This is to certify that the

thesis entitled

STUDY OF FACTORS INFLUENCING
THE PHYSICAL PROPERTIES OF
FREEZE-DRIED DIRECT SET YOGURT

presented by

Katsuyuki Shirohata

has been accepted towards fulfillment
of the requirements for

MASTER degree in FOOD SCIENCE
and HUMAN NUTRITION

Charles M Stine
Major professor

Date May 11, 1987

STUDY OF FACTORS INFLUENCING THE PHYSICAL PROPERTIES OF FREEZE-DRIED DIRECT SET YOGURT

By

Katsuyuki Shirohata

A THESIS

Submitted to

Michigan State University

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

Department of Food Science and Human Nutrition

1987

ABSTRACT

STUDY OF FACTORS INFLUENCING THE PHYSICAL PROPERTIES OF FREEZE-DRIED DIRECT SET YOGURT

By

Katsuyuki Shirohata

Some process factors influencing the physical properties of freeze-dried direct set yogurts were studied. An acceptable, fresh direct set yogurt having good body and texture was obtained without cultures by using glucono delta lactone as an acidogen, but freeze-drying process caused the loss of typical body and texture.

In order to investigate this problem, many yogurts were prepared by varying parameters such as fat and solids not fat (SNF) content, stabilizers, heat treatment and pH. Physical properties of the various yogurts so prepared were examined by use of the penetrometer and the Brookfield viscometer.

The effects of these variables on the characteristics of the reconstituted products were generally similar to the effects observed with fresh fermented yogurts. However, some additional fortification of the yogurt with milk solids and stabilizers was indispensable to compensate for the physical loss of structure due to freezing and dehydration.

ACKNOWLEDGMENTS

The author would like to express his sincere thanks to his adviser, Dr. C.M. Stine, for his advice and guidance throughout this study and in the preparation of this manuscript.

Appreciation is extended to his committee members: Dr. E.K. Beneke, Dr. P. Markakis, Dr. J.A. Partridge, for their critical review of this manuscript. Sincere thanks are extended to Dr. J.R. Brunner and Dr. M.A. Filadelfi for their critical advice.

The author also wishes to express his thanks to Mr. K. Nakrani and Mr. S.T. Hong as well as Mrs. Colleen Wood and to many graduate students for their help.

Appreciation is also extended to many colleagues at Snow Brand Milk Products Co., Ltd. for providing the opportunity to carry out this research work.

Lastly, he wishes to thank his wife for her help and encouragement during the course of his graduate studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

INTRODUCTION

Yogurt is one of the most appealing dairy products because of its pleasant taste and high nutritional value.

A wide range of flavored yogurts, particularly fruit yogurt, has stimulated increased consumption of this fermented food product. In addition, yogurt-based products such as yogurt-like desserts, yogurt drink and salad dressing, have appeared on the market as a result of technological improvements and better understanding of the factors affecting the physical and chemical properties of yogurt.

One concern in yogurt production is the problem of uniform production from day to day because of difficulties in controlling rate of bacterial growth and in protecting the culture from contamination. The use of a chemical acidogen to attain the desired pH obviates this problem.

Meanwhile the change of life-style has encouraged the food industry to produce "instant" and "convenience" type foods. The food industry responds to the demand for such products through product development and constant research effort to improve quality.

Interest in freeze-drying products has been increasing, because freeze-drying usually produces a superior product compared with products dehydrated by other means (Stein, 1966). Loss of typical body and texture, however, is often observed as a result of freeze-drying.

The goal of this research was to investigate the use of an acidogen in preparing a direct set or imitation yogurt for subsequent freeze-drying and evaluate means of preserving body and texture in the reconstituted product.

REVIEW OF LITERATURE

Yogurt

Yogurt is a coagulated milk product produced by lactic acid fermentation by *Lactobacillus bulgaricus* and *Streptococcus thermophilus* growing symbiotically. The advantage of using mixed cultures was well reviewed by Wong et al. (1982). Generally, more than one culture is used for commercial yogurt production though Marshall et al. (1982) indicated that single starter yogurts with some chemical additive had acceptable acidities, acetaldehyde level and good quality.

There are two main types of yogurt, set and stirred yogurt, which depend on the process method and on the physical structure of the coagulum. Set yogurt, which is fermented in the retail container, is in a continuous semi-solid mass. On the other hand, the stirred yogurt is coagulated in bulk and its gel structure is broken before cooling and packaging. Another method to be used to differentiate various types of yogurt is flavoring difference. There are three categories: plain, fruit and flavor yogurt.

Nutritional Value of Yogurt

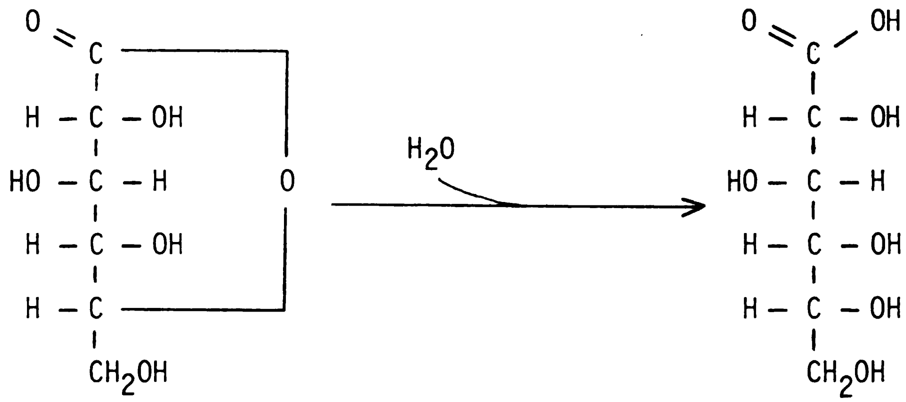
According to Rasic et al. (1978), the chemical changes of milk constituents during fermentation result in reducing the content of lactose and the formation of lactic acid, in increasing the content of free peptides, amino acids and fatty acids and in considerable changes of content of some vitamins. There are some fermentative changes in milk constituents that may give yogurt nutritional superiority over milk due to superior digestibility (Rasic and Kurmann, 1978; Tamime and Deeth, 1980; and Broussalian and Westhoff, 1983). However, Wong (1983) suggested the growth stimulating factor of rats that were fed yogurt was within the cells of *Streptococcus thermophilus* and did not depend upon fermentation of milk.

Direct Acidification of Dairy Products

For the production of good fermented dairy products such as yogurt and cheese, a correct rate of acidification and degree of acidity is essential. Therefore problems involving the starter organisms may cause severe consequences. This is why alternative methods of acidification are attractive to consider. A successful method would, at one stroke, eliminate the problems of bacteriophage, antibiotics, winter slowness and other difficulties.

Trop (1984) studied pH decrease in milk by various chemical acidogens such as propionic anhydride, lactic acid, glucono delta lactone (GDL), ethyl butyrate with its esterase and glucose with oxidase. According to his research, GDL gave the best coagulation of milk without unfavorable taste.

