vacuum pump. A modification of the apparatus used by Best (15) was used for this drying. The apparatus was improved so that four, six or eight flasks could be attached simultaneously. Approximately 12 hours were required to obtain a dry albumen containing approximately 5 to 8 percent moisture. When concentrated liquid containing 20-40 percent solids was desired the flasks were removed after shorter drying intervals.

Approximately 4½ hours were required to obtain concentrated albumen containing 30 percent solids. The time usually varied with the amount of liquid originally present in the flasks and the total quantity of liquid being dried.

The solids contents of the various lots of concentrated and dried albumen were determined by the method of the Association of Official Agricultural Chemists (50, p. 308).

## G. Angel Cakes

In many instances it was desirable to check the results of the whipping test with the actual performance of the egg white in angel cake. For this purpose, the method of Hanson (33) was used.

### 1. Ingredients

The angel cake formula used was as follows:

| | |
|---|---|
| Egg white | 61.0 g. |
| Sugar | 62.5 g. |
| Cake flour | 22.5 g. |
| Cream of tartar | 0.9 g. |
| Salt | 0.3 g. |

### 2. Method of mixing

The temperature of the egg whites was brought to 70°F. before beating. The eggs were beaten until frothy on the third speed of a Hobart "Kitchen Aid", Model 4, electric mixer.

Cream of tartar and salt were added after 10 seconds of beating. Sugar was added in four equal portions, after 20, 30, 37 and 45 seconds of beating. The meringue was beaten until peaks of foam turned down slightly when the wire whip was removed. The total time of beating the meringue was recorded and the specific gravity was determined. The flour and sugar were sifted, one-fourth at a time, over the top of the meringue. Each portion was then combined with the meringue using ten strokes of a French balloon whip. The specific gravity of the batter was then obtained in the same manner as that of the meringue.

3. Baking

The rectangular pans used in baking the cakes measured approximately 2.75 inches in height, 3.5 inches in width, and 5.5 inches in length. Their volume ranged from 750 to 760 ml. A layer of wax paper was cut to fit the bottom of the pans. For each cake, 120 grams of batter were weighed into the pans. Cakes were baked one at a time in the center of the lower rack of a Clark Jewel gas oven maintained at 347°F. for 25-27 minutes. After baking they were inverted until cool. They were then covered with thin wax paper and stored until the following morning, at which time they were tested.

4. Testing

Only cake volume was determined since previous information obtained by Hanson (33) indicated that other tests such as tensile strength and palatability were closely related to the cake volume. The volume was determined by seed displacement while the cakes were still in the pans. Rape seeds were dropped onto the cakes from a constant height, and the volume of the seeds was subtracted from the volume of the pan to give the volume of the cake.

# IV. EXPERIMENTAL RESULTS

## A. Whipping Test

In this study the whipping test itself was relied on as a means of showing differences in the foaming property of egg white due to various treatments. The question as to whether this test actually was a measure of change occurring in the functional property of the egg white had to be answered and in addition it was essential to show whether or not replicable results could be obtained when whipping a particular lot of egg white.

### 1. Reproducibility

Three different lots of fresh egg whites were prepared and 20 whip tests were made on each lot. The results of these tests are presented in Table 1. These results indicate that there is very little variation within lots in the specific gravity of the foam after whipping for 75 seconds.

### 2. Effect of storage at 35°F.

Since in these experiments it was necessary that prepared egg white be allowed to remain in the refrigerator (35°F.) for one to two days before the beating tests could be completed, sets of prepared whites were whipped after one, two, three and four days' storage under these conditions. The results of these tests are presented in Table 2 and indicate practically no difference in the specific gravity after this short storage period at 35°F.

TABLE 1

SPECIFIC GRAVITY OF EGG WHITE FOAMS

| Replication No. | Lot No. I | II | III |
|---|---|---|---|
| 1 | 0.155 | 0.167 | 0.165 |
| 2 | 0.155 | 0.163 | 0.165 |
| 3 | 0.157 | 0.167 | 0.167 |
| 4 | 0.155 | 0.167 | 0.167 |
| 5 | 0.155 | 0.163 | 0.170 |
| 6 | 0.160 | 0.168 | 0.168 |
| 7 | 0.158 | 0.167 | 0.170 |
| 8 | 0.160 | 0.163 | 0.168 |
| 9 | 0.157 | 0.167 | 0.168 |
| 10 | 0.155 | 0.167 | 0.167 |
| 11 | 0.153 | 0.167 | 0.170 |
| 12 | 0.155 | 0.170 | 0.170 |
| 13 | 0.160 | 0.168 | 0.167 |
| 14 | 0.157 | 0.167 | 0.168 |
| 15 | 0.155 | 0.170 | 0.167 |
| 16 | 0.157 | 0.167 | 0.167 |
| 17 | 0.153 | 0.167 | 0.167 |
| 18 | 0.155 | 0.167 | 0.167 |
| 19 | 0.155 | 0.167 | 0.168 |
| 20 | 0.157 | 0.167 | 0.168 |

TABLE 2

EFFECT OF STORAGE AT 35°F. ON THE SPECIFIC GRAVITY OF EGG WHITE FOAM

| Time of Storage Days | Specific Gravity* |
|---|---|
| 0 | 0.163 |
| 1 | 0.165 |
| 2 | 0.165 |
| 3 | 0.167 |
| 4 | 0.167 |

*Average of three tests

3. Effect of freezing

In a number of experiments it was essential that sufficient white be broken out and blended so that tests covering a fairly large number of variables could be studied at one time. Since all of the whites could not be subjected to treatment and whip tests at the same time, it was necessary to freeze aliquot portions. In order to ascertain what effect freezing had on the whipping qualities of the white, it was necessary that the effect of freezing alone be determined.

Table 3 includes the data obtained with egg white which was frozen and held at -10°F. for varying lengths of time. These results indicate that freezing and holding the frozen eggs at -10°F. for periods up to six weeks has no apparent effect on the beating power of the egg white. A second test gave the same results.

TABLE 3

EFFECT OF FREEZING AND STORAGE AT -10°F. ON THE SPECIFIC GRAVITY OF EGG WHITE FOAM

| Days Storage at -10°F. | Specific Gravity of Foam* |
|---|---|
| 0 | 0.161 |
| 6 | 0.161 |
| 11 | 0.161 |
| 42 | 0.160 |

*Average for three samples

4. Effect of heat-treatment

The effect of heat treatment was one of the most important factors studied. Early in the work several samples of egg white were placed in test tubes and the tubes submerged in a water bath at 140°F. The tubes were agitated quite vigorously so that the temperature of the egg white reached 138°F. within one minute. The tubes were immediately cooled in ice water and whip tests run. No observable change such as increased turbidity could be detected in the egg white by visual means.

However, the whip tests indicated an increase in the specific gravity of the foam obtained from the heated egg white. The specific gravity (average of 3 samples) of the unheated egg white was 0.152 and that of the heated white 0.163.

5. Correlation of whipping test with cake performance

Because the whip test used in this study was assumed to be measuring actual cake performance and since it is believed that this ability to perform is a functional property of the white which becomes impaired by various treatments, it was essential that some tests be conducted to correlate the results of whipping tests with cake tests.

Throughout this study, a number of trials were conducted to indicate the degree of relationship between whip test and cake performance. Angel cakes were baked using egg whites subjected to various treatments and the performance of the product in angel cake was compared to the performance of the same lot of egg white in the whip test.

a. Effect of heating. Table 4 contains the data of cake performance and beating tests conducted with egg whites which were heated to $138^{\circ}F.$ and $140^{\circ}F.$ in approximately three seconds.

TABLE 4

EFFECT OF HEAT TREATMENT ON ANGEL CAKE
AND BEATING PERFORMANCE

| Treatment | Specific Gravity of Foam* | Cake Volume* ml. |
|---|---|---|
| Control | 0.157 | 707 |
| Heated to 138°F. | 0.187 | 699 |
| Heated to 140°F. | 0.193 | 665 |

*Average of three samples

Additional comparisons with egg white heated at 120°F. for varying lengths of time were made and the results obtained are shown in Table 5. Each value given is the average result of triplicate samples.

TABLE 5

EFFECT OF HEAT TREATMENT ON ANGEL CAKE
AND BEATING PERFORMANCE

| Treatment | Specific Gravity of Foam | Cake Volume ml. |
|---|---|---|
| Control | 0.157 | 706 |
| 30 Minutes at 120°F. | 0.185 | 606 |
| 1 Hour at 120°F. | 0.205 | 598 |
| 2 Hours at 120°F. | 0.240 | 600 |

The results of these tests indicate that the adverse effect of heat on whipping quality was also noted in the tests to determine cake performance. The results do show however that the beating test is apparently more sensitive than the cake test. With the beating tests, the differences between samples with longer heating times or heated to higher temperatures are more pronounced.

b. Effect of homogenization. To correlate the observed differences in the beating quality of egg whites which were homogenized with cake performance, a quantity of egg white was prepared as usual and one portion was homogenized on a hand homogenizer. The samples were subjected to the beating test and angel cakes were also prepared. The results obtained are given in Table 6.

TABLE 6

EFFECT OF HOMOGENIZATION ON EGG WHITE PERFORMANCE IN ANGEL CAKE AND FOAM

| Sample | Specific Gravity of Foam | Cake Volume ml. |
|---|---|---|
| Control | 0.160 | 693 |
| Homogenized | 0.253 | 648 |

As in the case of the heat treated samples the results of the whip tests are reflected in cake performance although the whip test shows a greater variation in foam specific gravity than the volume differences found in the angel cake.

c. Effect of addition of sugar. In this study, it was observed that sugar added to the liquid white prior to heat treatment resulted in a stabilization of the egg albumen to heat as reflected in the results of whipping tests. Angel cake performance was also tested and the results obtained correlated with the whip tests. The results obtained are shown in Table 7.

TABLE 7

EFFECT OF HEAT AND SUGAR ON WHIPPING POWER AND CAKE MAKING PROPERTIES OF EGG WHITE

| Treatment | Specific Gravity of Foam | Cake Volume ml. |
|---|---|---|
| Test No. 1 | | |
| No Sugar - Control | 0.160 | 693 |
| 30% Sugar - Control | 0.145 | 712 |
| No Sugar - 30 Seconds at 140°F. | 0.263 | 636 |
| 30% Sugar - 3 Minutes at 140°F. | 0.158 | 681 |
| Test No. 2 | | |
| No Sugar - Control | 0.173 | 710 |
| No Sugar - 1 Hour at 120°F. | 0.201 | 679 |
| No Sugar - 3 Hours at 120°F. | 0.247 | 682 |
| 30% Sugar - Control | 0.147 | 732 |
| 30% Sugar - 3 Hours at 120°F. | 0.160 | 716 |
| 30% Sugar - 24 Hours at 120°F. | 0.168 | 700 |

d. Effect of pH adjustment. Since lowering the pH of egg albumen to the range of 6.5 to 7.5 resulted in a decrease in beating power as measured by the whip test, angel cake performance was also tested. Whip tests and angel cakes were made from a lot of egg white with the pH adjusted by means of hydrochloric acid. The results obtained are presented in Table 8.

TABLE 8

EFFECT OF pH ADJUSTMENT ON PERFORMANCE OF EGG WHITE IN ANGEL CAKE AND WHIPPING TESTS

| pH | Specific Gravity of Foam | Cake Volume ml. |
|---|---|---|
| 8.7 | 0.153 | 716 |
| 7.4 | 0.175 | 706 |
| 6.6 | 0.187 | 715 |
| 6.0 | 0.222 | 667 |

These results indicate that satisfactory cakes were baked even when the pH was lowered to 6.6, but at a pH of 6.0 a definite decrease in volume of angel cake was observed. It will be noted that the whip test shows a steady increase in specific gravity of foam but the cake volume remains the same until a pH of 6.0 is reached. This again indicates that the whip test is more sensitive in measuring change in the egg white which has been treated than is the angel cake performance. However one should observe that although a loss in beating power occurred at pH levels 7.4 and 6.6, the actual specific gravity of the foam is still in the range where satisfactory angel cakes may be expected. When the pH is lowered to 6.0 however, a loss in cake volume results and the specific gravity of the foam at this pH is outside the range of satisfactory angel cake performance. This low pH is below the isoelectric point of mucin and the implication that the properties of this protein play an important part in the preparation of angel cake is again apparent.

### B. Variation in Whipping Power of Fresh Egg White

Throughout this study fresh egg white, used as controls for the various experiments, was whipped. It was apparent that there was a variation in the whipping power of fresh white. No specific attempt was made to correlate the beating property with either the season, source of eggs, or egg quality as measured by Haugh units or any other measure of egg quality. It was felt that although it was important to round out the knowledge of factors affecting functional properties of egg albumen, obtaining this information would require considerable time and effort, and the results would not be very pertinent to the present needs.

Observations over 18 months indicated a wide variation in the whipping quality of fresh eggs. It was noted that this property improved during the warm summer months and decreased during the late fall and winter. Figure 1 contains the results of specific gravity determinations of freshly broken egg whites received throughout the year. Each dot represents the average of several tests. The variation appears to be seasonal but may also be caused by variations in temperature, feed, age of birds, etc.

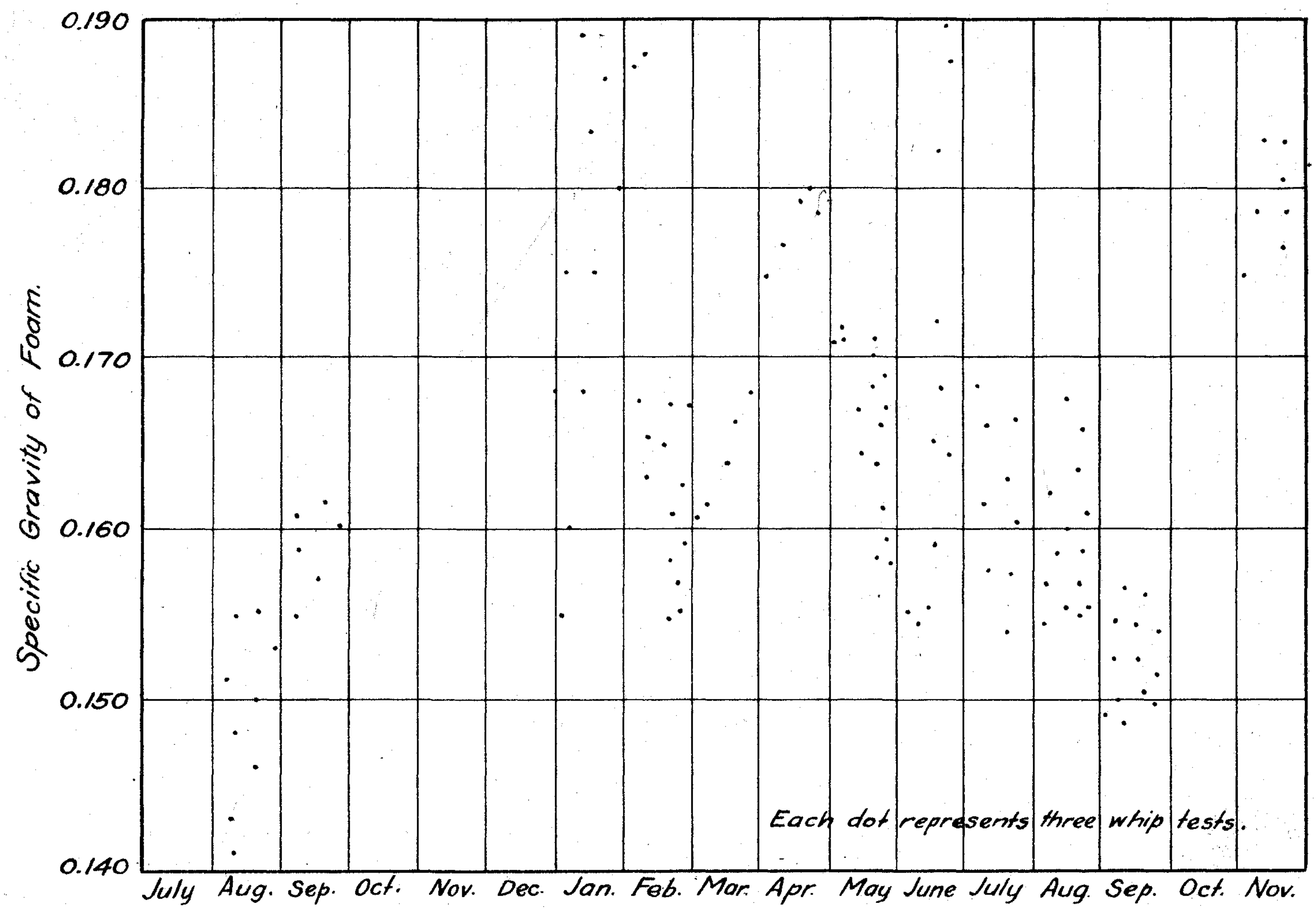


Fig. 1 Variation of Beating Power of Fresh Egg White with Season.

## C. Effect of Time and Temperature on Whipping Property of Egg White

Since it was apparent that in the commercial processing of dried egg albumen some loss of the ability of the product to perform in angel cake occurs and since all the present commercial procedures involve dehydration by means of heat, it was essential to determine the stability of egg albumen to heat.

Because the present commercial methods of concentrating egg whites are not suitable for the preparation of a product for angel cake, it was believed desirable to attempt to devise a suitable method of concentration which could be adopted to commercial practise. The lyophilizing method although apparently quite satisfactory has several disadvantages, the greatest of which is its present impracticability.

In order to devise a suitable method which might have commercial possibilities, it was thought essential that the time, temperature and concentration relationships for egg white be studied in order that the various limits of these variables be known at which the functional properties of the egg white are impaired.

At first, it was decided to try several concentrations of egg white - 12 percent solids (normal egg white) and some other solids content at which the product is still liquid and fairly easily handled (below 45% solids). The initial temperatures to which these concentrations were to be subjected were 85°F. and 140°F. The lower temperature was chosen since some information was already available indicating satisfactory retention of functional properties at this temperature for periods up to 12 hours (33). 140°F. was chosen as the possible maximum to which the egg white may be subjected without immediate coagulation. Previous work (60) has indicated practically no increase in viscosity of egg white (12% solids) at 136°F. for short periods and only very slight increase in viscosity at 140°F.

Preliminary tests conducted with egg white stored at 85°F. indicated practically no change in the whipping property over a one-week period. Various lots of egg white were subjected to heat treatment by one of two methods discussed in the experimental procedure, that is, heating to a given temperature in a few seconds and the second holding the heated egg white at any given temperature for a few seconds to several hours.

1. Instantaneous heating

Egg white was prepared, blended on the Waring Blendor and then heated to temperatures of 120°-146°F. in a period of 2-3 seconds, cooled immediately and whip tests run to determine the change in specific gravity due to the treatment. The effect of temperature as measured by changes in the specific gravity of the foam after 75 seconds of beating is shown in Figures 2 and 3, and Tables 9 and 10 (appendix).

The results of these tests indicate that liquid egg albumen when heated instantaneously to temperatures of 135°F. or higher begins to lose its beating property and on reaching a temperature of 144°F. or higher results in a foam having a specific gravity in that range where inferior angel cake performance results. The increase in specific gravity is greater the higher the temperature.

2. <u>Holding time</u>

Egg white prepared in the usual manner was heated to temperatures of 120°F. to 140°F. and held there for various intervals up to 4 minutes prior to cooling and determinations of specific gravity of the foam by the beating test. The beating power of the egg white is definitely affected by temperature and time. The increase in specific gravity is roughly linear with time. The beating power is decreased at higher temperatures and as can be seen from Figure 4 and Table 11 (appendix) at temperatures above 130°F. less than one minute is needed to impair whipping property so that the specific gravity of the egg white after the correct beating period is above the range where good angel cake performance can be expected.

Additional data was obtained to determine the time-temperature effect on foaming quality of egg white when

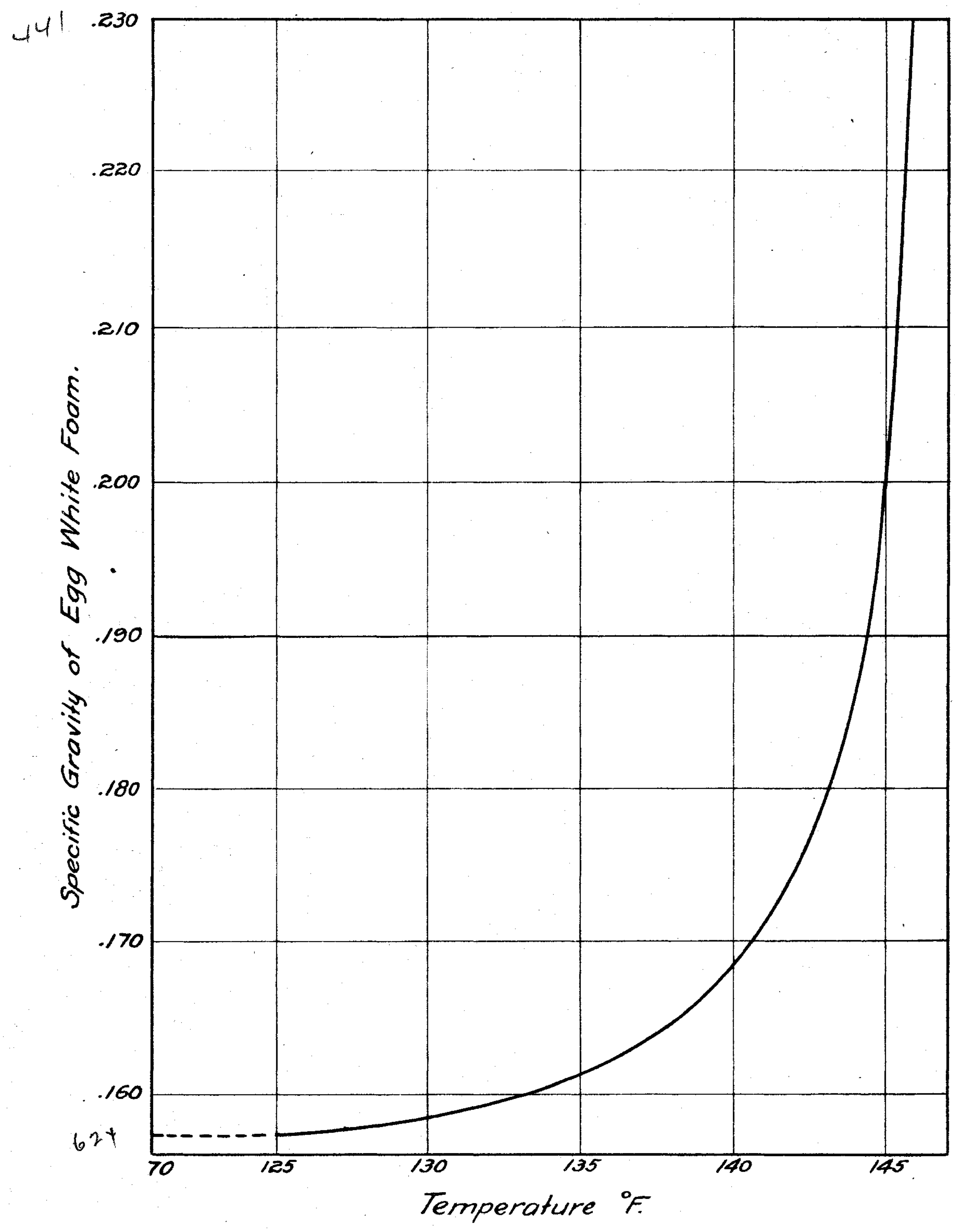


Fig. 2 Effect of heat on specific gravity of Egg White Foam.

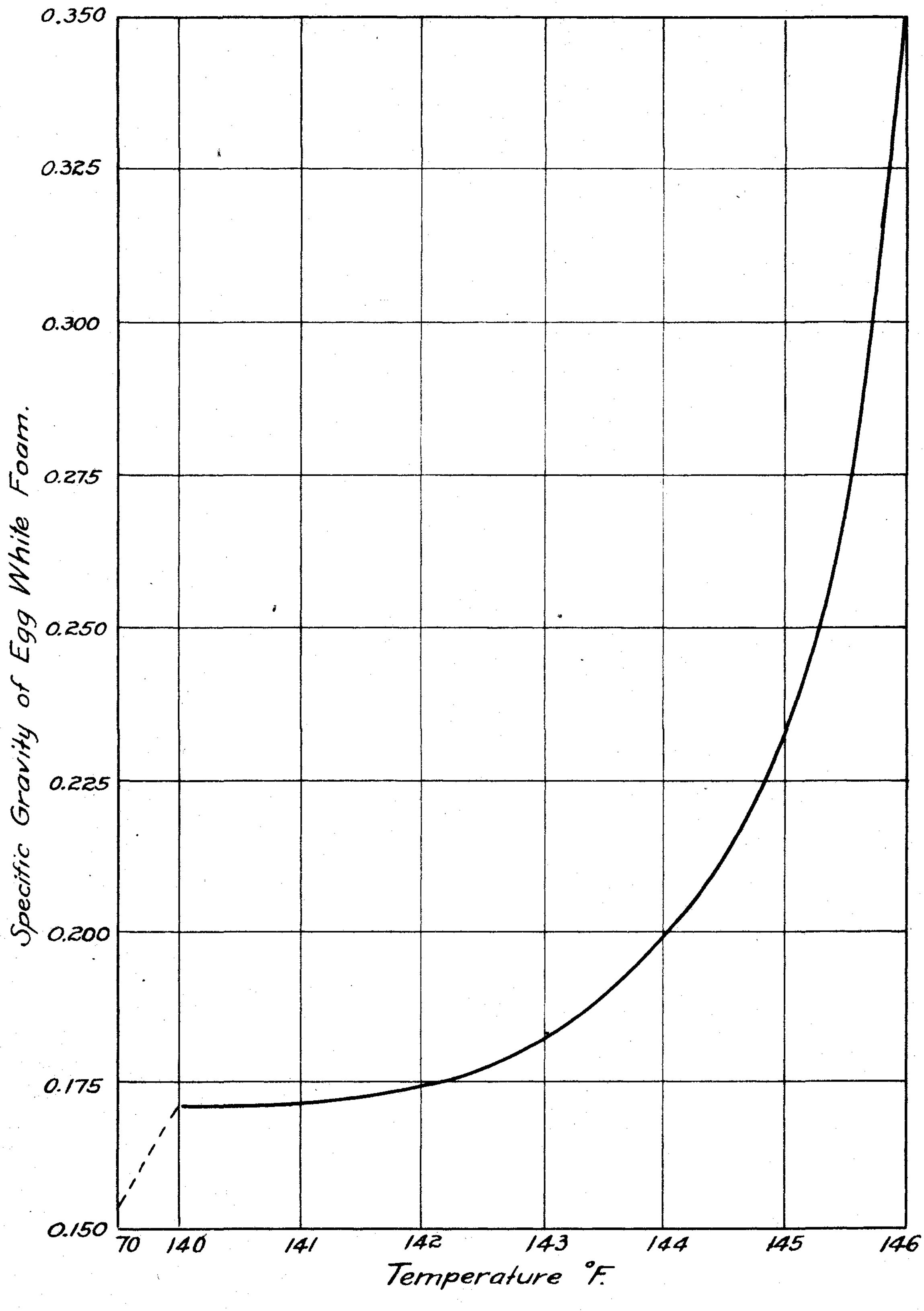


Fig. 3. Effect of heat on specific gravity of Egg White Foam.

lower temperatures, 125°F. and less were used. In Figure 5, the data from Table 12 (appendix) were plotted and from these results it can be seen that prolonged heating of one hour or more at temperatures above 115°F. results in a rapid decrease in beating property of egg white.

Data, comparing the relative lengths of time egg white may be subjected to various temperatures with comparable loss of beating property were obtained and are presented in Table 13. From these data, it can be seen that the reaction causing loss of beating power has a high temperature coefficient, the time at which the product can be held at any temperature decreases at a very rapid rate as the temperature is increased.

TABLE 13

TIME AND TEMPERATURE AT WHICH EGG WHITE MAY BE TREATED TO OBTAIN COMPARABLE BEATING POWER

| Temp. °F. | Specific Gravity of Foam 0.175 - 0.190 | 0.208 - 0.225 | 0.233 - 0.250 |
|---|---|---|---|
| 105 | 1200 min. | --- | --- |
| 110 | 480 " | --- | --- |
| 115 | 120 " | 240 min. | 360 min. |
| 120 | 30 " | 60 " | 120 " |
| 125 | 6 " | 30 " | 40 " |
| 130 | 1.25 " | 2 " | 4 " |
| 135 | 0.50 " | 0.67 " | 1.0 " |
| 140 | 0.05 " | 0.20 " | 0.33 " |

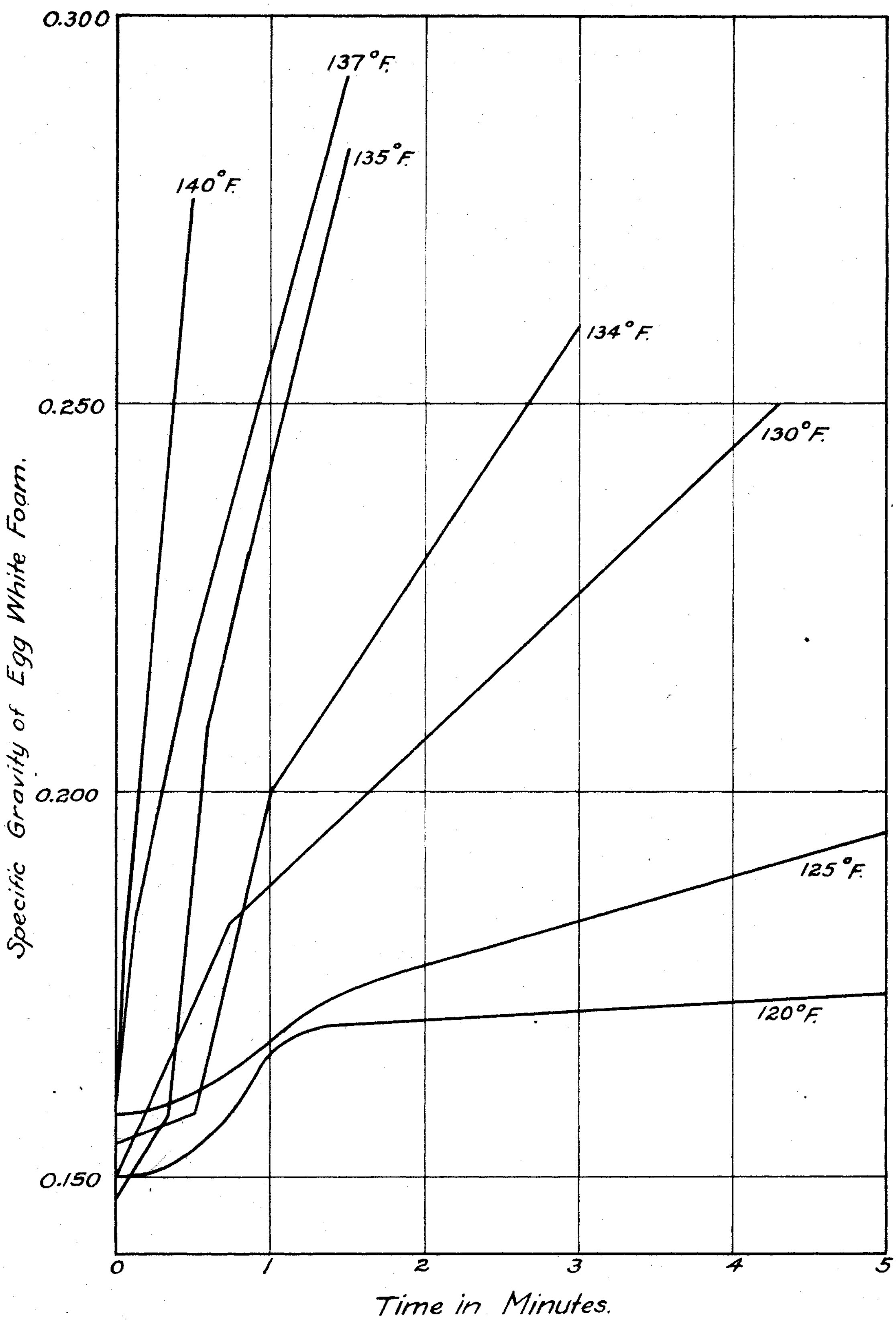


Fig. 4 Effect of Time and Temperature on Beating Property of Egg White.

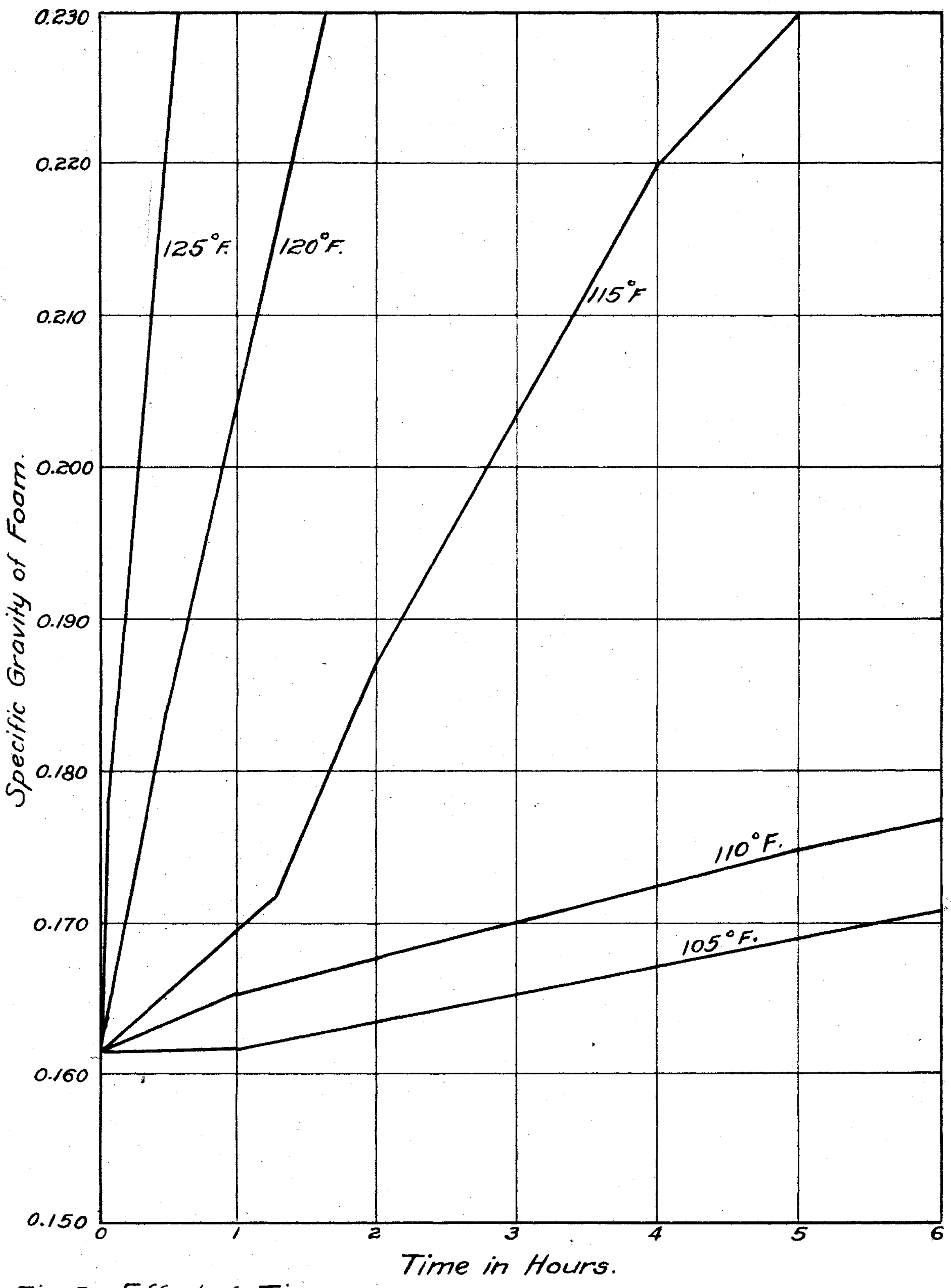


Fig. 5. Effect of Time and Temperature on Beating Power of Egg White.

D. Effect of pH on Beating Power of Egg Albumen

That pH has an effect on the rate of denaturation of proteins has been reported by many investigators (3, 38, 49, 50). They have all indicated that the rate of denaturation and coagulation is increased as the isoelectric point of the various proteins are approached. Since the pH of freshly laid egg white (7.6) rapidly increases after laying and holding to 9.5, this range of pH as well as the more acid range were studied.

The pH adjustments were made using two methods; one, by the addition of acid, acid salts or alkali and the other by spontaneous fermentation.

1. Acidification

Fresh blended egg white was divided into a number of aliquot portions and pH adjusted using: lactic acid, potassium acid tartrate, hydrochloric acid, and sodium hydroxide.

In each case, the acid or alkali was added dropwise with vigorous stirring using a mechanical stirrer. This procedure minimized local areas of high acidity or alkalinity. Even with all these precautions it was observed that on adding the acid very small areas of turbidity appeared and on stirring dispersed but reappeared when the pH of the entire liquid albumen reached a pH of 7.0 or lower. This phenomena was observed even when a .05 percent hydrochloric acid solution was added.

When alkali was added, it was noted that where the local concentration was high, immediately on contact a gel formed. On stirring, this broke up. However, when the final pH of the egg white reached approximately 10.0, the white became quite viscous and in some cases set up to a gel-like consistency. This was probably due to the mucin present in the egg white which exists in a gel-like state at high pH values.

a. Acidification with lactic acid. From 0.1 to 0.5 ml. of 50 percent lactic acid was added to 61 g. of liquid egg white with vigorous stirring. The pH was determined and whip tests conducted. As may be seen from Table 14, as the pH was decreased to below 8.0, the beating power decreased. Apparently increasing the acidity of the liquid white results in a loss in beating power.