Glucono Delta Lactone



GDL

Gluconic Acid

Glucono delta lactone (GDL) hydrolyzes to the free acid at a convenient rate (Mabbit et al., 1951). It is readily available, non-toxic and free from other objectionable properties such as insolubility of calcium salts and unpleasant taste. The study of pH decrease of milk by GDL was followed by O'Keeffe et al. (1975). Their data indicated the falling pH depends on the concentration of GDL and the temperature of hydrolysis. pH decrease was relatively rapid and continuous, and about 70% of total pH decrease occurred within 90 minutes. They also reported the advantage of using GDL compared with acidification by starters from the viewpoint of stable and rapid fall in pH. They concluded the merit of yogurt acidified with GDL as follows:

1. rapid pH decrease
2. relatively stability of pH after 90 minutes
3. ease of handling
4. no problems with contamination of a starter culture

Freezing Process

Tremendous amounts of frozen foods can be seen in supermarkets and frozen foods today are one of the most popular food items. One reason is the superiority of freezing as a means of preservation and another is convenience since most of them are preprocessed and precooked. However, freezing process sometimes causes a serious problem to dairy products. Dahle (1941) observed the disruption of the milk fat emulsion by freezing lent to the formation of a surface layer of fat aggregates in the thawed material. This phenomenon was studied by Webb and Hall (1935) in products before being stored. According to Desai et al. (1961), the loss of soluble lactose through crystallization during freezing enhanced destabilization. Wildasin and Doan (1951) studied the effect of hemogenization and preheat treatment on protein stability of frozen milk products.

It has been suggested that ice crystals exert pressure on the suspended milk fat globules and disrupt the colloidal protein suspension during freezing (Doan and Baldwin, 1936).

Dehydration

The storage life of yogurt refers to maintaining its characteristics unaltered until the product is consumed. There are many different methods to accomplish this objective, but dehydration is the most unique and the best method from the viewpoint of storage energy cost, shelf-life and ease of handling. Dried yogurt, which is essentially free of enzymatic and microbial spoilage, can be produced by sun-drying, spray-drying and freeze-drying. In industrial production of dried yogurt by spray-drying or freeze-drying a loss of some flavor compounds was indicated by Tamime and Deeth (1980).

Freeze-Drying

In recent years there has been substantial processing of foods by freeze-drying, and such products are used widely as convenient, "instant" food materials. Freeze-drying is a process of sublimation which removes moisture from frozen products by changing ice to vapor without going through the liquid state, and thus, represents a combination of freezing and drying processes. This combination has great effect on the finished product and a lot of examples have shown to overcome disadvantages caused by using either process alone. The superiority of freeze-drying was well described by Stein (1966) and King (1970). Reconstituted freeze-dried foods are generally superior in flavor and other quality attributes when compared to products dehydrated by more conventional methods.

Desai (1966) studied the effects of different drying methods on some of the physical, chemical and organoleptic properties of cultured cream. She observed the complete loss of the typical body and texture during freeze-drying. However, the retention of volatile flavor compounds was better in the freeze-dried sour cream than in spray-dried sour cream.

One of the big problems in freeze-drying is its high energy cost, which was estimated to be approximately seven times greater than spray-drying (Goldblith, 1965).

pH of Yogurt

pH of yogurt is variable, but it must be below the isoelectric point (pH 4.6), because low acidity in yogurt influences the consistency unfavorably due to insufficient protein hydration and/or charge stabilization of the coacervate. Cooling of yogurt must be carried out within a narrow pH interval, since too slow cooling causes over-ripening, which results in a grainy and sandy structure. On the other hand, cooling too rapidly results in changing in the structure of coagulum with corresponding whey separation due to the very rapid contractions of protein filaments and their disturbed hydration (Kurmann et al., 1978).

Using an acidogen rather than bacterial cultures may help solve the problem of cooling, since pH is relatively stable after 90 minutes. The common pH range of final products is pH 3.7 - 4.3 (O'Neil et al., 1979).

Fat Content of Yogurt

Milk fat favorably affects the various properties of yogurt such as flavor, aroma and viscosity.

Milk fat stabilizes contraction of the protein gel and prevents whey separation in the final product (Rasic and Kurmann, 1978). Regarding the taste, it has been observed that skim milk yogurt is more acid, less mild and less aromatic than whole milk yogurt. Commercial yogurt usually contains at least 1.5% milk fat, since low fat content in the milk also encourages whey separation in yogurt.

Total Solids Content of Yogurt

The level of total solids in the milk is significant for both the consistency and aroma of yogurt. In general, an increase in total solids will enhance these properties (Emmons and Tuckey, 1967). Tamime and Robinson (1983) indicated that the recommended range is 14 - 16% and Kozhev et al. (1972) concluded that the best yogurt was made from milk containing 15.5 - 16.0% total solids since too high fortification with skim milk powder (SMP) causes excessive acid production and some off-flavors (Gennip, 1973).

For this reason the solids not fat (SNF) content of yogurt is recommended in the range 10 - 13% (Jenson and Nielsen, 1982), which means that whole milk is usually fortified with an additional 3 - 4% serum solids.

Mickle (1966) studied the physical stability of reconstituted freeze-dried milk products. According to his research, solids not fat (SNF) improved fat stability and prevented the problem of poor dispersibility of freeze-dried milk products due to the instability of the milk fat emulsion.

Milk Protein as a Source of Additional Solid

Whey protein concentrate (WPC) produced by ultrafiltration or reverse osmosis was used in the manufacture of yogurt by Modler et al. (1983). Adding WPC produced by ultrafiltration of whey resulted in a high quality yogurt.

Caseinate possesses good functional properties such as stabilizing effects in yogurt manufacture. Sodium caseinate is effective in increasing gel strength and reducing syneresis. The effect of adding sodium caseinate and skim milk powder on the viscosity of stirred yogurt was studied by Gennip (1973). According to his research, sodium caseinate demonstrated a much greater effect on the viscosity of yogurt so that three parts of skim milk powder could be replaced by one part of sodium caseinate. Modler et al. (1983), however, indicated that yogurt containing sodium caseinate was less smooth in texture than yogurt containing only serum solids.

Stabilizer

Stabilizers have a multitude of functional properties. They are used as crystallization and syneresis inhibitors, adhesives, viscosity modifiers and as agents for binding, gelling and thickening. They are polymeric substances which gradually hydrate, when dispersed in water, whereby a large number of water molecules are bound, primarily by hydrogen bonding.

Since the addition of stabilizers increases the consistency of a coagulum due to increased water binding, some stabilizers are used in yogurt.

A variety of gums is used in dairy products to control viscosity. Guar gum, which is derived from the seed of the guar plant, is a polygalactomannan gum. It is a good stabilizer for many dairy products due to high solubility at low temperature. Carageenan, which is extracted from seaweeds, is an anionic polysaccharide gum having hydrocolloidal properties. It is commercially employed for increasing the viscosity and stabilizing various aqueous systems.

Pectin, which is obtained from the water-insoluble protopectin of fruit, is widely used in making jam and jellies. It is also useful as a stabilizer and thickener in various kinds of dairy products with particular application in products of low pH such as ices, sherbets and fermented foods.

The microstructure of yogurt with thickening agents such as gelatin, carageenan and starch was studied by Kalab et al. (1975). Scanning electron microscopic observation indicated the arrangement of the micelles and the formation of a protein skeleton which created large free spaces inside the network depending on the type of stabilizers and the mechanical treatments employed.

Stabilizers such as propylene glycol alginate, sodium carboxymethyl cellulose and pectin were used for cultured milk and their effects were studied by Towler (1984). These studies have indicated the usefulness and importance of using various stabilizers in yogurts as an agent which performs gelling and water-binding.

Homogenization in Yogurt Manufacture

Homogenization of yogurt milk has the following advantages (Rasic et al., 1978):

1. no rising of cream during incubation of yogurt milk and uniform distribution of fat
2. improvement of the consistency and viscosity of yogurt
3. greater stability of the coagulum against whey separation

According to Abrahamsen and Holmen (1981), some whey separation and a thin cream layer at the surface was observed in non-homogenized yogurt.

In addition, flavor and physical properties such as curd tension were also inferior to yogurt prepared from homogenized milk. The study of the effect of homogenization and heat treatment on the firmness and viscosity of yogurt by Galesloot (1958) coincided with these observations. Storgards (1964) reported that best results of yogurt were achieved with homogenization of 100 - 200 kg/cm^2 (1420 - 2840 psi) at 50 - 60^{o}C (122 - 140^{o}F).

Heat Treatment of Yogurt Milk

Heat treatment of yogurt milk is extremely important from the viewpoint of improving consistency as well as killing organisms and inactivating naturally occurring enzymes.

In general, milk for yogurt manufacture is preheated at 80 - 85^{o}C (176 - 185^{o}F) for 30 minutes or 90 - 95^{o}C (194 - 203^{o}F) for 5 - 10 minutes. Changes in the protein fraction through heat treatment are critical in determining the stability of the yogurt gel. Davies et al. (1978) and other scientists have considered that the heat treatment of milk resulting in denaturation of beta-lactoglobulin and the association of this protein with micelle surface is an important determinant of micelle fusion and gel strength.

The effects of heat treatment on rheological properties of yogurt were well studied by Labropoulos et al. (1984). According to their study, heat treatment had a definite effect on yogurt body and texture. They suggested good rheological properties, measured by penetrometer value and viscosity could be attributed to increased water-binding capacity of the milk proteins subjected to proper temperature and time relationships.

Flavor of Yogurt

Lactic acid fermentation during yogurt manufacture provides lactic acid as a main component with small quantities of carbonyl compounds, volatile fatty acids and alcohol. Important components as sources of flavor and aroma are carbonyl compounds such as acetaldehyde, diacetyl, acetoin (acetylmetylcarbinol) and acetone. Marshall et al. (1982) and many others have reported the major flavor component of yogurt is acetaldehyde. Typical yogurt flavor is obtained at 30 ppm acetaldehyde, according to Gorner et al. (1973). Fullness of flavor, however, also depends on the presence of other carbonyl components such as acetone and diacetyl, which are produced at very low concentration (Bottazzi et al., 1973). Flavor components can arise from fat, protein or lactose, but those which have important relationships to flavor are formed by microbial fermentation of lactose (Tamime and Deeth, 1980).

Rheological Analysis of Dairy Products

In order to study physical properties of products such as viscosity and gel firmness, rheological analysis is indispensable. Various techniques have been developed and used according to the nature of characteristics to be evaluated.

In the field of dairy products, O'Neil et al. (1979) used the "Curd-O-Meter", an apparatus for measuring curd tension (a second generation version of the Submarine Signal curd tension meter produced eventually by the Raytheon Corporation) and the Brookfield viscometer, which was used to measure viscosity or consistency. A penetrometer used by Hamilton (1970) and Labropoulos et al. (1984) is employed to determine gel firmness by measuring the depth of penetration when a standard cone is dropped into the specimen.

Commercial Instant Yogurt Powder

It has been difficult to product "powdered yogurt" as a commercial product because of the loss of physical properties as well as the high energy cost involved in its production. However, the first instant yogurt including active cultures in the United States has recently been manufactured and introduced by a commercial corporation.

The desirable characteristics of this instant yogurt are claimed to be: extended shelf-life and content of active, viable organisms. The powder, which is called "Instant culture" for its active cultures, is promoted in different flavors. Active cultures may be used for a nutritional contributer, not for a function of coagulation. Mainly, the stabilizer system has the responsibility to form the good body and texture in this instant product. Instant yogurt powder may have the possibility to impact to the dairy industry as "instant coffee" did earlier to the coffee industry.

MATERIALS AND METHODS

Preparation of Fresh Direct Set Yogurt

Some specific conditions were changed each time according to the factors of interest, but the basic procedure (Figure 1) was accomplished as follows:

Standardizing

According to the desired formula, non-fat dry milk (NFDM) (Grade A Low-Heat Spray Non Fat Dry Milk, Michigan Milk Producers Association) and water were added to fresh raw whole milk which was obtained from the Michigan State University Dairy Plant or Michigan State University Dairy Barn. Other additives such as stabilizers, if used, were added and dispersed by means of a blender (Lightnin Mixer 10X, Mixing Equipment Co.) at 1725 RPM.

Heat Treatment (Pasteurization)

The standardized milk inside a container was put in a hot water bath. The milk was heated to, and maintained at, 80^{o}C (176^{o}F) for 30 minutes, unless otherwise specified.

Homogenization

After cooling the milk to 60^{o}C (140^{o}F), the milk was homogenized at 140 kg/cm^2 (2000 psi) by a homogenizer (Type 75K, Manton Gaulin Mfg. Co., Inc.). Although a two-stage homogenizer was used, the second stage was kept at 0 pressure through this research since the fat content of the mix was relatively low and did not require two-stage

Basic Procedure of Direct Set Yogurt

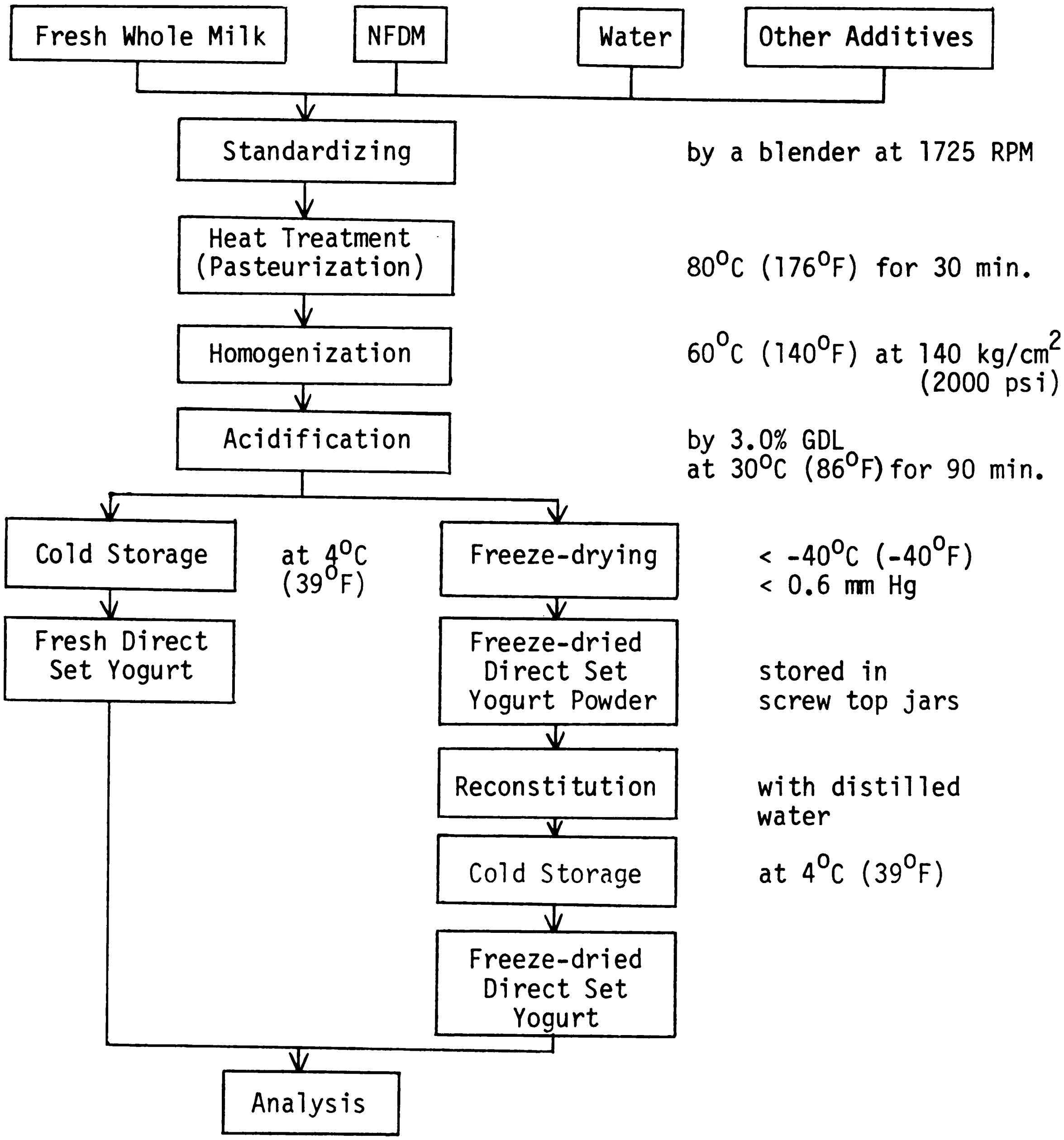


Figure 1. Preparation of samples

homogenization.