TABLE 14

EFFECT OF pH ON BEATING EGG ALBUMEN
ACIDIFIED WITH LACTIC ACID

| Sample | ml. Lactic Acid (50%) | pH | Specific Gravity of Foam |
|---|---|---|---|
| 1 | 0 | 9.0 | 0.160 |
| 2 | 0.1 | 7.9 | 0.160 |
| 3 | 0.2 | 6.9 | 0.187 |
| 4 | 0.3 | 6.5 | 0.210 |
| 5* | 0.4 | 6.2 | 0.245 |
| 6* | 0.5 | 5.9 | 0.280 |

*White precipitate observed.

Although samples 3 and 4 showed signs of cloudiness, samples 5 and 6 were definitely turbid and had noticeable precipitates in the bottom of the flasks. This precipitate is probably mucin since it is known to precipitate at pH 6.0 - 6.4. The loss in whipping property may be due to the physical change in mucin which occurs at this pH. Hanson (33) indicated that egg albumen containing precipitated mucin, either acid precipitated or precipitated by dilution, took longer to whip to a given specific gravity than did untreated egg white.

b. Acidification by potassium acid tartrate. In the preparation of egg white foam by the test being used in this study approximately 1.5% of cream of tartar is used in the test formula. The egg white is beaten for about 10 seconds to a slight froth before the cream of tartar and salt are added. Beating is continued with sugar added at later intervals. Using this method it has been observed that the cream of tartar never completely dissolves. Since the addition of this much cream of tartar apparently results in satisfactory beating, it was thought desirable to determine the effect of varying amounts of cream of tartar when dissolved in egg white prior to beating. The results obtained are presented in Table 15. It will be observed that reducing the pH by this means again results in a decrease in the beating power.

TABLE 15

EFFECT OF ACIDIFICATION WITH POTASSIUM ACID TARTRATE ON BEATING OF EGG ALBUMEN*

| Sample | % Tartrate | pH | Specific Gravity of Foam |
|---|---|---|---|
| 1 | 0 | 8.7 | 0.161 |
| 2 | 0.1 | 8.4 | 0.175 |
| 3 | 0.5 | 6.8 | 0.187 |
| 4 | 0.9 | 6.6 | 0.193 |

*The cream of tartar was dissolved in a few ml. of water prior to adding to the egg albumen. An equal volume of water was added to the control sample to compensate for any dilution factor.

c. Acidification with hydrochloric acid. The blended liquid white was acidified with a 1N solution of hydrochloric acid. The control sample in each case was diluted to the same extent as the acidified samples by the addition of an equal volume of water. The usual volume of water required for a 61 g. sample of egg white was about 1 ml.

Table 16 (appendix) and Figure 6 include the results of these beating tests. As may be seen from the data when the pH is changed from the normal range at which the whip tests were usually run (8.2 - 8.7) a decrease in beating power resulted.

2. Acidification by fermentation

In commercial practice, practically all the egg albumen is fermented prior to drying to remove the free glucose which otherwise would result in a deteriorated product on storage. This fermentation is usually not controlled but is allowed to proceed with the organisms normally present in the egg white as a result of breaking and handling operations. Some operators use a controlled fermentation, inoculating the egg albumen with a culture of certain organisms. It is felt this results in a faster and a cleaner fermentation (from the standpoint of organoleptic qualities).

To determine the effect of fermentation on the foaming property of egg albumen, a number of spontaneous and controlled

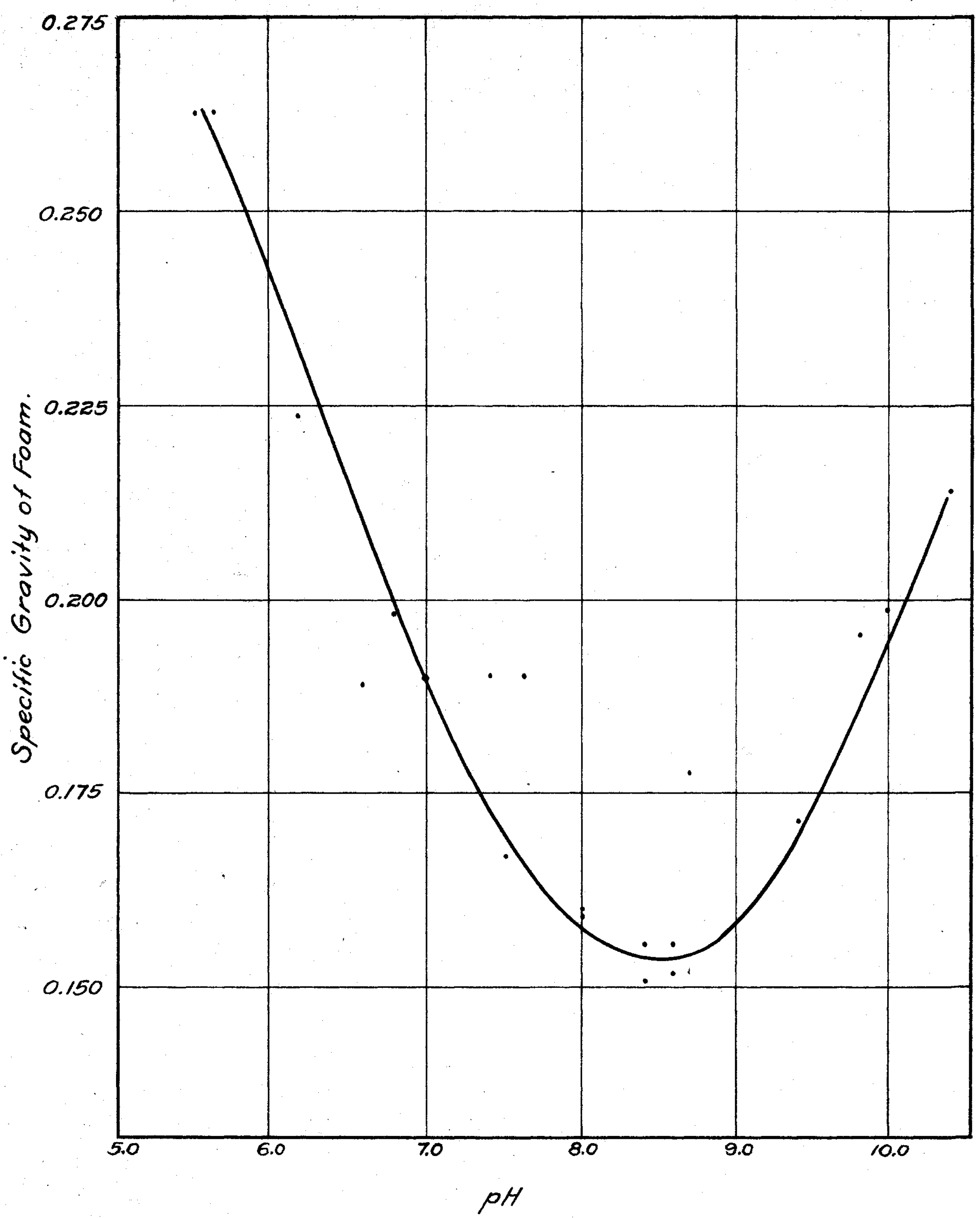


*Fig. 6. Effect of pH on Beating Power of Egg Albumen.*

fermentations were carried out. The decrease in pH was followed and whipping tests were made at various pH levels during fermentation.

In one of these tests about two liters of egg white were prepared, blended and 1,500 ml. allowed to remain at 86°F. for a period of one week. Approximately 500 ml. of the same lot of white was stored at 35°F. as a control. Samples were removed at intervals and the pH and foaming rate determined. The results are summarized in Table 17.

TABLE 17

EFFECT OF FERMENTATION ON BEATING PROPERTY OF EGG ALBUMEN

| Temperature | Fermentation Time Hours | pH | Specific Gravity of Foam |
|---|---|---|---|
| 35°F. | 0 (control) | 8.8 | 0.163 |
| 35°F. | 168 (control) | 8.6 | 0.165 |
| 86°F. | 0 (control) | 8.8 | 0.161 |
| 86°F. | 24 | 8.7 | 0.160 |
| 86°F. | 36 | 8.6 | 0.160 |
| 86°F. | 48 | 8.0 | 0.151 |
| 86°F. | 72 | 7.6 | 0.151 |
| 86°F. | 120 | 7.5 | 0.150 |
| 86°F. | 132 | 7.0 | 0.161 |
| 86°F. | 144 | 6.7 | 0.155 |
| 86°F. | 156 | 6.6 | 0.217 |
| 86°F. | 168 | 6.5 | 0.217 |
| 86°F. | 168 | 6.2 | 0.220 |

These results indicate that the pH fell to as low as 6.7 without any decrease in the beating power of the egg white. When the pH dropped to the range of 6.2 - 6.6 there was a decided decrease in the whipping power. It was observed that in this pH range, the samples became quite turbid; at 6.2 to 6.6 a grainy white precipitate was present in the bottom of the flask.

Two other fermentations were made using an inoculum of 10 percent egg white already fermented with *Aerobacter aerogenes*. One required four days at approximately 80°F. for completion. A pH of 6.2 was reached. Whip tests were run at the beginning and end of the fermentation; the results obtained are given in Table 18. It was observed that in both fermentations, the whip was adversely affected when the pH reached 6.2 or lower. Because these samples were subsequently used for drying, intermediate samples were not removed and whipped during the fermentation.

TABLE 18

EFFECT OF FERMENTATION ON BEATING POWER OF EGG ALBUMEN

| Lot | Sample | pH | Specific Gravity of Foam |
|---|---|---|---|
| 1 | Beg. of fermentation | 8.5 | 0.150 |
| | End of fermentation | 6.2 | 0.213 |
| | End of fermentation | 8.9* | 0.195 |
| 2 | Beg. of fermentation | 8.7 | 0.165 |
| | 4 days | 6.3 | 0.315 |
| | 5 days | 6.0 | 0.335 |

*pH adjusted to 8.9 with 5 N sodium hydroxide

In order to obtain a fermentation in which the lowest pH reached would not be as low as that obtained in normal fermentations, a test was made using a yeast culture to inoculate the egg albumen. A 10 percent inoculum was used and the fermentation allowed to proceed at 86°F. with constant stirring of the fermenting egg white by means of a slow mechanical mixer. The pH was followed carefully and samples were removed for whip tests after different intervals. The results of the whip tests are recorded in Table 19 (appendix) and shown in Figure 7 along with the pH data. The specific gravity change correlated quite closely with the decrease in pH as fermentation proceeded. A maximum specific gravity was reached when the pH of the liquid had begun to increase after reaching its lowest point of 6.5. Although the specific gravity shows an apparent decrease when the pH increased from 8.0 to 8.1, this is only one point and there is insufficient data available to justify any statement that there is a regeneration of the beating power of the liquid white on returning to its normal pH. From the curve showing pH change during fermentation, it was noted that no readings were recorded for a period of 12 hours after the pH had reached 6.5. It is possible that the pH may have gone lower before beginning its upward trend as indicated by the curve. It was observed however, that although the beating power decreased as fermentation proceeded, the highest specific gravity foam beaten during this run was still within the range

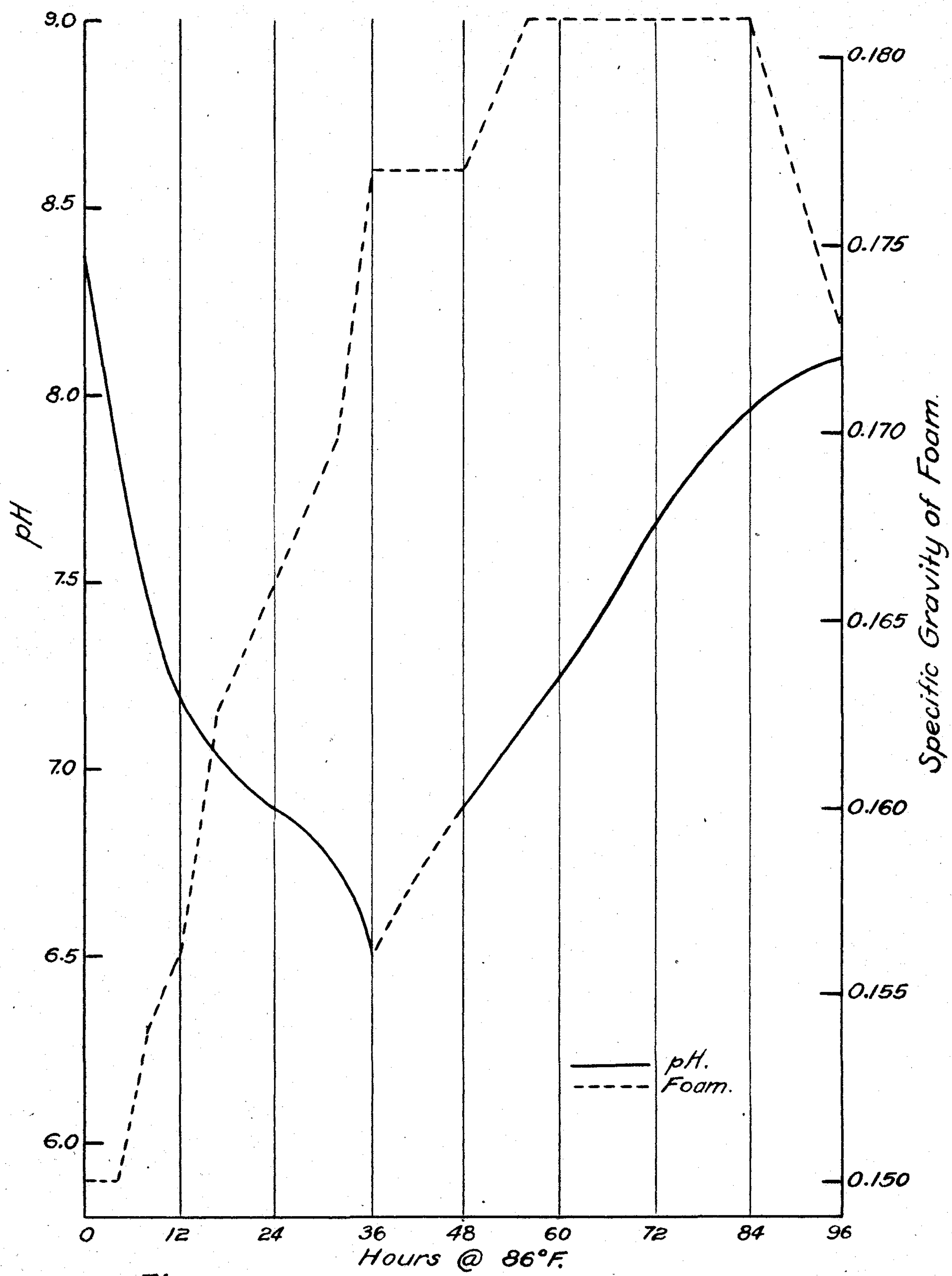


Fig. 7. pH Change and Effect on Beating Power in Fermentation of Egg Albumen Using Yeast Culture.

of satisfactory cake performance although actual cakes were not baked to prove this point. It can be seen however, that the increase in acidity produced by fermentation in this instance had much less effect on the beating power of egg albumen than did acidity produced by other means of acidification. Smears made at the end of the fermentation period showed that the organisms present at the end of fermentation were a mixture of yeast and _Aerobacter_.

Two additional fermentations were made under controlled conditions using inoculations of yeast and _Streptococcus_. The inoculum in these cases was 20 percent of an egg white containing an eighteen hour active culture of each of the organisms. The temperature was held at 86°F. and fermentation followed closely recording pH changes.

The _Streptococcus_ fermentation reached a minimum pH of 6.10 after 11 hours whereas the minimum pH of the yeast fermentation was 6.72 in 15 hours. Glucose was absent, as determined by the oven test, from the _Streptococcus_ fermentation after 12 hours and from the yeast fermentation after 19 hours. Samples were removed during fermentation at various intervals and whip tests were made. In addition angel cakes were baked from several samples taken immediately after inoculation, at the low pH when all the glucose was removed and again at a higher pH a number of hours after the minimum pH had been reached. The results obtained are given in Table 20.

TABLE 20

EFFECT OF FERMENTATION ON ANGEL CAKE VOLUME AND BEATING POWER OF EGG ALBUMEN

| Sample | Time Hours | pH | Specific Gravity of Foam | Cake Volume ml. |
|---|---|---|---|---|
| *Streptococcus* fermentation | Start | 7.6 | 0.195 | 728 |
| " | 11 | 6.1 | 0.203 | 652 |
| " | 36 | 7.0 | 0.197 | 733 |
| Yeast fermentation | Start | 7.7 | 0.177 | 707 |
| " | 22 | 6.8 | 0.166 | 714 |
| " | 36 | 7.6 | 0.165 | 720 |

From these results it can be seen that there is no definite correlation between angel cake volume and the whip tests in the case of the *Streptococcus* fermentation. From the results of the whip tests none of the samples would be expected to make top notch cakes. It will be noted however that at the low pH of 6.1 cake volume was definitely lost. With the yeast fermented samples, all of the whips are within the range of satisfactory angel cake performance and the cake volumes were entirely satisfactory. The most important point to be noted with the results obtained is that it appears entirely possible to ferment egg whites and remove glucose and yet obtain a product which performs satisfactorily at least from the standpoint of cake volume.

## E. Effect of pH on Heat Stability

The effect of pH on the heat stability of egg albumen was studied to determine if possible the pH at which heat stability was at a maximum. Egg white adjusted to various pH levels was subjected to various degrees of heating at the end of which the specific gravity of the foam, as measured by the whip test, was determined.

### 1. Instantaneous heating

A sample of freshly prepared white was divided into two lots. The pH of the original egg white was 8.7 and the aliquot portion was adjusted to pH 7.4 using 1N hydrochloric acid. Both samples were heated instantaneously (2-3 seconds) to temperatures from $140^{\circ}$-$146^{\circ}$F. and the beating power measured by the whip test. As can be seen from Table 21, the liquid having the lower pH showed less loss of beating power at the same temperature than did the egg white having the normal pH.

TABLE 21

EFFECT OF pH ON BEATING POWER* OF EGG WHITE HEATED TO TEMPERATURES OF 140°-146°F.

| Temperature °F. | pH 8.7 | pH 7.4 |
|---|---|---|
| Control | 0.153 | 0.153 |
| 140 | 0.171 | 0.170 |
| 142 | 0.175 | 0.175 |
| 144 | 0.200 | 0.178 |
| 145 | 0.233 | 0.196 |
| 146 | 0.300** | 0.201 |

*Specific gravity of foam.
**Coagulation in heating tube.

2. Holding time

Preliminary tests conducted at various temperatures to determine change of beating power with time indicated that 120°F. was a very satisfactory temperature. This was especially true when pH adjustments had been made or when substances had been added. A number of tests were made with pH-adjusted egg white when held for various intervals at 120°F. The effectiveness of pH adjustment in extending the time at which egg white could be heated is shown in Table 22 which contains the data obtained from four different tests.