Acidification

The homogenized milk was held at 30°C (86°F), unless specified, in a water bath and glucono delta lactone (F.C.C. Coarse Powder, Pfizer INC.) was added to the milk. The mix was initially stirred well and then held quiescent for 90 minutes. The condition of acidification; temperature, amount of glucono delta lactone and time were reviewed early in this thesis.

Freeze-Drying

The fresh direct set yogurt prepared was moved to special stainless trays and spread thinly in order to reduce the depth of yogurt to less than 1 cm. The trays including yogurt were rapidly frozen in a freeze-dryer (Virtis REPP Model FFD 42WS) by direct contact with the platens which were cooled to less than -40°C (-40°F). After freezing was accomplished, the drying process was initiated by lowering absolute pressure to 0.6 mm Hg, or less, by means of a Delco Model 2J4724-Z vacuum pump.

The process of freeze-drying was terminated when the temperature of the platen was between 16°C and 20°C (62°F and 67°F). In order to obtain a powder with less than 5% moisture, twenty-four hours were required for the dehydration process and the rise in temperature was not observed until the end of this process. The freeze-dried direct set yogurt was transferred to screw top jars for storage and subsequent analysis.

Preparation of Samples for Determining Physical Properties

A small portion of fresh direct set yogurt obtained was stored at $4^{O}C$ ($39^{O}F$) for at least 12 hours before analysis to eliminate the temperature influence on the body and texture of yogurt.

The freeze-dried direct set yogurt was reconstituted to the original total solids of the fresh yogurt with distilled water at room temperature. At that time the moisture content of each different sample was taken into consideration when hydrating. The powder and water were weighed into the same beaker on a top loading Mettler balance and mixed by a hand mixer (Mixette Model 97-1, Hamilton Beach). In order to reduce the physical damage to the body of reconstituted yogurt and achieve constant condition, the best procedure was studied early in this research. The mixer was operated at the lowest speed for one minute to achieve a homogeneous yogurt body.

The reconstituted yogurt was refrigerated at $4^{O}C$ ($39^{O}F$) for at least 12 hours before determining physical properties to allow extensive hydration and formation of gel structure and body.

Analytical Methods

Penetrometer Value (PV)

In order to determine the gel firmness of yogurt, a penetrometer ("Precision" Penetrometer, Precision Scientific Co.) was used. The chilled reconstituted yogurts and fresh yogurts which had been held quiescently for at least 12 hours at $4^{O}C$ ($39^{O}F$) were tested in duplicate by this equipment immediately following removal of the sample from the

refrigerator. 550 g fresh direct set and reconstituted direct set yogurts in 600 ml beakers were used for this determination. The tip of the cone was set to the center of yogurt surface in the 600 ml beaker and the cone (weight 102.4 g, diameter 65 mm and height 45 mm) was allowed to penetrate the surface of yogurts for five seconds. The depth of penetration was measured in tenths of millimeters. Readings shown in figures are averages of two determinations.

Consistency Using the Brookfield Viscometer

The consistency of chilled reconstituted yogurt was determined with a viscometer (Brookfield Syncro-lectric Viscometer Model RTV, Brookfield Engineering Laboratories). A modified operation of the method used by O'Neil et al. (1979) was used. The viscometer was operated at 2.5 RPM with a No. 4 spindle which was set in the center of a sample of 300 grams of undisturbed reconstituted yogurt in a 400 ml beaker. Samples were analyzed in duplicate on yogurt equilibrated to $5^{o}C$ ($41^{o}F$) and recorded as centipoises.

Moisture

The percent moisture of the freeze-dried yogurt powder was determined by a vacuum oven method using an oven (Model 524-A, Precision Scientific Co.) attached to a vacuum pump (Duo-Seal) and an analytical digital balance (Mettler, AE160). Approximately 2 g samples were accurately (±0.1 mg) weighed into aluminum moisture dishes and held at $100^{o}C$ ($212^{o}F$) and less than 100 mm Hg absolute pressure for at least five hours until constant weight was obtained. The weight was recorded to four significant figures and averages of triplicate determinations were obtained. These values were then used to calculate the amount of water required for reconstitution to the desired total solids content.

Fat

The fat content of the standardized milk was determined in duplicate by the official Babcock method and the average of two results was used to determine fat content of the standardized milk.

Total Solids

The percent total solids of the standardized milk was determined by a vacuum oven method. Approximately 5 g milk samples were examined in triplicate using the same equipment described earlier. The average of three determinations was used to calculate the total solids content of the standardized milk.

pH

The pH measurements were made with an analog pH meter (Model 301, Orion Research) using a calomel half cell and glass electrode standardized to read accurately in the range of pH 4.0 - 7.0. The reading was made to the nearest 0.1 unit after the system had equilibrated with the electrodes.

Sensory Evaluation

Sensory evaluation of four plain yogurts which were prepared by four different procedures were accomplished to supplement the physical analysis and confirm the sensory properties of these yogurts.

Approximately 2 oz (76 g) samples were placed in 3 oz (113 g) cups at 4.4^{o}C (40^{o}F) and evaluated by a selected panel of 10 trained or semi-trained judges among faculty and graduate students of Michigan State University. The evaluation of the four yogurts was made in the sensory evaluation room, using a hedonic scale with a range of 1 - 7 (Appendix Figure 1).

RESULTS AND DISCUSSION

Study of Glucono Delta Lactone

As a source of chemical acidogen for producing direct set yogurt, glucono delta lactone (GDL) was selected since Trop (1984) concluded GDL was the best acidifying agent among those he evaluated. It has been widely used in the manufacture of acidified dairy foods.

Several factors which relate to the effect of acidogens were examined early in this research work to select optimal conditions for lowering pH.

The Effect of GDL Content

The drop in pH of standardized milk after addition of GDL (Figure 2) follows a pattern similar to that reported by O'Keeffe et al. (1975). The change of pH indicates that 2% or more of GDL is needed to prepare yogurt, since the pH of the final product should be below the isoelectric point of caseins (pH 4.6) in order to form a good firm coagulum.