TABLE 22

EFFECT OF pH ON BEATING POWER OF EGG WHITE HELD AT 120°F. FOR VARYING HOLDING PERIODS

| Test | Hours at 120°F. | Specific Gravity of Foam at varying pH levels | | | |
|---|---|---|---|---|---|
| | | 8.7 | 8.4 | 6.8 | 6.6 |
| 1 | 0 | 0.177 | 0.175 | 0.187 | 0.193 |
| | 1 | 0.222 | 0.220 | 0.187 | 0.200 |
| | 2 | 0.233 | 0.241 | 0.196 | 0.200 |
| | | 8.4 | 9.4 | 10.4 | |
| 2 | 0 | 0.150 | 0.170 | 0.213 | |
| | 1 | 0.222 | 0.233 | 0.351 | |
| | 2 | 0.273 | 0.285 | 0.266 | |
| | | 8.6 | 7.8 | 7.4 | 6.9 |
| 3 | 0 | 0.183 | 0.188 | 0.191 | 0.197 |
| | 3 | 0.263 | 0.222 | 0.200 | 0.205 |
| | 6 | 0.280 | 0.256 | 0.200 | 0.206 |
| | | 8.5 | 7.5 | 7.0 | 6.5 |
| 4 | 0 | 0.151 | 0.171 | 0.183 | 0.185 |
| | 6 | 0.301 | 0.193 | 0.180 | 0.193 |
| | 12 | 0.345 | 0.225 | 0.201 | 0.196 |
| | 24 | 0.391 | 0.265 | 0.231 | 0.203 |

These results show that although lowering the pH affects the original beating power of the egg white there is a definite stabilization of the product to heat. When the pH was raised to the alkaline side of the original pH, there was also a deleterious effect on beating power which increased with heating. From the data, it will be noted that at a pH of 10.4, there is an apparent decrease in specific gravity after two hours' heating at 120°F. During this test, this particular sample was observed to have a strong odor of hydrogen sulfide and became quite turbid. It is probable that alkaline hydrolysis occurred resulting in the formation of peptides and other protein fragments possessing high foaming quality.

Throughout the tests in this study, it was observed that the pH of the liquid egg white increased on heating. The longer the heating period the higher the final pH. It appears that since the eggs used in all of these tests were relatively fresh all of the $CO_2$ present in the albumen had not as yet been lost. It has been reported (67) that the pH of freshly obtained egg white will rise from an original value of 7.6 to about 9.5 within a few days with proper temperature and ventilation. It seems probable that the temperature to which the egg white was heated during these tests played an important part in liberating additional $CO_2$ causing the rise in pH.

### F. Effect of Concentration on Beating Power

In order to obtain information regarding the effect of heat on egg albumen of varying concentrations several experiments were conducted in which egg albumen was concentrated to 20, 30 and 95 percent solids, by drying under high vacuum while frozen (lyophilizing). This method was used since it was desired to obtain the concentrated egg white without artificial heat being used in the process. This permitted a separate study of heat stability of the concentrated product. The effect of actual concentration on the beating power using air film drying method was also studied.

The results of these tests indicate that the heat stability of concentrated egg white containing 20 percent solids was quite similar to that of 12 percent solids (normal). The method of concentration itself apparently affected the beating power since it was observed in practically every case that there was some loss of whipping power during drying. When lyophilization was used, the effect was very slight. However, when the air film method of drying was used where egg temperatures of $105^{\circ}$ to $115^{\circ}$F. were reached, there was a definite effect noted in the beating power. Some of the data showing the effect on whipping power are given in Table 23.

TABLE 23

EFFECT OF CONCENTRATION ON BEATING POWER OF EGG ALBUMEN

| Sample | % Solids | Specific Gravity of Foam | Method of Concentration |
|---|---|---|---|
| 1 | 12 | 0.171 | Lyophilizing |
| | 30 | 0.189 | " |
| | 95 | 0.180 | " |
| 2 | 12 | 0.167 | " |
| | 20 | 0.187 | " |
| | 95 | 0.195 | " |
| 3 | 12 | 0.168 | Air Film |
| | 88 | 0.292 | " |
| 4 | 12 | 0.165 | " |
| | 90 | 0.265 | " |

It was observed that when the concentrated or dried egg albumen obtained by lyophilizing was reconstituted to its original solids content, a definite amount of thick transluscent material resembling thick egg white was present in the reconstituted liquid. This material could be dispersed using a hand egg beater but on standing it coalesced and floated back to the surface of the liquid. The material may have been the mucin portion of the egg white which had undergone some physical change due to the freezing and drying process.

Table 24 contains the results obtained when egg albumen of 20 percent solids content was heat treated.

TABLE 24

EFFECT OF HEAT TREATMENT ON BEATING POWER*
OF CONCENTRATED (20% SOLIDS) EGG ALBUMEN

| Min. at 120°F. | Control (12% Solids) | Concentrated (20% Solids) |
|---|---|---|
| 0 | 0.167 | 0.187 |
| 0.5 | 0.160 | -- |
| 1.0 | 0.167 | 0.192 |
| 30.0 | 0.173 | 0.215 |
| 60.0 | 0.203 | 0.220 |
| 90.0 | 0.225 | 0.237 |
| 120.0 | 0.241 | 0.250 |

*Specific gravity of foam.

## G. Effect of Added Substances

It has been reported in the literature that sugars and other compounds exert a protective action on proteins during heating (4, 13, 59, 62). Therefore it was believed that the addition of certain compounds to egg albumen might extend the times and temperatures to which the liquid could be heated without loss of functional properties. This might permit far more economical dehydration.

1. Sucrose

A large number of tests were made to determine the effect of varying concentrations of sucrose on the retention of foaming capacity of egg white when subjected to heat.

It will be recalled that the total amount of sugar used in the whip tests was 47 g. per 61 g. of egg white (77 percent). The sugar concentrations referred to in this section are expressed as the percent sugar in the egg white used.

a. Effect of sucrose on heat stability.

1. Instantaneous heating. Liquid egg white samples containing sugar concentrations from 0 to 60 percent were heated instantaneously to temperatures of from 140°F. to 166°F. and the beating tests of triplicate samples were made at each temperature. The specific gravity of the foam as a function of temperature and sugar concentration is given in Table 25 (appendix) and Figure 8.

It will be noted that as the sugar concentration increases, the temperature at which the egg white can be heated with a minimum loss of beating power is also increased. The differences among samples with concentrations above 20 percent sucrose are not very important up to 150°F. Above 150°F. however,

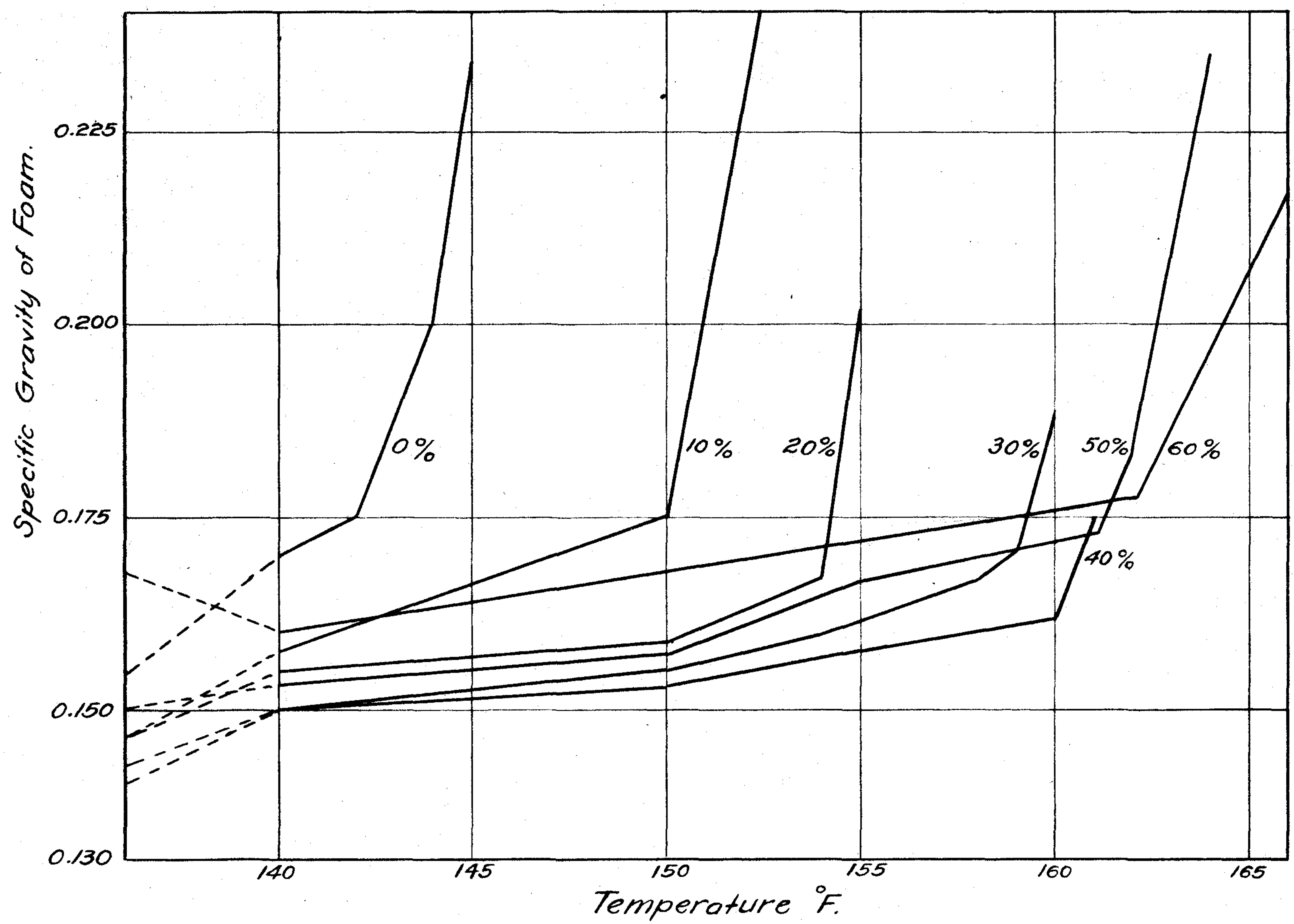


Fig. 8. Effect of Sugar Concentration on Heat Stability of Egg Albumen.

sugar concentrations exert a significant effect on thermal stability.

The sample containing 60 percent sucrose showed poorer whipping properties until rather high temperatures were reached. This is believed to be due to the fact that the viscosity of this egg white-sucrose solution is quite high; therefore the rate at which air can be incorporated into the foam is reduced.

2. Holding time. Liquid egg white samples containing sugar concentrations of from 0 to 77 percent were heated at 120°F. for one and two hours and the beating power was determined. The results are given in Table 26 (appendix) and are plotted in Figure 9.

It will be observed that the heat stability of the albumen increases with increase in sugar concentration. Only small differences were noted among the samples containing 30, 40 and 50 percent sucrose. At a concentration of 60 percent it will be observed that although the specific gravity of the foam is higher even before heating, no increase was observed during heating. Here again it is believed that the higher specific gravity is due to the increased viscosity of the egg albumen-sucrose solution retarding the rate at which air could be incorporated into a foam. This phenomena is even more exaggerated when the egg white

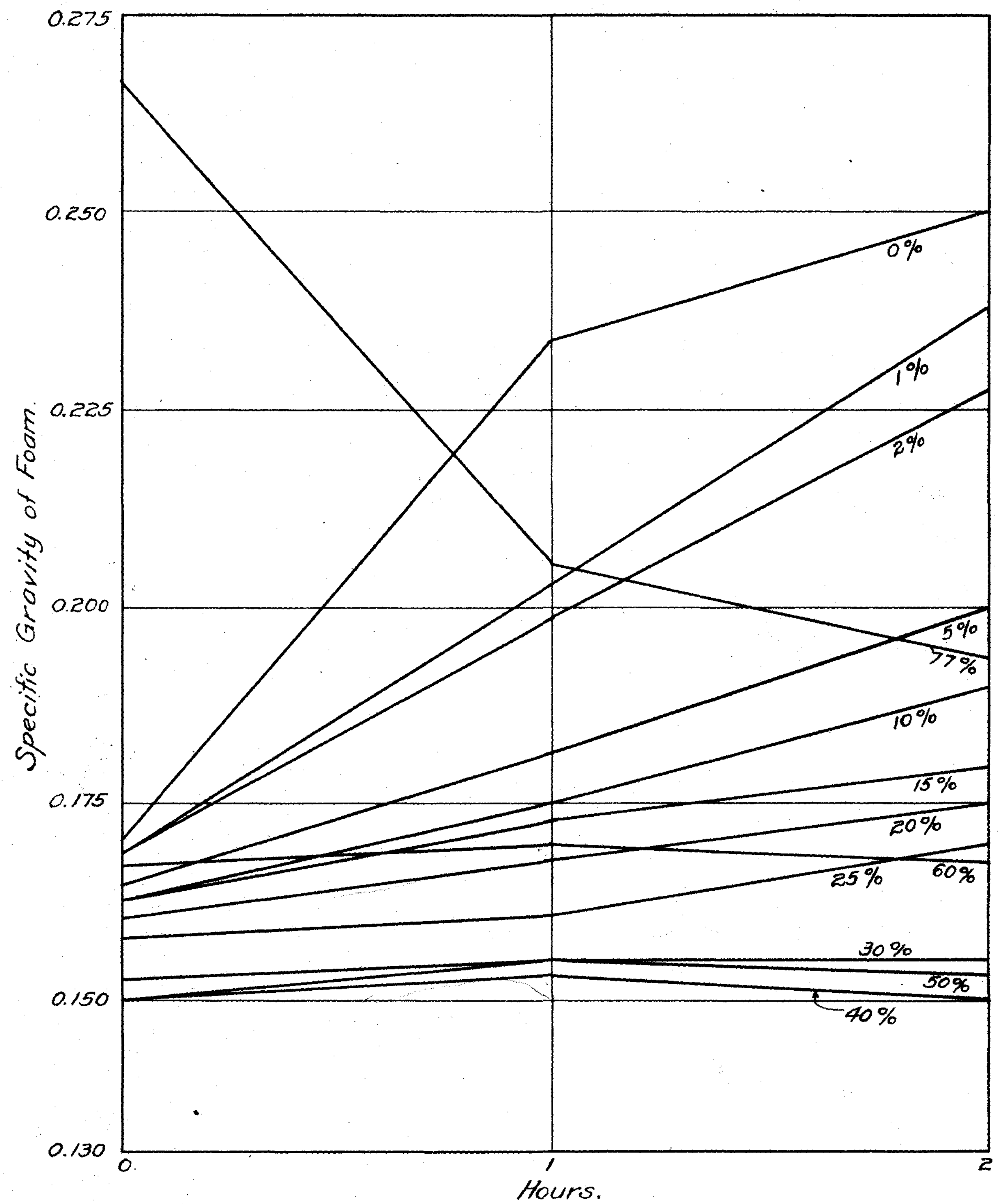


*Fig. 9. Effect of Holding Time at 120° F. on Beating Power of Liquid Egg White containing Various Sucrose Concentrations.*

contains 77 percent sugar. In this case the viscosity is so high initially that the specific gravity of the foam is very high at the end of heating (0.265). However, the specific gravity decreases significantly with holding.

3. Combined effects of sucrose and pH. It was decided to test the effect of pH at 8.5, 7.5, 7.0 and 6.5 and with concentrations varying from 0 to 77 percent. Adjustments of pH above 8.5 were not made since previous tests indicated that at higher values there was an adverse effect on beating power and heat stability. Triplicate samples of each treatment were whipped. The results of this test are given in Table 27 (appendix) and Figures 10a, b, c and d.

From these results, it will be observed that pH plays an important part in stabilizing the albumen when no sugar is present as well as the lower sugar concentrations. At sugar levels above 20 percent the effect of pH is only of minor importance.

b. Effect of sugar on beating power. In addition to the stabilizing effect sugar levels had on egg white another phenomena was observed regarding the effect of the addition of sugar on the beating property of control (unheated) samples. It was noted in the numerous tests conducted with albumen containing sucrose that these samples beat more rapidly than samples in which no sugar was dissolved prior to beating. At sugar concentrations of 10 to 50 percent, the time necessary

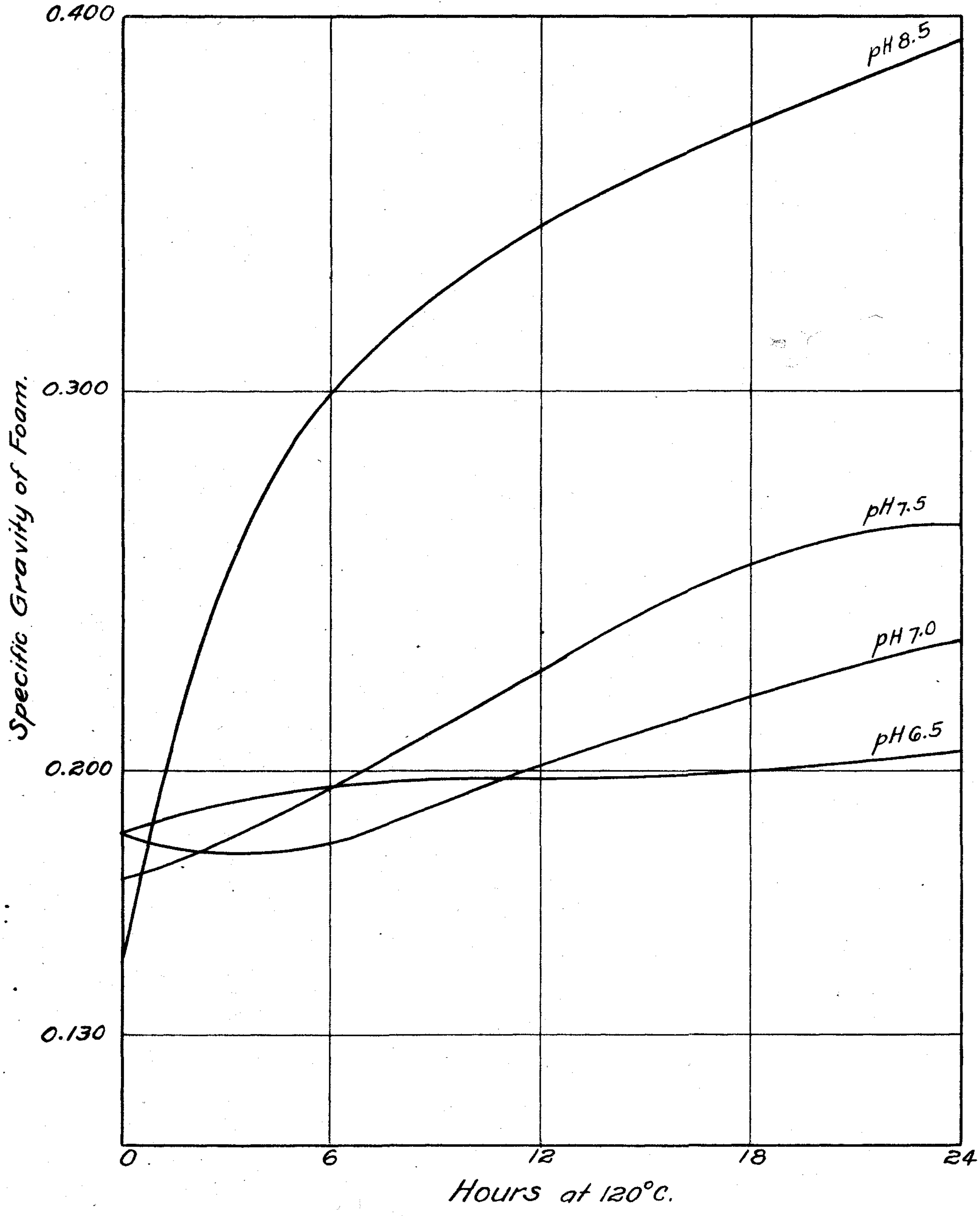


Fig. 10a. Effect of pH on Heat Stability of Egg White Containing no Sugar.

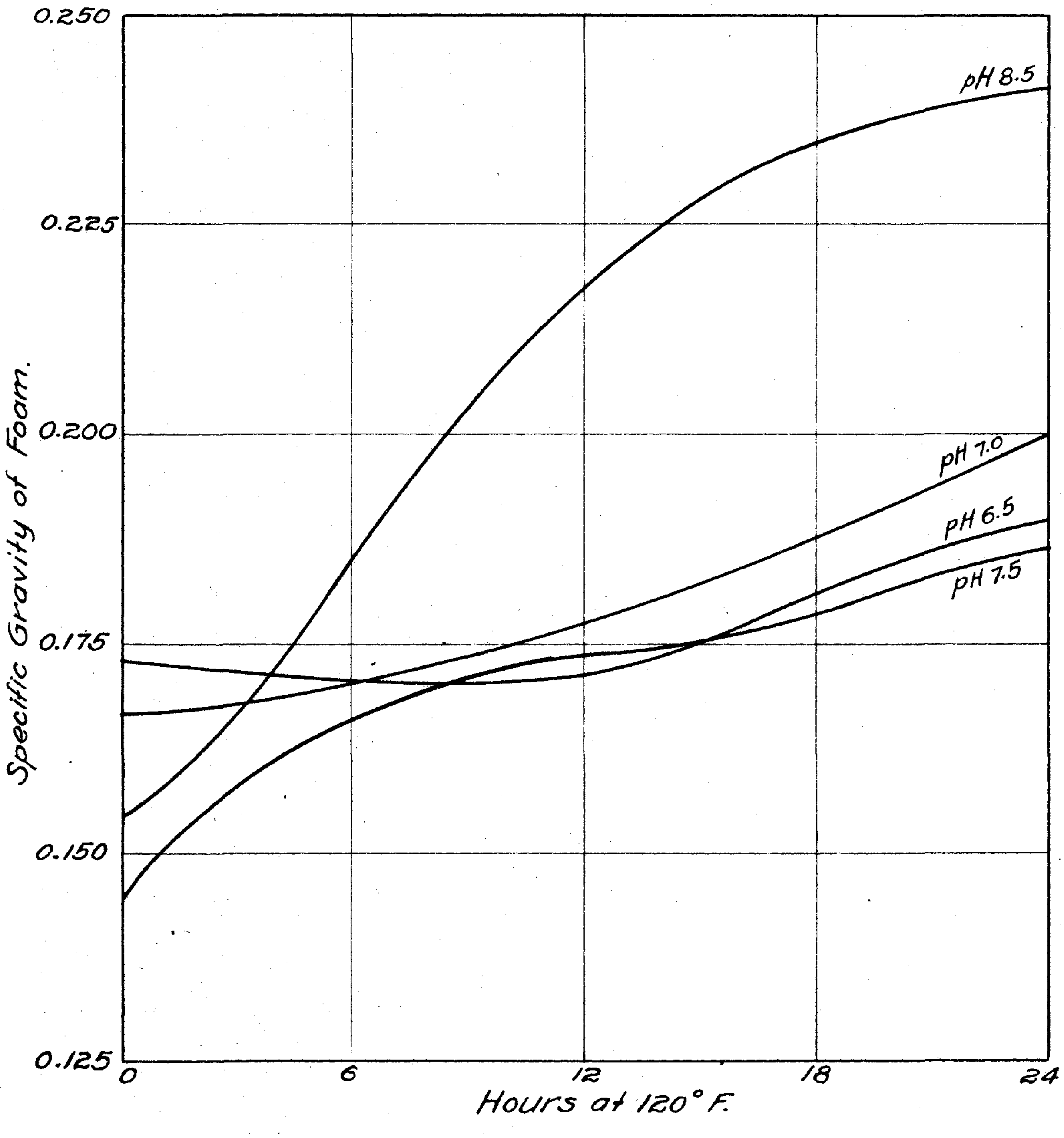


Fig. 10b. Effect of pH on Heat Stability of Egg White. Containing 10% Sugar.

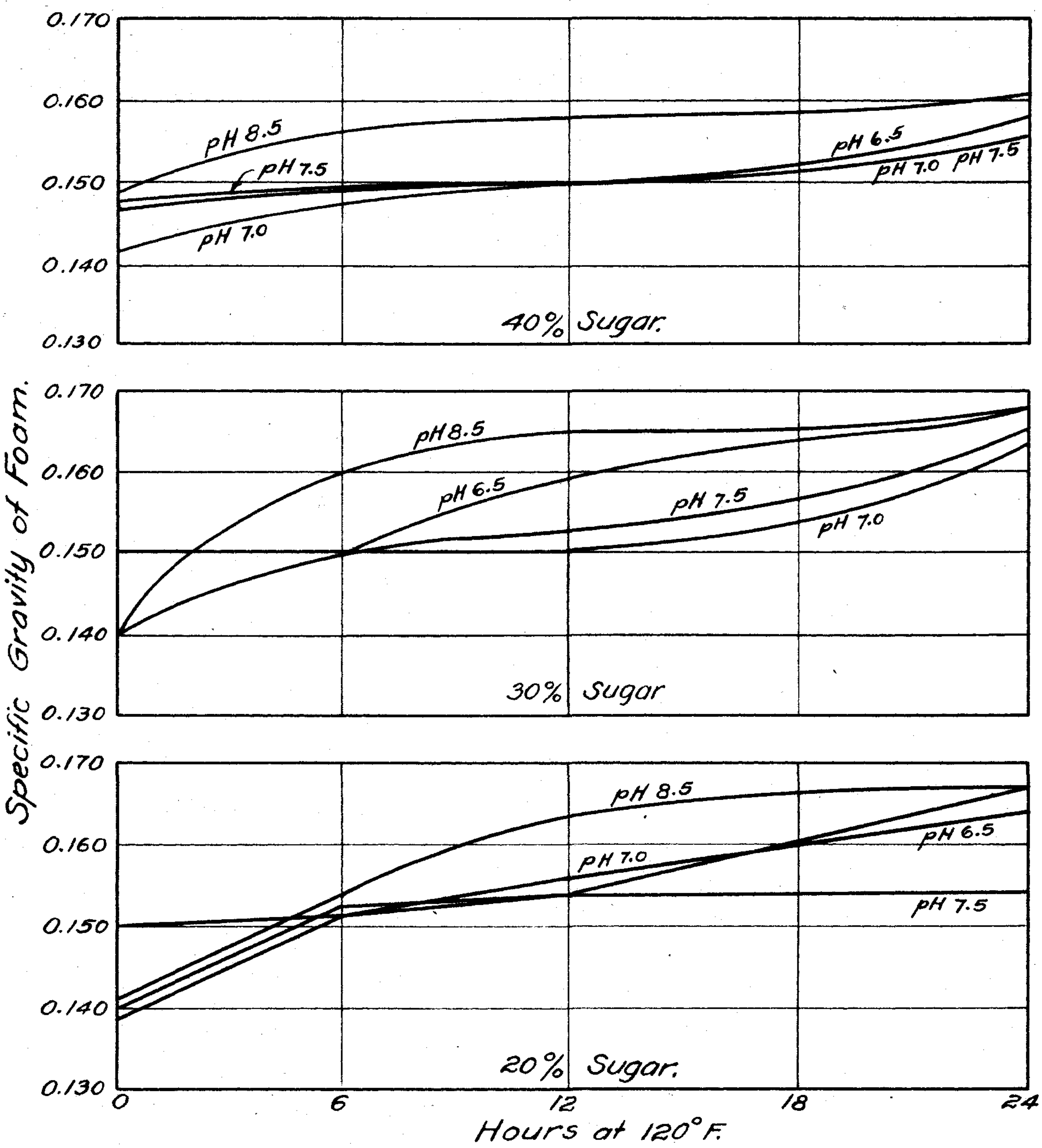


Fig. 10c. Effect of pH on Heat Stability of Egg White with Various Sugar Concentrations.

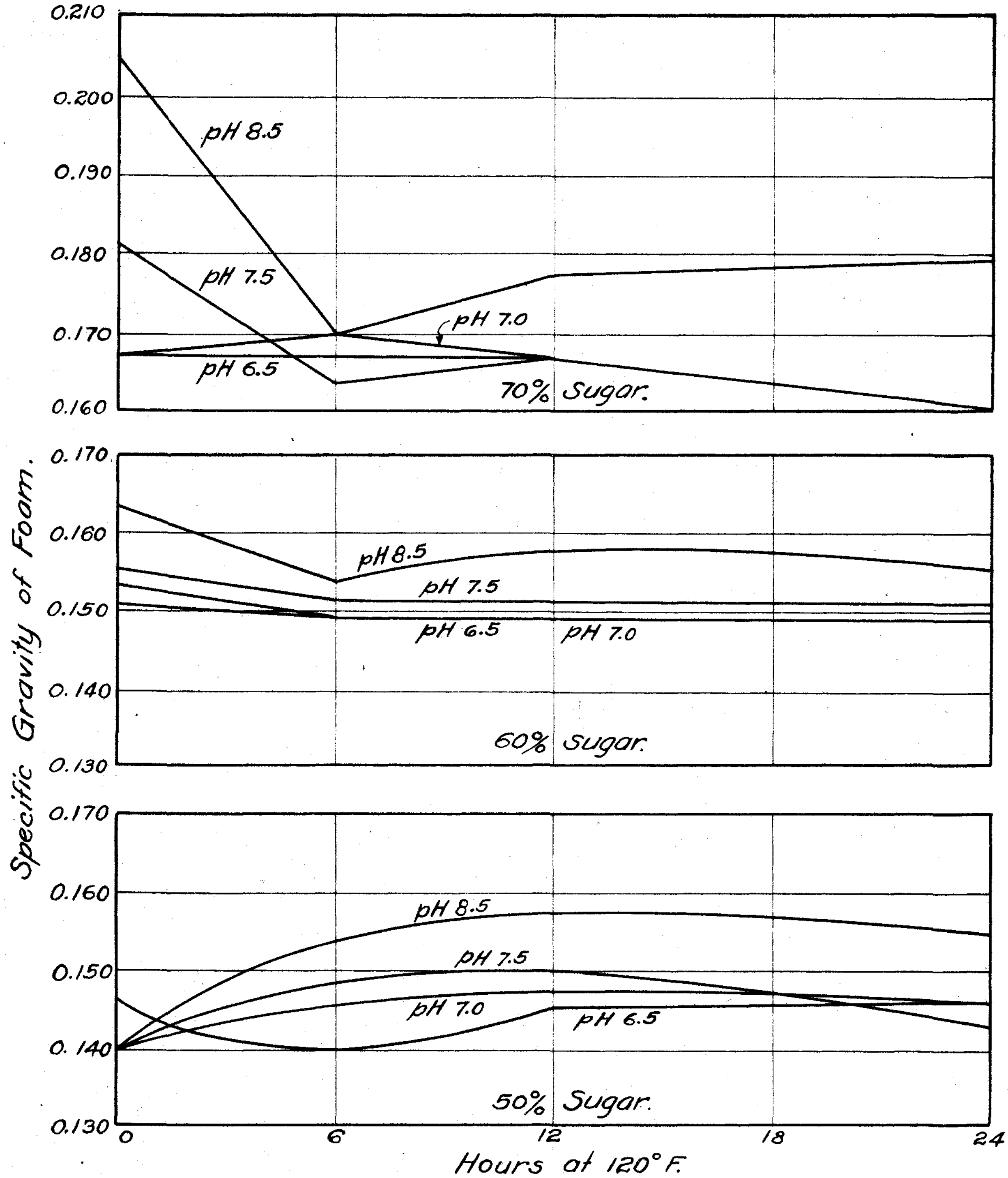


Fig. 10d. Effect of pH on Heat Stability of Egg White with Various Sugar Concentrations.

to beat egg white was reduced. (Table 28) Just why this increased rate of foam formation occurred is not quite clear. When whipping egg white foams by means of hand operated beaters or whisk beaters, it is the normal observation that longer times are required to beat egg white when sugar is added to the liquid white prior to beating. Whether or not this increased rate of whip due to sugar is reflected in other types of mechanical beaters either household sizes or large commercial sizes is not known at present but is a project worthy of some study.

It must be mentioned that the results in Table 28 are the composite of a large number of tests. It was observed during a number of the experiments that the time that the sugar was allowed to remain in solution in the egg white had an effect on the initial rate of foaming. This was especially true at the high sugar concentration where it was observed that in a few instances the beating power increased with the time that the sugar was allowed to remain dissolved in the egg white before beating. This was especially true when acid was added to reduce the pH.

TABLE 28

EFFECT OF DISSOLVING VARIOUS LEVELS OF SUCROSE
PRIOR TO WHIP TEST ON SPECIFIC GRAVITY OF FOAM

| % Sugar | Specific Gravity of Foam* |
|---|---|
| 0 | 0.170 |
| 1 | 0.170 |
| 2 | 0.167 |
| 5 | 0.161 |
| 10 | 0.158 |
| 20 | 0.158 |
| 30 | 0.147 |
| 40 | 0.150 |
| 50 | 0.170 |
| 60 | 0.192 |
| 77** | 0.275 |

*Average specific gravity for about 10 individual runs.
**Total required in formula--none added during whip test

2. Addition of other sugars and related compounds

It was decided to determine the effect of other sugars, both monosaccharides and disaccharides as well as related compounds such as the glycols on the heating power of egg white. It was believed that the observed effect of sucrose might be due to the large numbers of lyophilic, hydroxyl groups it contains. It also seemed desirable to obtain some information regarding the effect of free reactive groups such as the aldehyde group in glucose.

a. Effect of dextrose, lactose, maltose and mannitol. When 20 percent of dextrose was dissolved in egg albumen and tested in comparison with 20 percent sucrose, it was noted that the dextrose was the more effective in retaining the beating property during heating. (Table 29).

TABLE 29

THE EFFECT OF SUCROSE AND DEXTROSE ON BEATING PROPERTY OF HEATED ALBUMEN

| | Specific Gravity of Foam | |
|---|---|---|
| Hours at 120°F. | Sucrose* | Dextrose* |
| 0 | 0.155 | 0.148 |
| 1 | 0.165 | 0.158 |
| 2 | 0.171 | 0.157 |
| 5 | 0.177 | 0.150 |
| 8 | 0.183 | 0.163 |
| 12 | 0.195 | 0.165 |
| 24 | 0.205 | 0.167 |

*20% dissolved in albumen prior to whipping

To compare the effectiveness of disaccharides, monosaccharides and certain polyhydric alcohols, several tests were conducted. The results of one such test is shown in Table 30.

It will be noted that at a ten percent level both dextrose and lactose appear to be more effective than sucrose and mannitol. All sugars exerted a beneficial effect, however.

TABLE 30

COMPARATIVE EFFECT OF SUCROSE, LACTOSE, DEXTROSE AND MANNITOL ON BEATING POWER* OF ALBUMEN AFTER HEATING

| Hours at 120°F. | Control | 10% Sucrose | 10% Mannitol | 10% Lactose | 10% Dextrose |
|---|---|---|---|---|---|
| 0 | 0.170 | 0.140 | 0.138 | 0.138 | 0.140 |
| 6 | 0.206 | 0.177 | 0.161 | 0.158 | 0.160 |
| 12 | 0.255 | 0.179 | 0.173 | 0.163 | 0.167 |
| 24 | 0.278 | 0.200 | 0.198 | 0.183 | 0.178 |

*Specific gravity of foam

Previous tests had indicated the increased stability to heat when lowering the pH of the albumen solution to the range of approximately 7.5 especially at the lower sugar concentrations. It was decided to run additional tests at this pH using the previously tested sugars and commercial maltose.

(Table 31). As can be seen by comparing results from Tables 30 and 31, pH again aids in stabilizing the albumen. It will also be observed that maltose, dextrose and lactose were superior to sucrose and mannitol.

TABLE 31

COMPARATIVE EFFECT OF SUCROSE, LACTOSE, DEXTROSE, MALTOSE AND MANNITOL ON BEATING POWER* OF ALBUMEN AFTER HEATING AT A pH OF 7.5

| Hours at 120° F. | Sucrose | Mannitol | Lactose | Dextrose | Maltose** | Maltose*** |
|---|---|---|---|---|---|---|
| 0 | 0.148 | 0.150 | 0.145 | 0.141 | 0.147 | 0.147 |
| 6 | 0.155 | 0.157 | 0.145 | 0.148 | 0.147 | 0.150 |
| 12 | 0.160 | 0.160 | 0.148 | 0.148 | 0.150 | 0.153 |
| 24 | 0.181 | 0.175 | 0.157 | 0.153 | 0.155 | 0.158 |

*Specific gravity of foam.
**Commercial Maltose-(Maltose and Dextrose) 85% Maltose from Borcherdt Malt Extract Co.
***Commercial Maltose - Standard Brands Malto-Dextrin #156

Since most of these tests were conducted with commercial grades of sucrose, dextrose, lactose and maltose a test was conducted using purer products also. (Table 32). The results checked closely with those obtained using the commercial products.

TABLE 32

COMPARATIVE EFFECT OF PURE* SUCROSE, LACTOSE, DEXTROSE AND MALTOSE ON BEATING POWER** OF ALBUMEN AFTER HEATING

| Hours at | Sugar | | | |
|---|---|---|---|---|
| 120°F. | 10% Sucrose | 10% Lactose | 10% Dextrose | 10% Maltose |
| 0 | 0.148 | 0.158 | 0.150 | 0.160 |
| 6 | 0.163 | 0.163 | 0.148 | 0.160 |
| 12 | 0.177 | 0.177 | 0.167 | 0.168 |
| 24 | 0.205 | 0.180 | 0.177 | 0.168 |

*C. P. Sugars from Pfanstiehl Chemical Co.
**Specific gravity of foam.

b. Effect of glycols. Because of the results obtained with mannitol, it was thought advisable to compare the stabilizing effect of various glycols on egg albumen.