The Effect of Total Solids Content of the Mix

The decline in pH as a function of total solids content is shown in Figure 3. Due to the buffer capacity of the proteins and salts in the mix greater concentrations of GDL are needed to lower pH as solids not fat (SNF) content increases. It is concluded that larger amounts of GDL should be used as a chemical acidogen in direct set yogurt

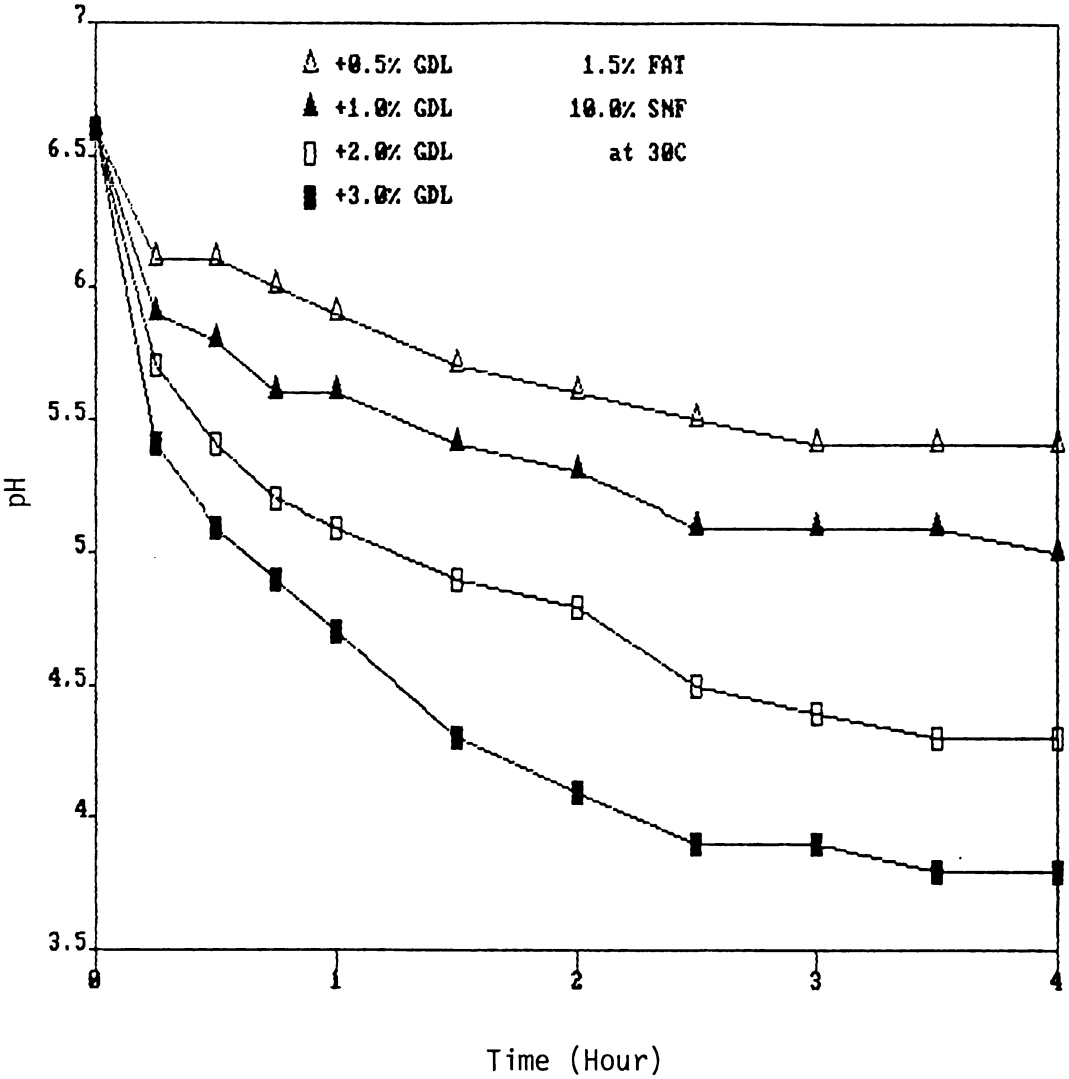


Figure 2. The effect of varying glucono delta lactone (GDL) content on the pH of standardized milk as a function of time; temperature 30°C (Milk standardized to 1.5% fat, 10.0% SNF)

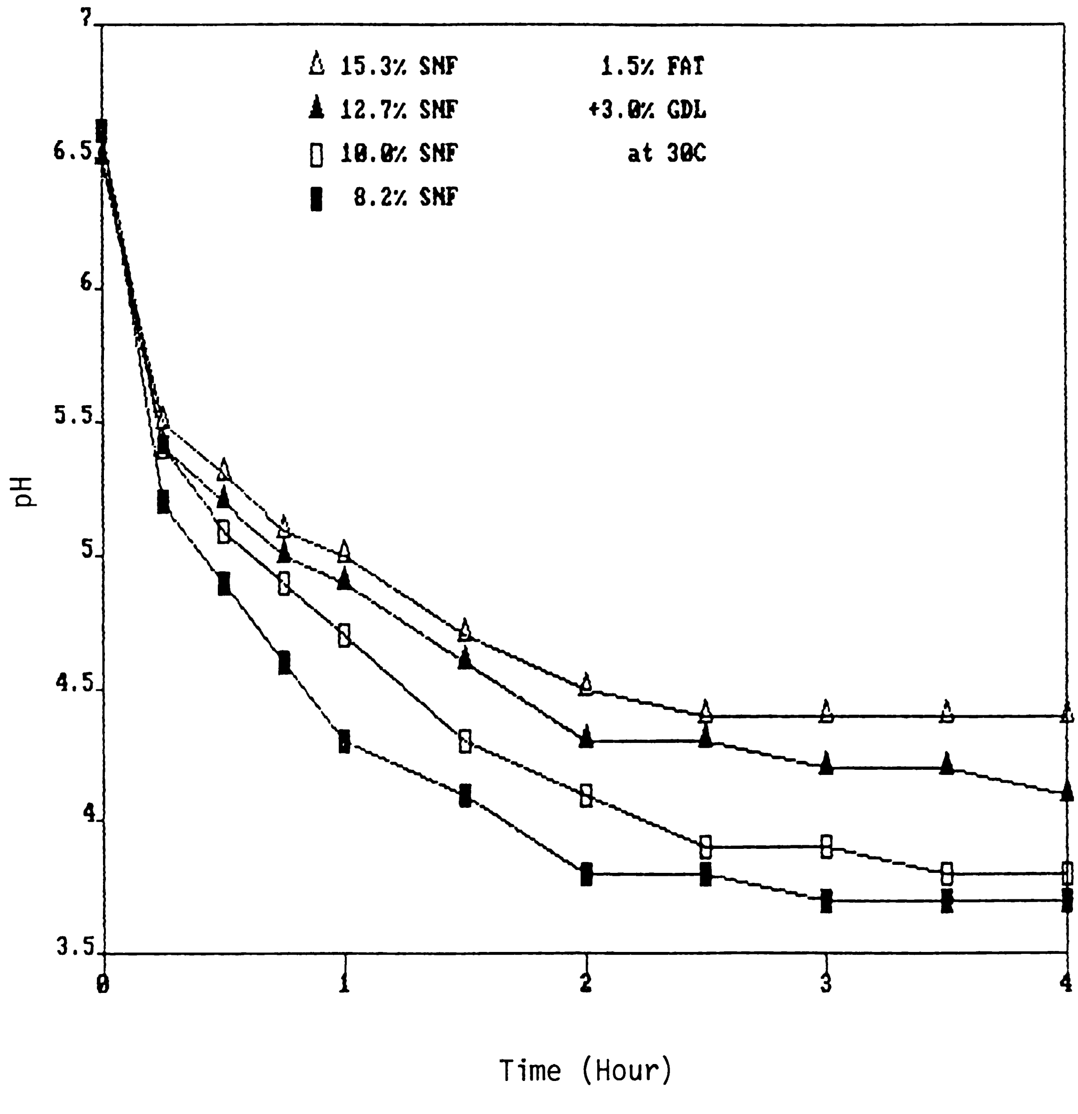


Figure 3. The effect of varying solids not fat (SNF) content on the pH of standardized milk as a function of time; 3.0% GDL, temperature 30°C (Milk standardized to 1.5% fat)

since most yogurt mix is fortified with varying levels of SNF.

The Effect of Temperature

The fall in pH of fortified yogurt mix containing 3% GDL was examined at 25°C (77°F), 30°C (86°F), 35°C (95°F) and 40°C (104°F) (Figure 4). The higher temperature seems to stimulate the hydrolysis of GDL more between 25°C and 35°C, but there is no significant difference between 35°C and 40°C.