At first it was decided to determine the effect of the glycols on the original whipping property of the egg white since it was reasonable to suppose that the mere addition of these substances to egg white might affect the beating power. Samples containing sucrose were tested simultaneously. The data obtained in these tests are shown in Table 33. The results indicate that all of these compounds, with the exception of Carbowax 4000, resulted in an increase in beating power. It may be seen that triethylene glycol and polyethylene glycol produced a greater effect than did sucrose.

TABLE 33

EFFECT OF GLYCOLS ON BEATING POWER
OF EGG ALBUMEN

| Sample | Specific Gravity of Foam |
|---|---|
| Control | 0.165 |
| 10% Sucrose | 0.150 |
| 10% Ethylene Glycol | 0.150 |
| 10% Glycerol | 0.147 |
| 10% Mannitol | 0.145 |
| 10% Triethylene Glycol | 0.116 |
| 10% Polyethylene Glycol 400 | 0.123 |
| 10% Carbowax 4000 | 0.300 |

A study was made to determine the effect of these compounds on the heat stability of egg white. The data (Table 34) (appendix), (Figure 11) indicates that none of these compounds, except glycerol, was effective in stabilizing the egg albumen. In fact all of them appear to have an adverse effect.

3. Addition of salt

It has previously been pointed out that salt concentrations affect the rate of denaturation of proteins and so it was decided to determine the effect of various salt concentrations

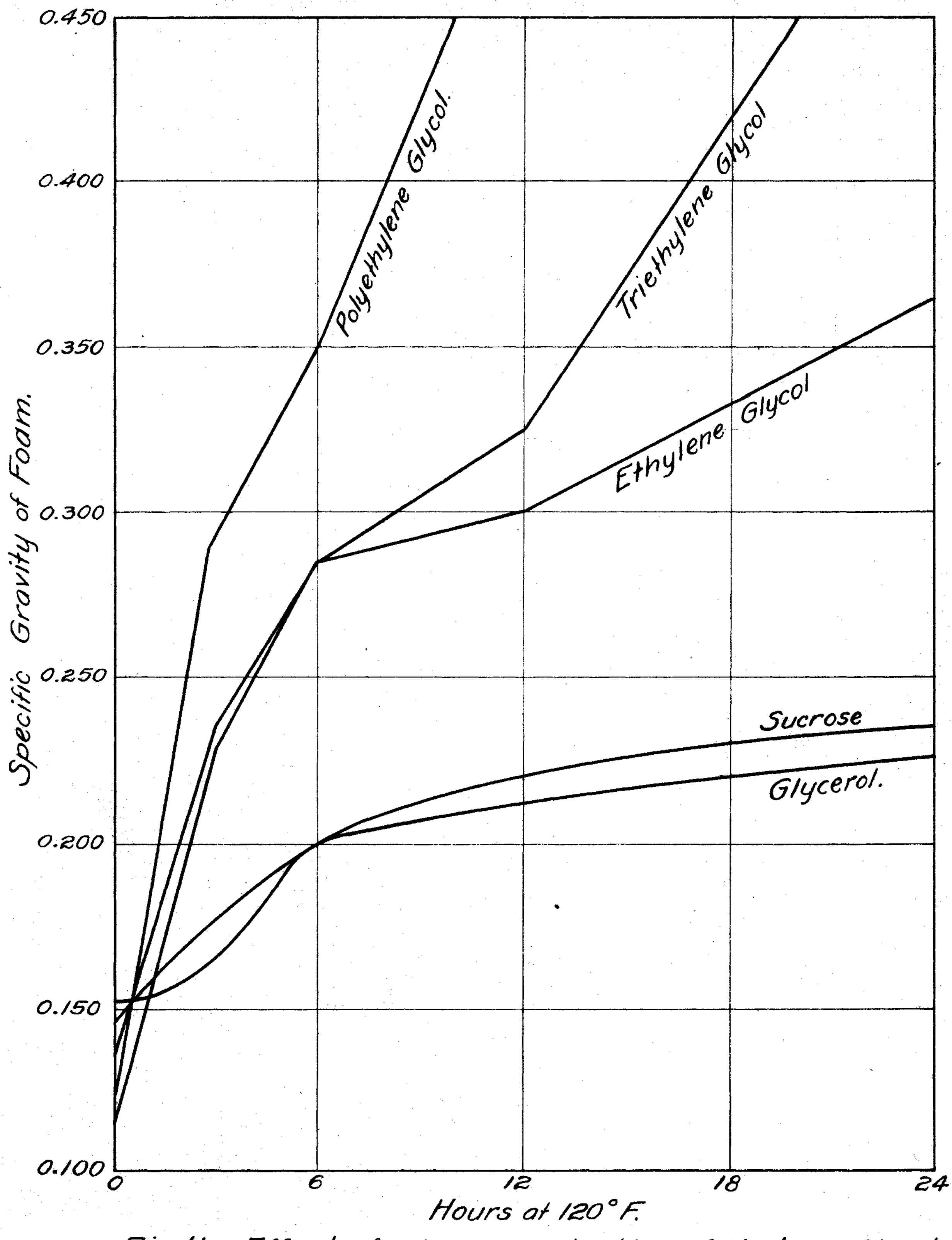


Fig. 11. Effect of 10% Concentration of Various Glycols on Heat Stability of Egg Albumen.

on the beating property of egg albumen. Concentrations of from 0.5 percent to 10 percent of sodium chloride were prepared and whip tests run. The results of these tests are presented in Table 35.

It will be observed that at 2 percent and higher, the beating power is reduced.

TABLE 35

EFFECT OF SODIUM CHLORIDE CONCENTRATION ON BEATING POWER OF EGG ALBUMEN

| Salt Conc. % | Specific Gravity of Foam |
|---|---|
| 0 | 0.175 |
| 0.5 | 0.175 |
| 1.0 | 0.175 |
| 2.0 | 0.193 |
| 5.0 | 0.200 |
| 10.0 | 0.210 |

The effect of salt concentration on the heat stability of egg white was checked at zero and 0.5 percent. The results which are presented in Table 36 indicate that 0.5 percent NaCl produces a slight increase in stability.

TABLE 36

EFFECT OF SODIUM CHLORIDE ON BEATING POWER OF EGG ALBUMEN

| Hours at 120°F. | Salt Conc. % 0 | 0.5 |
|---|---|---|
| 0 | 0.175 | 0.175 |
| 1 | 0.217 | 0.203 |
| 2 | 0.233 | 0.205 |

*Specific gravity of foam

### H. Role of Thick and Thin White

#### 1. Whipping property of thick and thin white--no heat treatment

There are numerous references in the literature (3, 10, 42) regarding the variation in whipping property and cake performance of thick and thin egg white. It has been observed (33) that when mucin is removed from egg white, the performance in angel cake is seriously affected. Since the thick white contains the greatest percentage of mucin, it was believed worthwhile to determine the role played by both thick and thin white (and indirectly mucin) in the foaming capacity of egg albumen.

The whipping property of the thick and thin portions was studied prior to treatment to determine the whipping power of each portion. It was observed that if the thick white were placed in the mixing bowl with little attempt to break down its gel structure, almost four minutes of whipping were required to obtain a specific gravity within the desired range (0.19 or lower). However, when the thick white was first blended in a Waring Blendor for approximately 30 seconds, it whipped to the desired specific gravity in 75 seconds or less. Some of these results are shown in Table 37.

The thin white did not beat to the desired specific gravity in the standard 75 seconds, an additional 30 seconds being necessary to bring the specific gravity to the desired range. Mixing the hand blended thick and thin together resulted in a product which whipped just slightly different than the thick alone. However, when the machine blended thick was mixed with the proper amount of thin, the specific gravity of the foam was within the desired range in 75 seconds.

TABLE 37

BEATING PROPERTY OF THICK AND THIN EGG ALBUMEN GIVEN VARIOUS TREATMENTS

| Sample | Blending | Whipping time Min. | Sec. | Specific Gravity of Foam |
|---|---|---|---|---|
| 1. Thick | - by hand | 1 | 15 | 0.440 |
| | | 2 | 15 | 0.340 |
| | | 3 | 15 | 0.195 |
| | | 3 | 45 | 0.167 |
| 2. Thick | - on Waring Blendor | 1 | 15 | 0.153 |
| 3. Thin | - on Waring Blendor | 1 | 15 | 0.200 |
| | | 1 | 45 | 0.167 |
| 4. Mixture of 1 and 3 -- | | 1 | 15 | 0.365 |
| | | 2 | 15 | 0.217 |
| | | 3 | 15 | 0.165 |
| 5. Mixture of 2 and 3 -- | | 1 | 15 | 0.175 |

2. <u>Effect of heat on thick and thin white</u>

Other tests were conducted to determine the effect of heat on each fraction of the egg white. Both the thick and thin portions were blended individually on the Waring Blendor, then heated, cooled and tested. The results of tests conducted with two different lots of eggs are presented in Table 38.

TABLE 38

EFFECT OF HEAT TREATMENT ON BEATING POWER OF THICK AND THIN EGG WHITE

| Sample | Treatment | Specific Gravity of Foam Test 1* | Test 2** |
|---|---|---|---|
| 1 | Thick not heated | 0.153 | 0.160 |
| 2 | Thin not heated | 0.200 | 0.230 |
| 3 | Mixture 1 and 2 | 0.160 | 0.175 |
| 4 | Thick-heated 1 hour at 120°F. | 0.250 | 0.243 |
| 5 | Thin-heated 1 hour at 120°F. | 0.215 | 0.258 |
| 6 | Mixture 2 and 4 | 0.215 | 0.212 |
| 7 | Mixture 1 and 5 | 0.158 | 0.179 |
| 8 | Mixture 4 and 5 | 0.250 | 0.230 |

*67% thick, 33% thin
**55% thick, 45% thin

The results of these tests indicate that the thick white is much more sensitive to heat than the thin white. It is observed that when the heated thick white is mixed with unheated thin, there is an adverse effect on the beating property. However, when the unheated thick white is blended with the heated thin, there is little or no change in beating capacity. Since the only difference between these two portions of egg white is the quantity of mucin present, it appears probable that this protein plays an important role in the whipping quality. It was observed that after heating the thick white a floating, thick scum was apparent on the surface. On shaking this material dispersed quite readily but reappeared on standing. This condition was not observed in the thin white. This is presumed to be denatured mucin.

## I. Effect of Homogenization

One of the treatments to which egg albumen is subjected in commercial spray drying is high pressure pumping and homogenizing. It seemed desirable to study the effect of homogenization on the whipping property of egg albumen; a number of tests were made.

### 1. Effect of homogenization on beating power of egg albumen.

The results of tests made to determine the effect of homogenization on beating power of egg albumen are presented in Table 39.

TABLE 39

EFFECT OF HOMOGENIZATION* ON BEATING PROPERTY OF EGG ALBUMEN

| Sample | Specific Gravity of Foam |
|---|---|
| Control | 0.150 |
| Homogenized - 1 pass | 0.237 |
| Homogenized - 2 passes | 0.260 |
| Homogenized - 3 passes | 0.271 |

*Central Scientific hand homogenizer

Several tests were also made using a laboratory model Mauton-Gaulin homogenizer. Homogenization was accomplished at pressures ranging from 1000 to 4000 pounds (as indicated by the pressure setting on the unit).

Table 40 (appendix) and Figure 12 show the results of two experiments.

Homogenization greatly affects the whipping power; the higher the pressure the greater the effect. Since homogenization is a process to which egg albumen is subjected in some commercial procedures, especially in spray drying, these data are particularly pertinent.

The liquid white remaining from samples which were whipped was placed in the laboratory freezer and held for approximately one month. At the end of this time the control sample and those homogenized at 1000 and 4000 pounds pressure

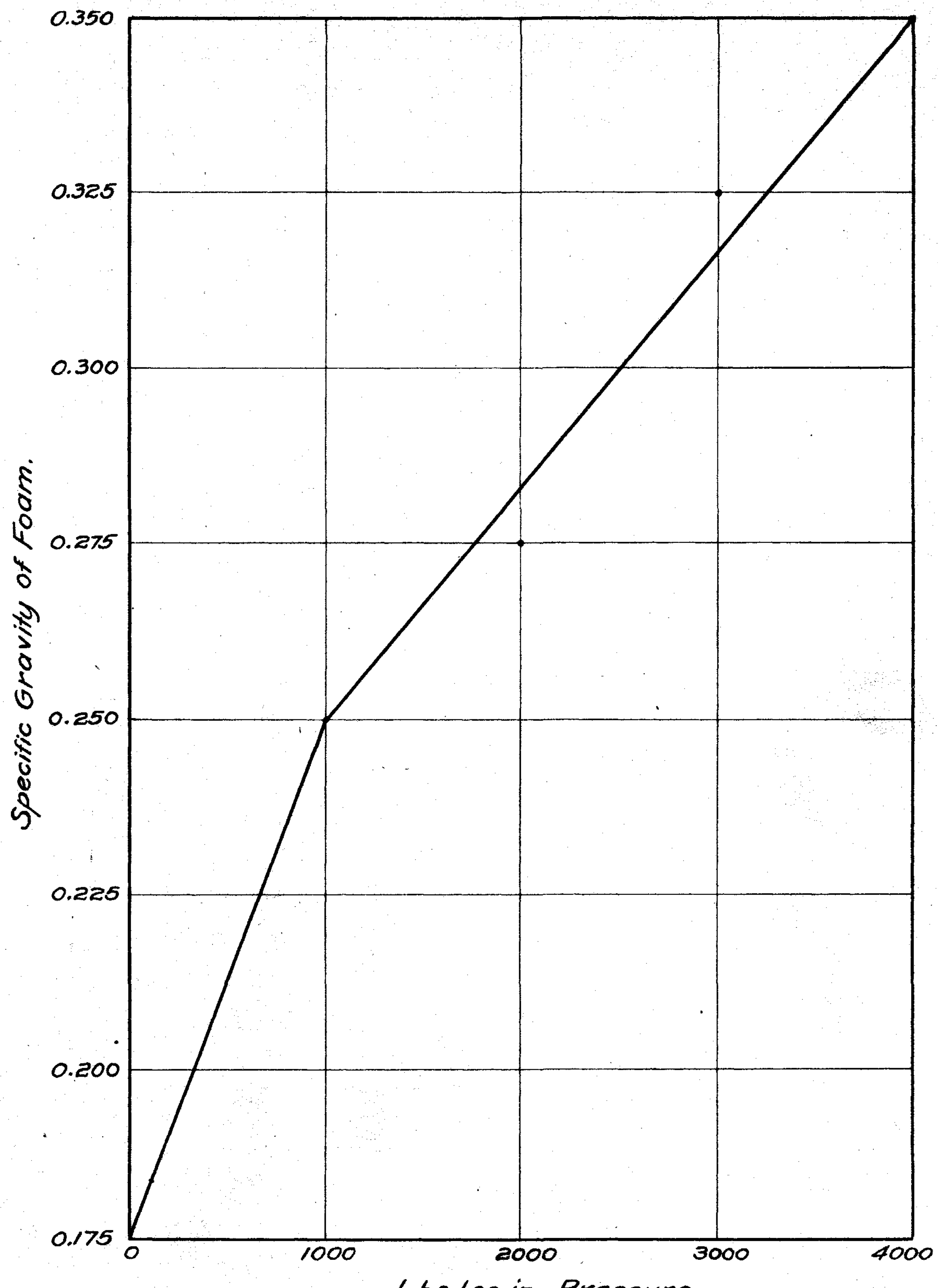


Fig. 12. Effect of Homogenization on Specific Gravity of Egg Albumen.

were thawed and angel cakes were prepared. The results obtained are presented in Table 41.

TABLE 41

EFFECT OF HOMOGENIZATION ON ANGEL CAKE VOLUME

| Treatment | Specific Gravity of Foam | Volume of Cake* ml. |
|---|---|---|
| Control | 0.178 | 710 |
| 1000 lbs. Pressure | 0.245 | 705 |
| 4000 lbs. Pressure | 0.342 | 662 |

*Average of two cakes.

As can be seen the cakes prepared from the control and 1000 lbs. homogenization pressure were of entirely satisfactory volume. When the egg white was homogenized at 4000 lbs. pressure however, a definite loss in cake volume was observed. From the whip tests, however, it appears that the egg white homogenized at 1000 lbs. pressure would not be expected to perform well in angel cake. These results imply that although a definite change in whipping power was observed, there is no correlation with its performance in angel cake.

2. Effect of pH and sugar on homogenization

Since sucrose increased the stability of egg albumen to heat, it appears reasonable that it also might play a role in stabilizing the egg white during homogenization. Accordingly its effect was studied. The results are presented in Table 42.

TABLE 42

EFFECT OF SUCROSE ON RETENTION OF BEATING PROPERTY* OF EGG WHITE WHEN HOMOGENIZED**

| Sample | Control | 30% Sugar |
|---|---|---|
| Control | 0.150 | 0.151 |
| Homogenized - 1 pass | 0.237 | 0.233 |
| Homogenized - 2 passes | 0.260 | 0.253 |
| Homogenized - 3 passes | 0.271 | 0.260 |

*Specific gravity of foam
**Central Scientific hand homogenizer

Similarly the influence of pH alone and with 30 percent sugar was also tested. The data are given in Table 43.

TABLE 43

EFFECT OF pH AND SUGAR ON RETENTION OF BEATING PROPERTY* OF EGG WHITE WHEN HOMOGENIZED

| Sample | Control pH 8.7 | Control pH 7.5 | 30% Sugar pH 8.7 | 30% Sugar pH 7.5 |
|---|---|---|---|---|
| Control | 0.158 | 0.161 | 0.141 | 0.140 |
| Homogenized - 1 pass | 0.297 | 0.312 | 0.277 | 0.278 |
| " - 2 passes | 0.333 | 0.322 | 0.300 | 0.303 |
| " - 3 passes | 0.362 | 0.355 | 0.313 | 0.313 |

*Specific gravity of foam

From these data it can be seen that homogenization greatly impaired the beating power regardless of the presence of sugar or change in pH. Apparently homogenization affects egg albumen in ways different from heating.

# V. DISCUSSION

## A. The Whipping Test as an Index of Change

Since the whipping test was set up in this study as the criterion by which angel cake performance was to be measured, the ability of this test to accurately portray changes in this particular function is all important. Unquestionably the particular beating test used is a very accurate measure of changes occurring in egg white when subjected to various treatments such as heating, acidification, fermentation and homogenization. Results of the various experiments performed in this study show that very slight alteration in the egg white was easily and accurately measured by this test.

Although a definite correlation was shown between the results of these whip tests and angel cake performance in a number of tests where the egg white was subjected to heat treatments, as well as certain physical treatment such as homogenization, it does not necessarily follow that if egg white cannot be whipped to within a given specific gravity range in the required time by this test, it will not perform satisfactorily in angel cake. A number of other factors apparently play a role in determining the relationship between whipping test results and angel cake performance. These factors may vary with the treatment given the egg white. Thus, it was observed that if egg white was not blended prior to running the whip test, the time necessary to beat it to the desired specific gravity range was longer than the maximum time used in these experiments (75 seconds). Of course, this does not mean that unblended egg white will not make a satisfactory angel cake. Certain limitations of this kind exist in respect to this test; undoubtedly it is a valid measure of angel cake performance only under the particular conditions which have been tested.

It was observed also that when the correlation between the whip test and angel cake performance was being determined using egg white which had been acidified, no definite trend was observed as to the angel cake performance of the treated product. At pH 6.3 or below there was a definite impairment in beating power of the egg white as well as loss of cake volume.

When the correlation of the whip test with angel cake performance was being tested using egg white which had been homogenized, similar results were observed. At the lower homogenization pressures the whip test showed a definite loss although the angel cake performance was still satisfactory. Only a few comparisons of this kind were tested. Unquestionably more investigations along this line should be made before definite conclusions can be drawn concerning the applicability of results of whip tests to angel cake performance.

The whip test gave reproducible results as was clearly indicated by repeated tests on a large lot of egg white. In addition it was observed that although it was necessary to have at least six different individuals assist in conducting these tests, none had any particular difficulty in obtaining consistent results. In many instances two or more individuals were able to replicate each others results when the same lot of egg white was being tested by both persons.

It was further observed that significant differences were noted among the many lots of fresh egg whites which were used during the eighteen months of experimental work. The figures varied from month to month. Although no work was done to relate these data on fresh eggs with the performance of the same egg whites in angel cake, such a study would have been of value in correlating whip tests with angel cake performance.

### B. Effect of Heating on Beating Power

A study of the relationship of heating conditions to the beating power of egg white showed linear relationship between heating time and beating power. It was observed that increases in temperature in the range of 130°F. to 145°F. decidedly impaired beating property of egg white. Similar results have been obtained by Wilkin and Winter (78). This temperature range is of course above the temperature of coagulation of egg white which has been given as $127^{\circ}F$. (28).

Since denaturation of certain proteins of egg white occurs at these temperatures and, since the whip test appears to be measuring a change in the egg white, it is probable that it is measuring the denaturation occurring in certain of egg white proteins. Other chemical and physical methods by means of which denaturation can be followed have been used by certain investigators especially with the pure proteins. No acceptable test has been devised for measuring denaturation in egg white. Hanning (32) used several methods for the detection of sulphydryl groups in egg white during beating. None was satisfactory. Payawal (60) followed the denaturation of egg white by heat by means of changes in viscosity. No increase in viscosity was noted when egg white was heated to $144.5^{\circ}F$. momentarily. Whip tests reported herein on whites similarly heated show definite changes in whipping power. Apparently some change in the egg white which occurs on heating and cannot be measured very accurately by means of viscosity, can be detected by the whip test. Probably sufficient alteration in the proteins take place which inhibit foaming.

To determine the actual protein fraction or fractions responsible for this loss in functional property would be an interesting and important problem. Some of the data collected in this study suggest that mucin may play an important role in this connection. For instance, it was shown that heating the thick portion of egg white results in a greater loss of foaming capacity than heating the thin white. Since the only known difference between these two portions is mucin content, it is suggested that this protein is important to beating power. More information should be obtained regarding the function of mucin in products in which egg white is used.

### C. Effect of pH on Beating Power

It has been pointed out that lowering the pH of white from its normal pH of 8.2 - 8.7 to 6.0 - 7.0 diminishes beating power. When the pH adjustment was made by the addition of acid, a loss in foaming property was observed at pH 7.0 and below. However, when the pH change was brought about by fermentation, the egg white retained good beating power down to a pH of 6.7. This indicates that possibly the rate of acidification is important. While in the former case the acid was added in dilute form (1N hydrochloric acid) there are unquestionably momentary areas of high acidity in the egg white where the acid is dropped into the liquid white and prior to distribution by means of a stirrer. Visible areas of turbidity were observed when the acid was added. This may have resulted in localized denaturation of the egg white protein, the visible results of which were dispersed on stirring. During fermentation pH changes are very slow; in such cases adverse effects were not observed until the pH reached 6.0 - 6.5.

It has been shown by McNally (54) that the isoelectric point of mucin is pH 6.2 - 6.6; it can be inferred that when this pH is reached the mucin is precipitated and loses its fiber-like structure and conceivably its functional properties. The relation of the properties of mucin to beating power would seem, therefore, to merit extensive study.

Tests with angel cake have indicated the importance of mucin in proper volume and texture. When mucin is removed by acidification or by dilution, the performance of the egg white in cakes is very definitely reduced. Even allowing the precipitated mucin to remain in the egg white results in a decided loss of angel cake volume (33).

Tests conducted in the present study showed that angel cake volume was greatly reduced when egg white, having a pH in the critical range for mucin precipitation was used. Fermented egg white at pH 6.13 produced cakes which were low in volume. When the pH increased to 6.9 the ability of the egg white to perform satisfactorily returned indicating that this loss of functional property is apparently reversible.

Although adjusting the pH to the acid side apparently impaired the foaming capacity of the egg white initially, experiments indicated that lowering the pH stabilized the egg white to heat. This result was not expected since it was believed that the nearer the protein is to its isoelectric point the more sensitive to denaturation and coagulation it becomes. Chick and Martin (23) found that acid accelerated the coagulation of albumin. Heat did not hasten denaturation. Block (16) pointed out that the denaturation rate increased with increasing pH but coagulation did not occur in alkaline solutions. Lepeschkin (49) observed that acid strongly accelerated the rate of coagulation of denatured albumin, while alkali strongly diminished it. Evidently coagulation does not play as important a role in the beating power as does denaturation.

D. Effect of Sugars and Other Added Substances

All sugars tested markedly increased the stability of albumen toward heat. Increasing levels of sugar exerted still greater effects.

Just how sugars accomplish heat stability of the egg proteins is not definitely known. The action of the sugars may be to retard denaturation in several ways. The added substance may combine with the protein in its native state, giving rise to a product which is not readily susceptible to denaturation by heat. On the other hand heat denaturation may bring about a combination of the protein with the sugar.

The resultant aggregates, thus formed of denatured protein and sugars might be as soluble or more soluble than the denatured protein itself. Soluble aggregates of both native and denatured proteins with detergents are known (7, 52).

Ball, Hardt, and Duddles (4) indicated that the resistance to heat coagulation of albumin to which sugars are added is due to an influence on the native protein and not to a peptization of the coagulated protein. They showed that when stabilizing egg albumin with d-glucose or d-fructose, no coagulation occurred even after all of the sugar was removed by dialysis, the pH of the solution was adjusted to the isoelectric point. In this case if the egg albumin had been denatured during heating, coagulation should have occurred on removal of the stabilizing agent (sugar) and adjusting the pH to 4.7.

Brooks and Hawthorne (19) observed that the mechanism involved in the protective action of carbohydrates on proteins was not known for certain. They feel, however, that there is some fairly good evidence that carbohydrate - protein complexes exist. It would appear possible that these complexes are more stable than the parent proteins. On the other hand, they feel that the effect may be due to an alteration in the water relationships in the system, brought about by the presence of sugar.

The effect of the sugars on stability of egg white to heat does not appear to be related to molecular weight since lactose has the same stabilizing effect as dextrose. A similar example is to be found with mannitol and sucrose. Sugars having free aldehyde groups exhibited a greater stabilizing effect than did sugars having none. Just how such a difference might account for differences in heat stability is not clear. Perhaps the relationship is not a cause and effect one.

That pH exerts a definite effect on heat stability of plain egg white was observed in this study. Its effect when sugars were present was not so distinct. At low sugar concentrations a lowering of the pH from 8.5 to 7.0 or lower produced a slight increase in heat stability; at higher sugar concentrations the effect of pH was hardly observable.

Tests conducted with polyhydric alcohols indicated that although they apparently increased the beating power prior to heat treatment, only glycerol and mannitol had any stabilizing effect. In fact ethylene glycol, triethylene glycol and polyethylene glycol decreased the heat stability of albumen. These results are not readily explained; one might expect them to act in a way similar to the sugar because of their hydrophilic nature.

## E. Effect of Homogenization

It has been shown that homogenizing the egg white results in an appreciable loss of beating power as indicated by the whip test. The loss appears to be a linear function of homogenization pressure. The addition of sugar or the adjustment of pH to lower levels had no effect on the adverse effects of homogenization.

This loss of beating power may be due to the physical dissolution of certain constituents of egg white. Since mucin exists in a fibrous state homogenization may actually bring about a physico-chemical change in the protein. More work along these lines with specific emphasis on mucin seems essential in order to obtain a better understanding of the problems involved here.

It should be pointed out that the effects of a large number of factors affecting the functional properties of egg albumen were barely explored. Several factors were studied quite thoroughly, others were barely touched. Undoubtedly, much more work should be done to determine the effect of these various factors on whipping power and angel cake performance.

It is hoped that this study has pointed out certain avenues of approach and that it will stimulate other investigators to study the many problems which have been uncovered. In time this will lead to the application of the results of such investigations to the commercial processing of egg albumen for greater economy and (or) improvements in quality.

## VI. CONCLUSIONS

Results of the experiments described in this study lead to the following conclusions:

1. The whip test is a sensitive and reproducible criterion for measuring changes occurring in egg white when subjected to various treatments such as heating, acidification and homogenization.
2. There is a definite though imperfect correlation between the whip test and angel cake performance.
3. Heating egg white to temperatures of 142°F. or higher results in a rapid loss of whipping power and angel cake making properties.
4. Holding egg albumen at a temperature of 120°F. for one or more hours also causes losses in its whipping properties. Lowering the pH of egg white to 6.0 - 7.0 results in an increased stability of the egg white to heat.
5. The addition of sucrose, glucose, lactose, maltose, glycerol and mannitol increases the stability of egg albumen to heat as reflected by the results with the whip test. Sugars having the free aldehyde group (glucose, lactose and maltose) are more effective than are those with non-reducing groups. The stabilizing effect varies directly with the sugar concentration.
6. The effect of pH on heat stability of sugared egg white

was significant at low sugar concentrations. Above 20 percent sugar little increase in heat stability was observed when the pH was lowered from 8.5 to the 6.5 - 7.5 range.

7. Adjusting the pH of liquid albumen by direct addition of acid or by fermentation below 6.6 results in losses of beating property and in angel cake performance.
8. The addition of glycols to egg white increases the beating power prior to any treatment but decreases its stability to heat.
9. Salt in concentrations up to 2.0 percent has a slight effect on increasing the heat stability of egg white.
10. Homogenization of egg albumen decreases its whipping power and performance in cakes. The addition of sugar or adjustments in pH does not alter the effects of homogenization.

## VII. SUMMARY

A study has been made of some factors affecting the beating and leavening properties of egg albumen.

A whip test, which fairly accurately measures the property of egg albumen to perform in angel cake was devised and used. This test was an accurate measure of changes in egg white resulting from certain treatments such as heating, acidification, fermentation and homogenization. The test was capable of showing slight differences in treatment and correlated fairly closely with actual performance of the white in angel cake. However, many factors affect the relationship between the whipping test and the angel cake performance. Good correlation holds only under certain specified and tested conditions to certain limitations. It is necessary to determine the correlation of the whip test and angel cake performance with each specific treatment so that erroneous conclusions will not be drawn.

It was found that fresh egg white loses its foaming property when heated to 142°F. Holding periods in excess of 30 seconds at 140°F. resulted in a loss in angel cake performance. Holding times at a temperature of 120°F. for one hour or more resulted in similar losses in beating and cake performance.

Lowering the pH of egg white from 8.5 to 7.0 - 6.0 by

acid results in a slight loss of beating capacity. However, the stability to heat is definitely increased by such adjustments. Fermentation also lowers the pH of egg white but the loss of beating power in this case is not observed until a pH of 6.6 or lower is reached.

The addition of sugars to egg white resulted in a definite beneficial effect on its functional properties when subjected to various treatments. Sucrose exhibited a marked heat stabilizing effect on egg white. The stabilization to heat increased with increase in sugar concentration.

It was also shown that at the same concentrations, glucose, lactose and maltose were more effective in stabilizing the egg white to heat than were sucrose and mannitol. Glycerol exhibited the same effect as did sucrose. Ethylene glycol, triethylene glycol and polyethylene glycol, although increasing the beating power of egg white prior to heat treatment had an adverse effect on heating. The loss of whipping property was greater on heating when these glycols were added than when the egg white was heated alone.

The addition of sugars to egg white increased the whipping power. Sugar also permitted the pH of egg white to be lowered to 6.5 without impairing the initial foaming capacity.

The addition of sodium chloride in concentrations up to 1.0 percent had no effect on the initial foaming rate of egg white. When subjected to heat, however, these low concentrations did show a slight stabilizing effect.

It is suggested that the results of this study indicate that mucin plays an important role in the whipping property and angel cake performance of egg white. Adjusting the pH to near the isoelectric point of mucin results in a loss in cake performance. In addition when thick white (containing a majority of mucin) is heated a greater loss in whipping property occurred than when heating thin white.

Homogenization resulted in a definite loss of whipping capacity; this effect varied with the homogenization pressure used. The addition of sugar and lowering the pH did not have any beneficial effect when homogenization was used. Angel cake performance did not always correlate the beating test. For instance, satisfactory cakes were made from egg whites homogenized at low pressures. However, when high homogenizing pressures were used unsatisfactory cake performance resulted.

## VIII. LITERATURE CITED


1. Almquist, H. J. and Lorenz, F. W. Liquifaction of egg whites. U. S. Egg and Poultry Mag. 38, No. 4:20-23. 1932.

2. Anson, M. L. and Mirsky, A. E. The effect of denaturation on the viscosity of protein systems. J. Gen. Physiol. 15:341-350. 1932.

3. Bailey, M. I. Foaming of egg white. Ind. Eng. Chem. 27: 973-976. 1935.

4. Ball, C. D., Hardt, C. R., and Duddles, W. J. The influence of sugars on the formation of sulfhydryl groups in heat denaturation and heat coagulation of egg albumin. J. Biol. Chem. 151:163-169. 1943.

5. Balls, A. K. and Hoover S. R. Behavior of ovomucin in the liquifaction of egg white. Ind. Eng. Chem. 32:594-596. 1940.

6. Balls, A. K. and Swenson, T. L. Dried egg white. Food Research 1:319-324. 1936.

7. Ballou, G. A., Boyer, P. D., Luck, J. M., and Funston, G. L. The heat coagulation of human serum albumin. J. Biol. Chem. 153:589-605. 1944.

8. Bancroft, W. D., and Rutzler, J. E. Jr. The denaturation of albumin. I. Denaturation by heat. J. Phys. Chem. 35: 144. 1931.

9. Barker, H. A. The effect of water content upon the rate of heat denaturation of crystallizable egg albumin. J. Gen. Physiol. 17:21-34. 1933.

10. Barmore, M. A. The influence of chemical and physical factors on egg white foams. Colo. Agr. Exp. Sta. Tech. Bul. No. 9. 1934.

11. ______________________The influence of various factors, including altitude, in the production of angel food cake. Colo. Agr. Exp. Sta. Tech. Bul. No. 15. 1936.

12. Barrot, H. C. and McNally, E. H. Heat treating shell eggs; opacity and infertility produced by thermostabilization process at 125°F. and 144°F. U. S. Egg and Poultry Mag. 49:320-322. 1943.

13. Beilinsson, A. Thermostabilisation der eiweisslosungen mit rohrzucker und glycerin. Biochem. Z. 213:399-405. 1929.

14. Bennion, E. B., Hawthorne, J. R., and Bate - Smith, E. C. Beating and baking properties of dried egg. J. Soc. Chem. Ind. 61:31-34. 1942.

15. Best, L. R. Some factors affecting the production and storage of low moisture dried eggs. Unpublished M. S. Thesis, Library. Iowa State College. Ames, Iowa. 1944.

16. Block, R. J. The chemical constitution of the proteins. In Schmidt, C. L. A., Ed. The Chemistry of The Amino Acids and Proteins, 2nd ed. pp. 287-288. Springfield. Charles C. Thomas. 1944.

17. Bovie, W. T. and Woolpert, O. C. The inhibition of coagulation in albumin solutions produced by radiation. Science. 60:70. 1924.

18. Bridgman, P. W. The coagulation of albumin by pressure. J. Biol. Chem. 19:511-512. 1914.

19. Brooks, J. and Hawthorne, J. R. Dried Egg. IV. Addition of carbohydrates to egg pulp before drying. A method of retarding the effects of storage at high temperatures and of improving the aerating power of spray-dried eggs. J. Soc. Chem. Ind. 62:165-167. 1943.

20. Brosteaux, J. and Eriksson-Quensel, I. B. Etude sur la dessication des proteins. Arch. Phys. Biol. 12:209-226. 1935.

21. Bull, H. B. Viscosity of solutions of denatured and of native egg albumin. J. Biol. Chem. 133:39-40. 1940.

22. Bumzahnov, A. D. The dehydration of egg products. U. S. Egg and Poultry Mag. 50:259-262, 277, 282, 284-285, 312-315, 327-334, 356-358, 374. 1944.

23. Chick, H. and Martin, C. J. On the heat coagulation of proteins. J. Physiol. 40:404-430. 1910.

24. Conrad, R. M. and Scott, H. M. Changes in ovomucin gel of egg white. Poultry Sci. 22:25-29. 1943.

25. Duddles, W. J. The effect of sugars and mannitol upon coagulation of egg albumin. Unpublished M. S. Thesis, Mich. State College. 1932.

26. Eggs and Egg Products. U. S. Dept. of Agriculture. Circular No. 583. 1941.

27. Epstein, A. K. Eggs, their property and their function in cake baking. U. S. Egg and Poultry Mag. 37, No. 10: 56, 57, 74-76, 78-80. 1931.

28. ________________ Pasteurization of egg meat for drying purposes. Proceedings of Dried Egg School Held at Kansas City, Missouri. 1941. Mimeograph.

29. Funk, E. M. Stabilizing quality in shell eggs. Missouri Agr. Exp. Sta. Res. Bul. No. 362. 1943.

30. ________________ Pasteurization of shell eggs. Missouri Agr. Exp. Sta. Res. Bul. No. 364. 1943.

31. Glabau, C. A. Angel cake. III. Effect of the specific gravity of the meringue on angel cake. Bakers' Weekly 65:64-68. 1930.

32. Hanning, F. M. Effect of sugar or salt upon denaturation produced by beating and upon the ease of formation and the stability of egg white foams. Ph. D. Thesis. Library, Iowa State College. Ames, Iowa. 1944.

33. Hanson, H. L. Effect of concentrating egg white on desirability of angel cake. Unpublished Ph. D. Thesis, Library, Iowa State College, Ames, Iowa. 1945.

34. Harris, L. J. On the existence of an unidentified sulfur grouping in the protein molecule. Part 1. On the denaturation of proteins. Proc. Roy. Soc. London 94B:426-441. 1923.

35. Hay, R. L. and Pearce, J. A. Dried whole egg powder. XIX. Accelerated storage tests to assess the effect of heat treatment, moisture content, and materials on the quality of dried sugar-egg mixtures. Canadian Journal of Research F, 24:168-182. 1946.

36. Hedstrom, L. Angel Cake I. The effect of consistency of the egg white upon volume and texture. Unpublished M. S. Thesis, Library, Iowa State College, Ames, Iowa. 1933.