In addition, the body and texture of yogurt tends to deteriorate at higher temperature and severe whey separation can be seen in the yogurt treated at 40°C. It is possible that denaturation of protein in the mix is responsible for this phenomenon.

The Time Required to Attain Desired pH

For yogurt mix containing 3% GDL, the decrease in pH is relatively rapid during the initial 90 minutes and then slows down during the ensuing time to 120 minutes (Figure 3 and Figure 4). In addition, keeping the mix for a long time at higher temperatures is not desirable from the viewpoint of effect on body and texture and perhaps undesired microbial growth. For these reasons, incubation for 90 minutes is considered to be reasonable as an acidification time.

Arrangement of Process Conditions

From the above experiments the basic process conditions for acidification with GDL were selected as follows:

1. amount of GDL 3%
2. mix temperature 30°C
3. acidification time 90 minutes

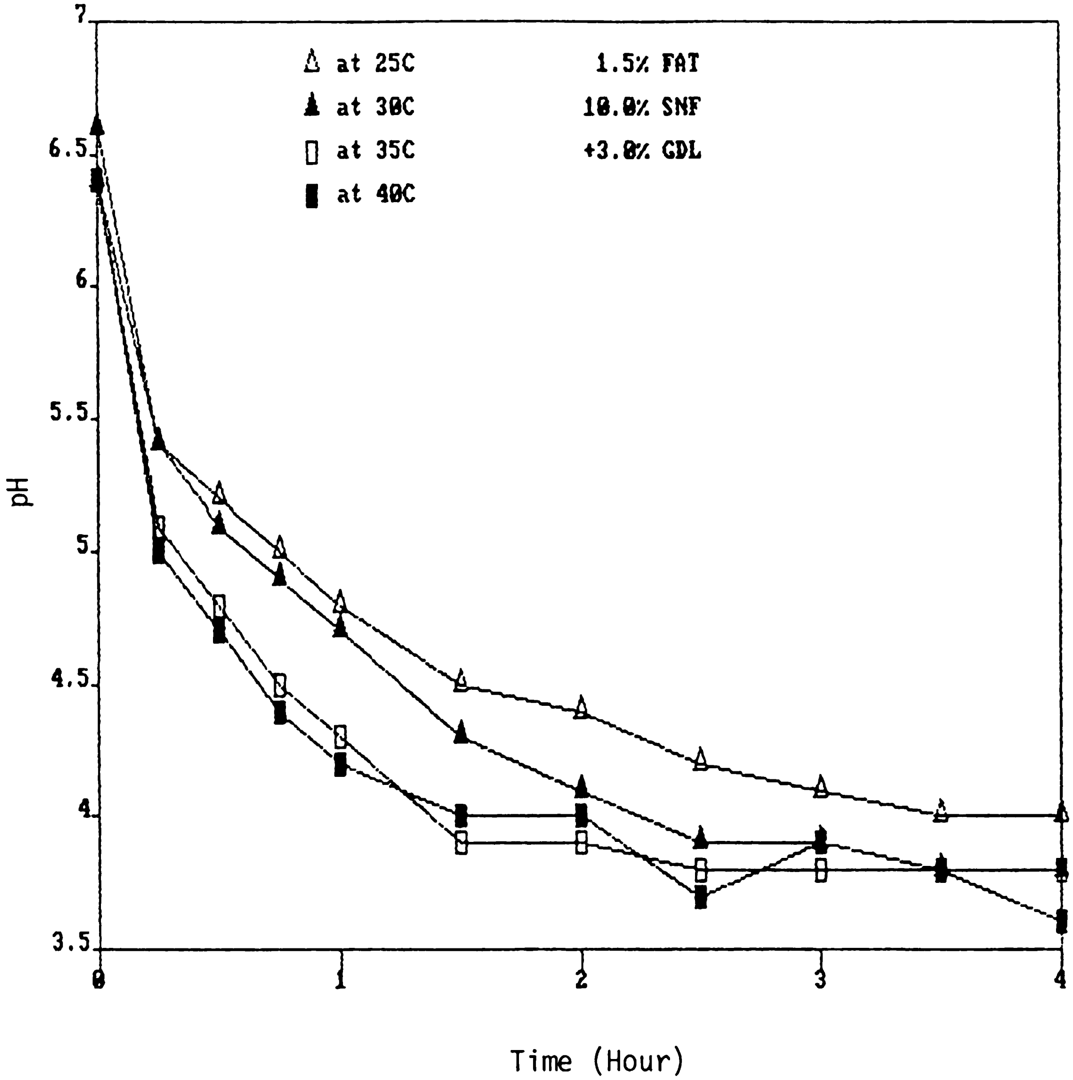


Figure 4. The effect of varying mix temperature on the pH of standardized milk as a function of time; 3.0% GDL (Milk standardized to 1.5% fat, 10.0% SNF)

By employing these conditions any problem on physical properties in fresh direct set yogurt was not observed.

Effect of Stabilizer on Physical Properties of Freeze-Dried Direct Set Yogurt

The loss of typical body and texture of yogurt through freeze-drying was observed by the author early in this research, as was earlier noted by Desai (1966) in freeze-dried cultured cream. This phenomenon may be due to the destruction of matrix structure during freeze-drying process. Therefore, higher levels of solids not fat (SNF) and varying amounts of pectin (Grade 150, Sunkist Growers) were added to yogurt milk in order to compensate for this loss of desirable structure.

Nevertheless, the comparison of data (Figure 5 and Figure 6) indicates very clearly the loss of gel firmness when direct set yogurt is freeze-dried. Although there is no significant effect of pectin on gel firmness in fresh yogurts (Figure 5), there is a very significant effect in reconstituted yogurts (Figure 6). It is interpreted that the yogurt milk fortified with NFDM can create a firm gel by proper acidification without stabilizers, but the freeze-dried powder requires additional stabilization to exhibit the desired properties upon reconstitution.

As a matter of fact, the body of reconstituted yogurt with 0.5% pectin can be maintained within 100 Penetrometer Value (PV), but the loss of gel firmness increases as pectin content decreases. The complete loss of typical yogurt body can be observed for reconstituted