37. Heidelberger, M., Davis, B. and Treffers, H. P. Phosphorylated egg albumin. J. Am. Chem. Soc. 63:498-503. 1941.

38. Hendrix, B. M. and Wharton, P. S. The effect of variation of pH upon the process of heat denaturation of egg albumin. J. Biol. Chem. 105:633-642. 1934.

39. Henry, W. C. and Barbour, A. D. Beating properties of egg white. Ind. Eng. Chem. 25:1054-1058. 1933.

40. Holst, W. F. and Almquist, H. J. Measurement of deterioration in the stored hen's egg. Hilgardia 6:49-60. 1931.

41. ______________ ______________ Constancy of specific rotation with age in material egg white. Poultry Sci. 11:81. 1932.

42. Hunt, L. W. and St. John, J. L. Angel cake from the thick and thin portions of egg white. J. Home. Econ. 23:1151-1156. 1931.

43. Iwanosky, N. Uber die einwirkung des glycerins auf huhnereiweiss beim erhitzen. Biochem. Z. 257:57-61. 1933.

44. King, F. B., Morris, H. P. and Whiteman, R. F. Some methods and apparatus used in measuring the quality of eggs for cake making. Cereal Chem. 13:37-49. 1936.

45. Kline, R. W. Dried egg albumen. I. Studies of the non-microbiological changes during storage. Unpublished Ph. D. Thesis. Library, Iowa State College, Ames, Iowa. 1945.

46. Kruyt, H. R. and deJong, J. R. Zur kenntnis der lyophilen kolloide. Die hitzekoagulation die eialbumins. Kolloid - Beihefte 40:55-86. 1934.

47. Le Clerc, J. A. and Bailey, L. H. Freshly frozen and dried eggs and egg products. Cereal Chem. 17:279-312. 1940.

48. Leighton, A. and Mudge, C. S. On the endothermic reaction which accompanies the appearance of visible curd in milk coagulated by heat. J. Biol. Chem. 56:53-73. 1923.

49. Lepeschkin, W. W. The heat coagulation of proteins. Biochem. J. 16:678-701. 1922.

50. Lewis, P. S. The kinetics of protein denaturation. II. Biochem. J. 20:978-983. 1926.

51. Loughlin, W. J. and Lewis, W. C. M. The denaturation of proteins. VIII. The effects of denaturation on the viscosity of solutions of certain proteins. Biochem. J. 26:476-485. 1932.

52. Lundgren, H. P. and O'Connell, R. A. Artificial fibers from corpuscular and fibrous proteins. Ind. Eng. Chem. 36:370-374. 1944.

53. McNally, E. H. Relative amount of mucin in thick and thin egg white. Proc. Soc. Exptl. Biol. Med. 30:1254-1255. 1933.

54. ______________ Some characteristics of the ovomucin gel of egg white. Poultry Sci. 22:25-29. 1943.

55. Markevich, I. T. The colloidal properties of albumin in the presence of alcohol and sugar. Bull. inst. colloides Voronege No. 1, 22-25. 1934. Original not seen: abstracted in C. A. 32:4048. 1938.

56. Miller, E. L., and Vail, G. E. Angel food cakes made from fresh and frozen egg whites. Cereal Chem. 20: 528-535. 1943.

57. Moran, T. Gas storage of eggs. J. Soc. Chem. Ind. 56: 96T-100T. 1937.

58. Mulvaney, H. A. How eggs are dried - methods and standards. Food Industries 13, No. 12:50-53. 1941.

59. Pauli, Wo. and Weissbrod, J. Uber beiziehungen zwischen kolloiden und konstitutiven anderungen einiger protein. IV. Hitzegerinnung und kolloider aufbau der albumine. Kolloid-Beihefte 42:429-462. 1935.

60. Payawal, S. R., Lowe, Belle, and Stewart, G. F. Pasteurization of liquid-egg products. II. Effect of heat treatments on appearance and viscosity. Food Research 11: 246-260. 1946.

61. Peter, P. N. and Bell, R. W. Normal and modified foaming properties of whey protein and egg albumin solutions. Ind. Eng. Chem. 22:1124-1128. 1930.

62. Przylecki, St. J. V. and Cichocka, J. Untersuchungn uber kovalenzartige symplexe aus kohlenhydraten und eiweisskorpern. II. Verbindungen zwis chen lysinresten und reduzierenden zuckern. Biochem. Z. 299:92-99. 1938.

63. Pyke, W. E. and Johnson, C. Relationship between certain physical measurements upon fresh and stored eggs and their behavior in the preparation and baking of cake. Poultry Sci. 20:125-138. 1941.

64. Romanoff, A. L. and Romanoff, A. J. A study of preservation of eggs by flash heat treatment. Food Research 9:350-366. 1944.

65. Ruprecht, Karl. Die Fabrikation von Albumin und Eier -- Konserven pp. 88-108. A. Hartleben, Wien und Leipzig, 1928.

66. Schaible, P. V., Moore, J. M. and Davidson, V. A. A note on the structure of egg white. U. S. Egg and Poultry Mag. 41: No. 12, 38-39. 1935.

67. Sharp, P. F. and Powell, C. K. Physico - chemical factors influencing the keeping quality of hen's eggs in storage. World's Poultry Congress, Ottawa, Canada. Report of Proceedings 1927:309-402. 1928.

68. ________________The pH of the white as an important factor influencing the keeping quality of hen's eggs. Science 69:278-280. 1929.

69. ________________and Stewart, G. F. Carbon dioxide and the keeping quality of eggs. U. S. Egg and Poultry Mag. 37, No. 6:30-32, 63, 65, 66, 68. 1931.

70. ________________and Powell, C. K. Increase in the pH of the white and yolk of hen's eggs. Ind. Eng. Chem. 23:196-199. 1931.

71. ________________Preservation and storage of hen's eggs. Food Research 2:477. 1937.

72. Stewart, G. F., Gans, A. R., and Sharp, P. F. The relation of the percentage of thin white to interior quality as determined by candling and from the opened egg. U. S. Egg and Poultry Mag. 38, No. 8:14-18. 1932.

73. ____________and Kline, R. W. Dried egg albumen. I. Solubility and color denaturation. Proc. Inst. Food Technologists 1941:48-56. 1941.

74. St. John, J. L. and Flor, I. H. A study of whipping and coagulation of eggs of varying quality. Poultry Sci. 10:71-82. 1931.

75. Stuart, L. S. and Goresline, H. E. Bacteriological studies on the natural fermentation process of preparing egg white for drying. J. Bact. 44:541-549. 1942.

76. Townley, R. C. and Gould, I. A. A quantitative study of heat labile sulfides of milk. III. Influence of pH, added compounds, homogenization and sunlight. J. Dairy Sci. 26:853-867. 1943.

77. Wilhelm, L. A. and Heiman, V. The effect of temperature and time on the interior quality of eggs. U. S. Egg and Poultry Mag. 44:661-663, 712. 1938.

78. Wilkin, M. and Winter, A. R. Pasteurizing liquid egg yolk and white. Manuscript submitted to Poultry Sci.

79. Winter, A. R., Greco, P. A. and Stewart, G. F. Pasteurization of liquid-egg products. I. Bacteria reduction in liquid whole egg and improvement in keeping quality. Food Research 11:229-245. 1946.

80. Winter, A. R. and Stewart, G. F. Pasteurization of liquid-egg products. III. Destruction of Salmonella in liquid whole egg. Am. J. of Pub. Health 36:451-460. 1946.

## IX. ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. George F. Stewart for his continued interest and guidance throughout this study andto Mr. Victor Conquest of Armour and Company, Chicago, Illinois, for financial support of the work. The writer also wishes to express his gratitude to Dr. Helen Hanson and Mrs. Betty Stepp for their cooperation in baking the angel cakes used in this study and to the other members of the Poultry Products Laboratory Staff for their interest and valuable assistance.

# X. APPENDIX

TABLE 9

EFFECT OF INSTANTANEOUS HEAT TREATMENT ON BEATING POWER OF EGG ALBUMEN

| Temperature °F. | Specific Gravity of Foam |
|---|---|
| Control | 0.175 |
| 125 | 0.158 |
| 130 | 0.160 |
| 133 | 0.160 |
| 135 | 0.160 |
| 138 | 0.167 |
| 140 | 0.169 |
| 141 | 0.170 |
| 142 | 0.171 |
| 144 | 0.188 |
| 145 | 0.203 |
| 146 | 0.230 |

TABLE 10

EFFECT OF INSTANTANEOUS HEAT TREATMENT ON BEATING POWER OF EGG ALBUMEN

| Temperature °F. | Specific Gravity of Foam |
|---|---|
| Control | 0.153 |
| 140 | 0.171 |
| 142 | 0.173 |
| 144 | 0.200 |
| 145 | 0.231 |
| 146* | 0.350 |

*Coagulated in heating tube.

TABLE 11

EFFECT OF HOLDING TIME AT VARIOUS TEMPERATURES ON THE BEATING PROPERTY* OF EGG ALBUMEN

| Temp. °F. | Time in Seconds 0 | 3** | 15 | 30 | 60 | 90 | 120 | 180 | 240 |
|---|---|---|---|---|---|---|---|---|---|
| 120 | 0.150 | -- | 0.150 | -- | 0.167 | -- | 0.170 | -- | 0.173 |
| 125 | 0.158 | -- | -- | 0.170 | 0.168 | -- | 0.178 | -- | 0.188 |
| 130 | 0.150 | -- | 0.160 | 0.172 | -- | 0.182 | 0.208 | -- | 0.245 |
| 134 | 0.154 | -- | -- | 0.157 | 0.200 | 0.210 | 0.230 | 0.260 | -- |
| 135 | 0.148 | -- | 0.155 | 0.190 | 0.245 | 0.283 | -- | -- | -- |
| 137 | 0.160 | 0.175 | -- | 0.220 | 0.260 | 0.292 | -- | -- | -- |
| 140 | 0.160 | 0.180 | 0.275 | -- | -- | -- | -- | -- | -- |

*Specific Gravity of Foam
**Time to heat egg white to desired temperature - no actual holding time.

TABLE 12

EFFECT OF HOLDING TIME AT VARIOUS TEMPERATURES ON

THE BEATING PROPERTY* OF EGG ALBUMEN

| | Time in Hours | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. $^{o}$F. | 0 | 0.1 | 0.25 | 0.5 | 1.0 | 1.5 | 2 | 3 | 4 | 5 | 6 |
| 105 | 0.161 | -- | -- | -- | 0.161 | -- | 0.163 | -- | -- | -- | 0.171 |
| 110 | 0.161 | -- | -- | -- | 0.165 | -- | 0.167 | -- | -- | 0.175 | 0.177 |
| 115 | 0.161 | -- | -- | 0.165 | 0.169 | -- | 0.188 | -- | 0.220 | 0.230 | -- |
| 120 | 0.160 | -- | -- | 0.184 | 0.205 | 0.225 | -- | -- | -- | -- | -- |
| 125 | 0.158 | 0.178 | 0.230 | -- | -- | -- | -- | -- | -- | -- | -- |

*Specific Gravity of Foam

TABLE 16

EFFECT OF pH ON WHIPPING POWER OF EGG ALBUMEN

| Sample | pH | Specific Gravity of Foam |
|---|---|---|
| 1 | 8.4* | 0.155 |
| | 8.0** | 0.158 |
| | 7.0** | 0.190 |
| | 6.1** | 0.223 |
| | 5.6** | 0.262 |
| | 9.9*** | 0.195 |
| 2 | 8.7* | 0.183 |
| | 7.8** | 0.190 |
| | 7.4** | 0.191 |
| | 6.9** | 0.197 |
| 3 | 8.6* | 0.155 |
| | 8.0** | 0.158 |
| | 7.0** | 0.190 |
| | 6.0** | 0.225 |
| | 5.5** | 0.262 |
| | 10.0*** | 0.197 |
| 4 | 8.6* | 0.151 |
| | 7.5** | 0.171 |
| | 7.0** | 0.183 |
| | 6.5** | 0.187 |
| 5 | 8.4* | 0.150 |
| | 9.4*** | 0.171 |
| | 10.4*** | 0.213 |

*Control
**HCl
***NaOH

TABLE 19

EFFECT OF pH CHANGE DURING FERMENTATION ON
BEATING POWER OF EGG ALBUMEN

| Sample | pH | Specific Gravity of Foam |
|---|---|---|
| 1 | 8.35 | 0.150 |
| 2 | 8.0 | 0.150 |
| 3 | 7.7 | 0.153 |
| 4 | 7.4 | 0.157 |
| 5 | 7.15 | 0.163 |
| 6 | 6.9 | 0.163 |
| 7 | 6.75 | 0.170 |
| 8 | 6.5 | 0.177 |
| 9 | 6.8 | 0.177 |
| 10 | 7.0 | 0.173 |
| 11 | 7.1 | 0.181 |
| 12 | 7.7 | 0.181 |
| 13 | 7.8 | 0.180 |
| 14 | 8.0 | 0.181 |
| 15 | 8.1 | 0.173 |

TABLE 25

EFFECT OF SUCROSE CONCENTRATION ON BEATING PROPERTY* OF HEATED EGG ALBUMEN

| | % Sugar | | | | | | |
|---|---|---|---|---|---|---|---|
| Temp. °F. | 0 | 10 | 20 | 30 | 40 | 50 | 60 |
| 70 | 0.155 | 0.147 | 0.147 | 0.143 | 0.141 | 0.150 | 0.168 |
| 140 | 0.170 | 0.157 | 0.155 | 0.150 | 0.150 | 0.153 | 0.160 |
| 142 | 0.175 | | | | | | |
| 144 | 0.200 | | | | | | |
| 145 | 0.235 | | | | | | |
| 150 | | 0.175 | 0.158 | 0.155 | 0.153 | 0.157 | 0.168 |
| 153 | | 0.255 | | | | | |
| 154 | | | 0.163 | 0.160 | | | |
| 155 | | | 0.200 | | 0.158 | 0.167 | 0.172 |
| 158 | | | | 0.172 | | | |
| 159 | | | | 0.175 | | | |
| 160 | | | | 0.183 | 0.162 | | |
| 161 | | | | | 0.175 | 0.172 | |
| 162 | | | | | | 0.183 | 0.177 |
| 164 | | | | | | 0.235 | 0.195 |
| 166 | | | | | | | 0.217 |

*Specific Gravity of Foam

TABLE 26

EFFECT OF HOLDING TIME AT 120°F. ON BEATING POWER* OF LIQUID EGG WHITE CONTAINING VARIOUS SUCROSE CONCENTRATIONS

| | Time in Hours | | |
|---|---|---|---|
| Sucrose - % | 0 | 1 | 2 |
| 0 | 0.170 | 0.233 | 0.250 |
| 1 | 0.168 | 0.203 | 0.237 |
| 2 | 0.168 | 0.198 | 0.227 |
| 5 | 0.165 | 0.177 | 0.200 |
| 10 | 0.163 | 0.175 | 0.190 |
| 15 | 0.162 | 0.173 | 0.180 |
| 20 | 0.160 | 0.168 | 0.175 |
| 25 | 0.158 | 0.161 | 0.170 |
| 30 | 0.150 | 0.155 | 0.155 |
| 40 | 0.150 | 0.153 | 0.150 |
| 50 | 0.153 | 0.155 | 0.150 |
| 60 | 0.168 | 0.170 | 0.168 |
| 77 | 0.266 | 0.205 | 0.193 |

*Specific Gravity of Foam

TABLE 27

EFFECT OF pH AND SUGAR CONCENTRATION ON WHIPPING CAPACITY* OF LIQUID EGG ALBUMEN AFTER HEATING AT 120°F.

| | pH | | | | pH | | | |
|---|---|---|---|---|---|---|---|---|
| % Sucrose | 8.5 | 7.5 | 7.0 | 6.5 | 8.5 | 7.5 | 7.0 | 6.5 |
| | Control | | | | Heated - 6 hr. | | | |
| 0 | 0.173 | 0.171 | 0.183 | 0.185 | 0.302 | 0.192 | 0.180 | 0.192 |
| 10 | 0.153 | 0.145 | 0.167 | 0.173 | 0.185 | 0.167 | 0.171 | 0.171 |
| 20 | 0.141 | 0.140 | 0.138 | 0.150 | 0.155 | 0.153 | 0.151 | 0.151 |
| 30 | 0.140 | 0.141 | 0.140 | 0.150 | 0.160 | 0.151 | 0.150 | 0.150 |
| 40 | 0.148 | 0.147 | 0.141 | 0.148 | 0.157 | 0.151 | 0.147 | 0.150 |
| 50 | 0.140 | 0.140 | 0.140 | 0.147 | 0.153 | 0.148 | 0.145 | 0.140 |
| 60 | 0.163 | 0.155 | 0.151 | 0.153 | 0.153 | 0.151 | 0.148 | 0.148 |
| 70 | 0.225 | 0.181 | 0.167 | 0.167 | 0.170 | 0.163 | 0.170 | 0.167 |
| 77 | 0.195 | 0.167 | 0.158 | 0.161 | 0.165 | 0.157 | 0.157 | 0.161 |

TABLE 27

(continued)

| % Sucrose | pH 8.5 | pH 7.5 | pH 7.0 | pH 6.5 | pH 8.5 | pH 7.5 | pH 7.0 | pH 6.5 |
|---|---|---|---|---|---|---|---|---|
| | Heated - 12 hr. | | | | Heated - 24 hr. | | | |
| 0 | 0.345 | 0.225 | 0.202 | 0.196 | 0.392 | 0.265 | 0.232 | 0.203 |
| 10 | 0.216 | 0.175 | 0.177 | 0.173 | 0.242 | 0.187 | 0.200 | 0.190 |
| 20 | 0.163 | 0.153 | 0.153 | 0.155 | 0.167 | 0.153 | 0.167 | 0.163 |
| 30 | 0.163 | 0.153 | 0.150 | 0.158 | 0.167 | 0.160 | 0.158 | 0.167 |
| 40 | 0.157 | 0.143 | 0.150 | 0.150 | 0.161 | 0.155 | 0.155 | 0.158 |
| 50 | 0.157 | 0.150 | 0.147 | 0.145 | 0.155 | 0.143 | 0.147 | 0.147 |
| 60 | 0.158 | 0.151 | 0.150 | 0.148 | 0.155 | 0.150 | 0.148 | 0.148 |
| 70 | 0.177 | 0.167 | 0.167 | 0.167 | 0.178 | 0.161 | 0.160 | 0.160 |
| 77 | 0.163 | 0.158 | 0.158 | 0.158 | 0.167 | 0.157 | 0.157 | 0.153 |

*Specific Gravity of Foam

TABLE 40

EFFECT OF HOMOGENIZATION ON BEATING

PROPERTY* OF EGG ALBUMEN

| Pressure lbs. per sq. in. | Run 1 | Run 2 |
|---|---|---|
| 0 | 0.178 | 0.171 |
| 1000 | 0.245 | 0.255 |
| 2000 | 0.275 | 0.275 |
| 3000 | 0.325 | 0.330 |
| 4000 | 0.342 | 0.355 |

*Specific Gravity of Foam