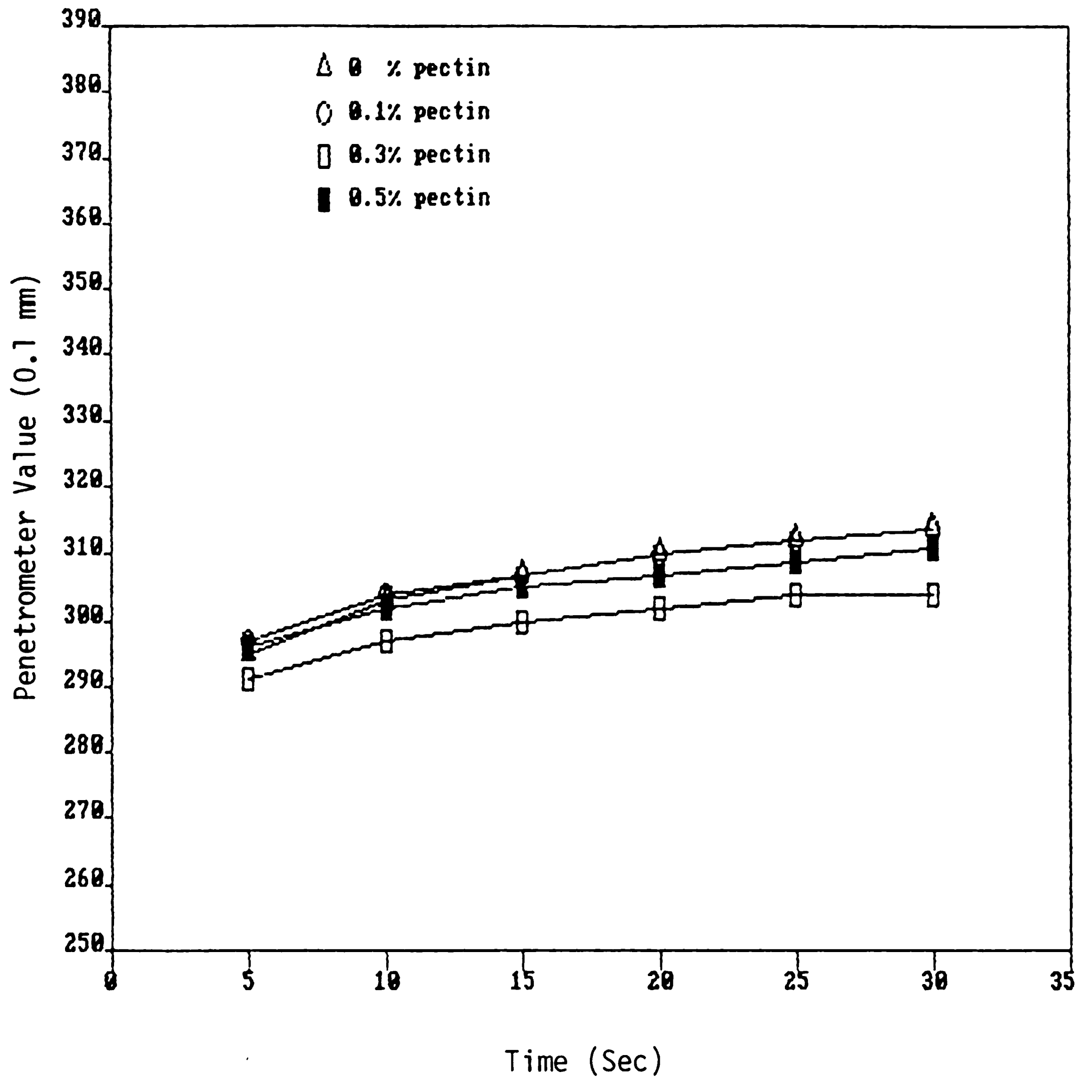


Figure 5. The effect of varying pectin content of mix on the gel firmness of fresh direct set yogurt (Milk standardized to 3.0% fat, 15.5% SNF)

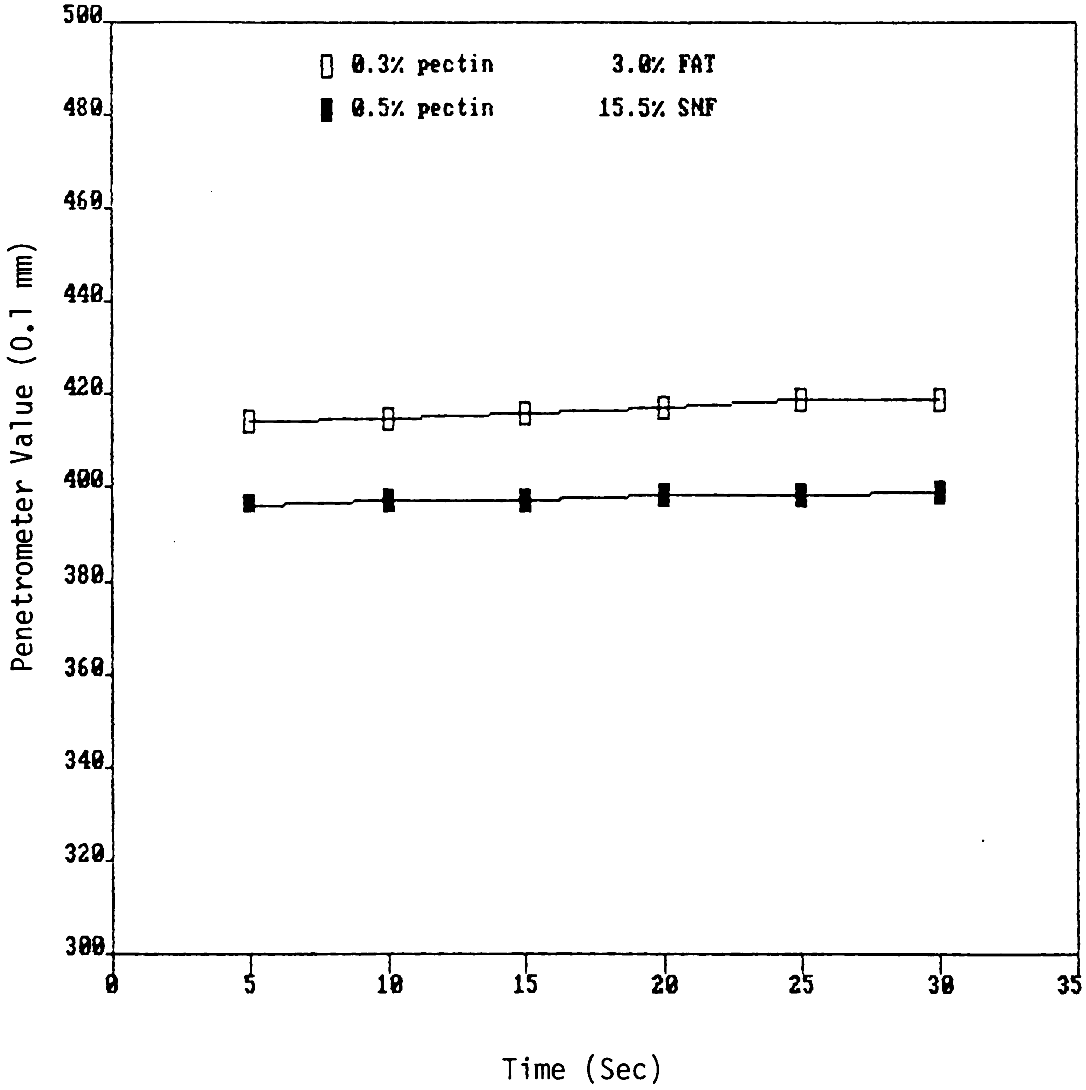


Figure 6. The effect of varying pectin content of mix on the gel firmness of freeze-dried direct set yogurt (Milk standardized to 3.0% fat, 15.5% SNF)

yogurts with less than 0.3% pectin, making it impossible to determine PV due to the very weak body. The penetrometer cone "bottoms out" due to very low resistance of the body to the penetrating force.

Measurement of consistency in reconstituted yogurts (Figure 7) reveals a non-Newtonian behavior of yogurt. There is a large difference of consistency between the yogurt containing 0.3% or more pectin and the sample with less than 0.3% pectin. Yogurt containing no pectin or 0.1% pectin had extremely low consistency upon reconstitution.

These results show the importance of stabilizer performance in the reconstituting process and the strong swelling and gelling capacity of pectin which may be as important as the effect of coagulation in such a system. They also indicate that at least 0.3% pectin should be added to yogurt mix to insure good body in the reconstituted product.

In the food industry proprietary blends of stabilizers are often used for yogurt production, because various stabilizers in combination may exhibit complementary effects.

One attempt to evaluate a blend in this research involved the addition of guar gum (Celanese Jaguar A-20-B, Polymer Specialties Company) with pectin in the yogurt mix, since guar gum performs as a syneresis inhibitor.

An advantage in using the stabilizer combination was obvious, but other desired effects were not noted. For example, the data in Figure 8 show a decrease in gel strength when guar gum was added to the 0.5% pectin systems. Likewise (Figure 9) the gel strength of the reconstituted yogurt was lower in the products containing 0.5% pectin plus additional guar gum and consistency (Figure 10) indicated weaker

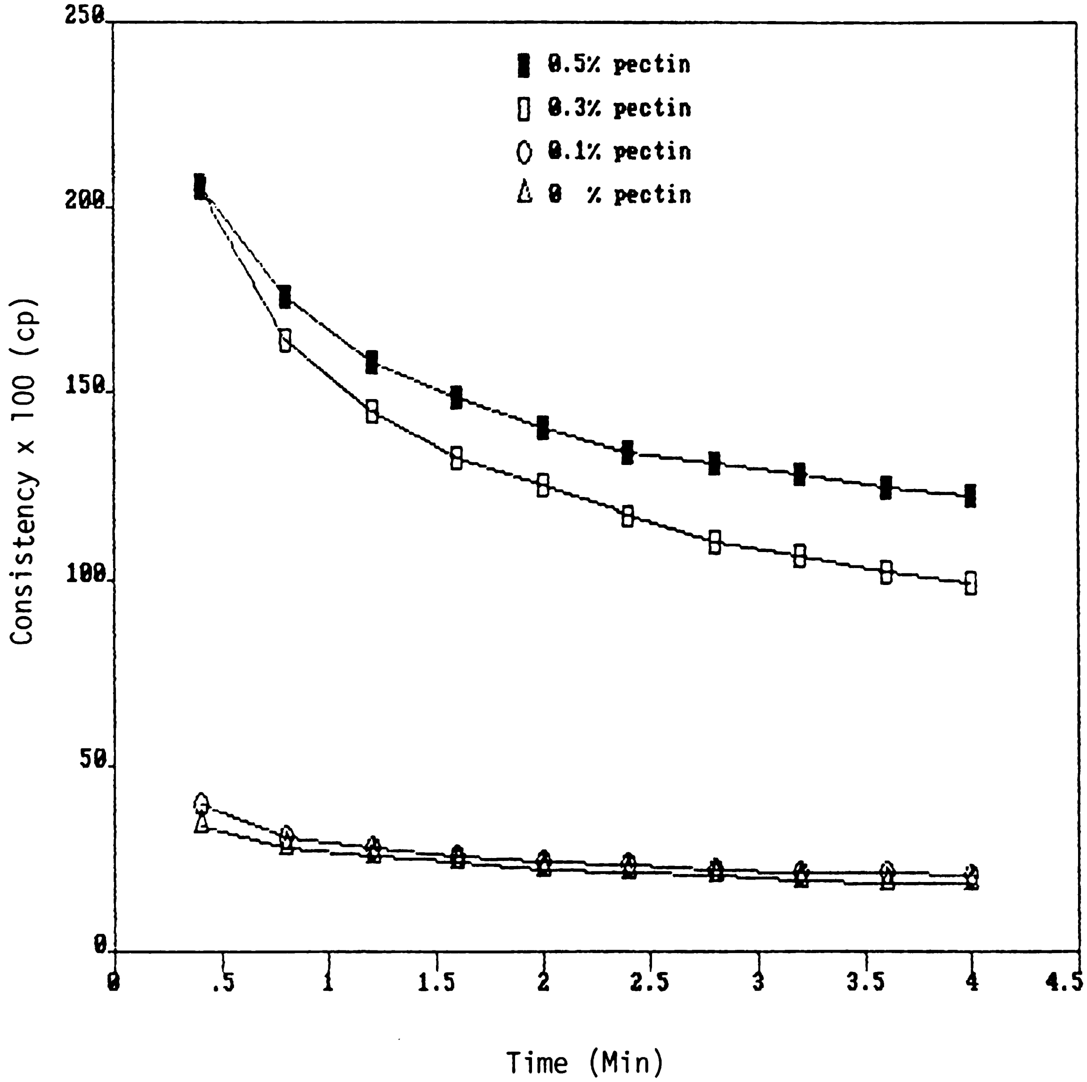


Figure 7. The effect of varying pectin content of mix on the consistency of freeze-dried direct set yogurt (Milk standardized to 3.0% fat, 15.5% SNF)

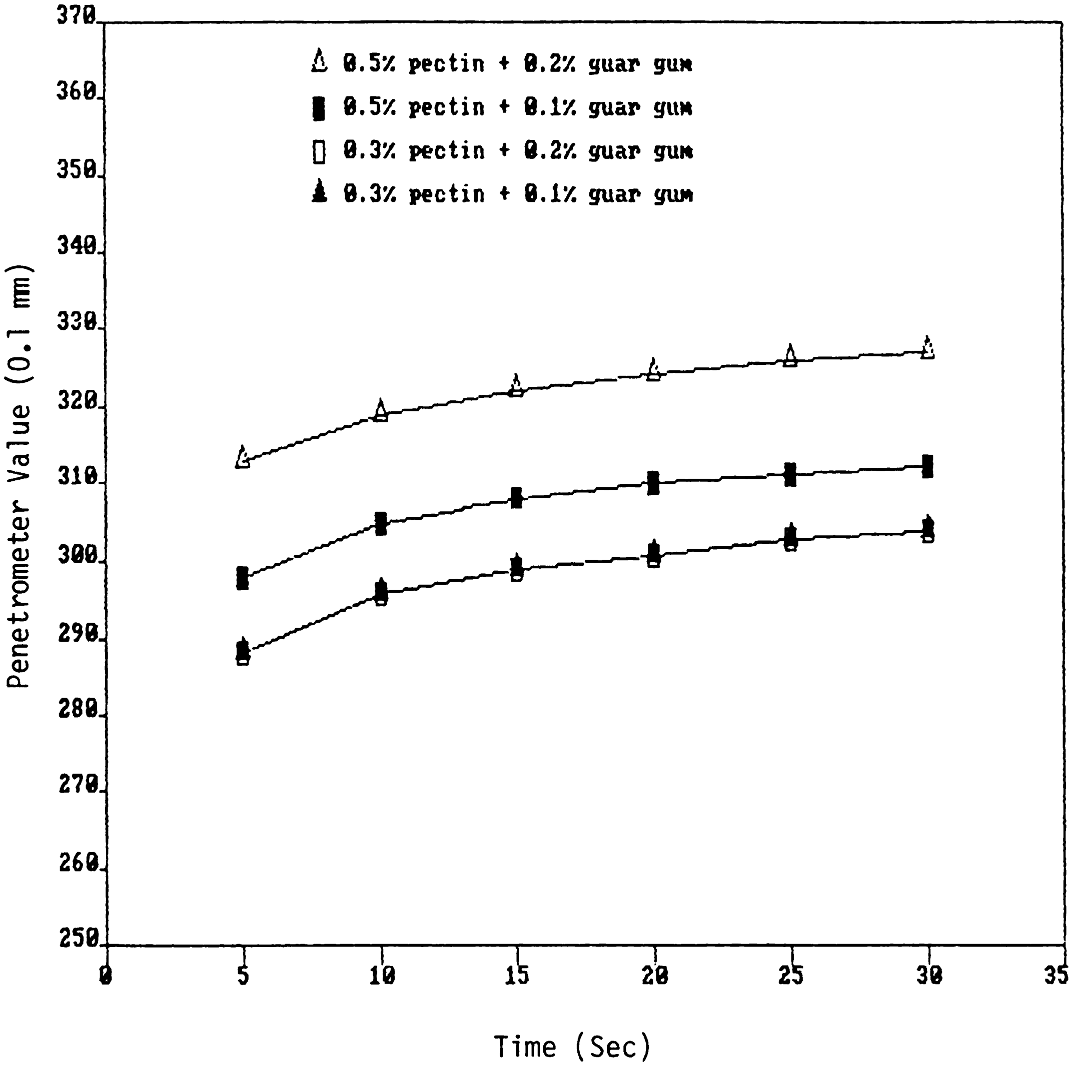


Figure 8. The effect of stabilizer blends on the gel firmness of fresh direct set yogurt (Milk standardized to 2.9% fat, 15.5% SNF)

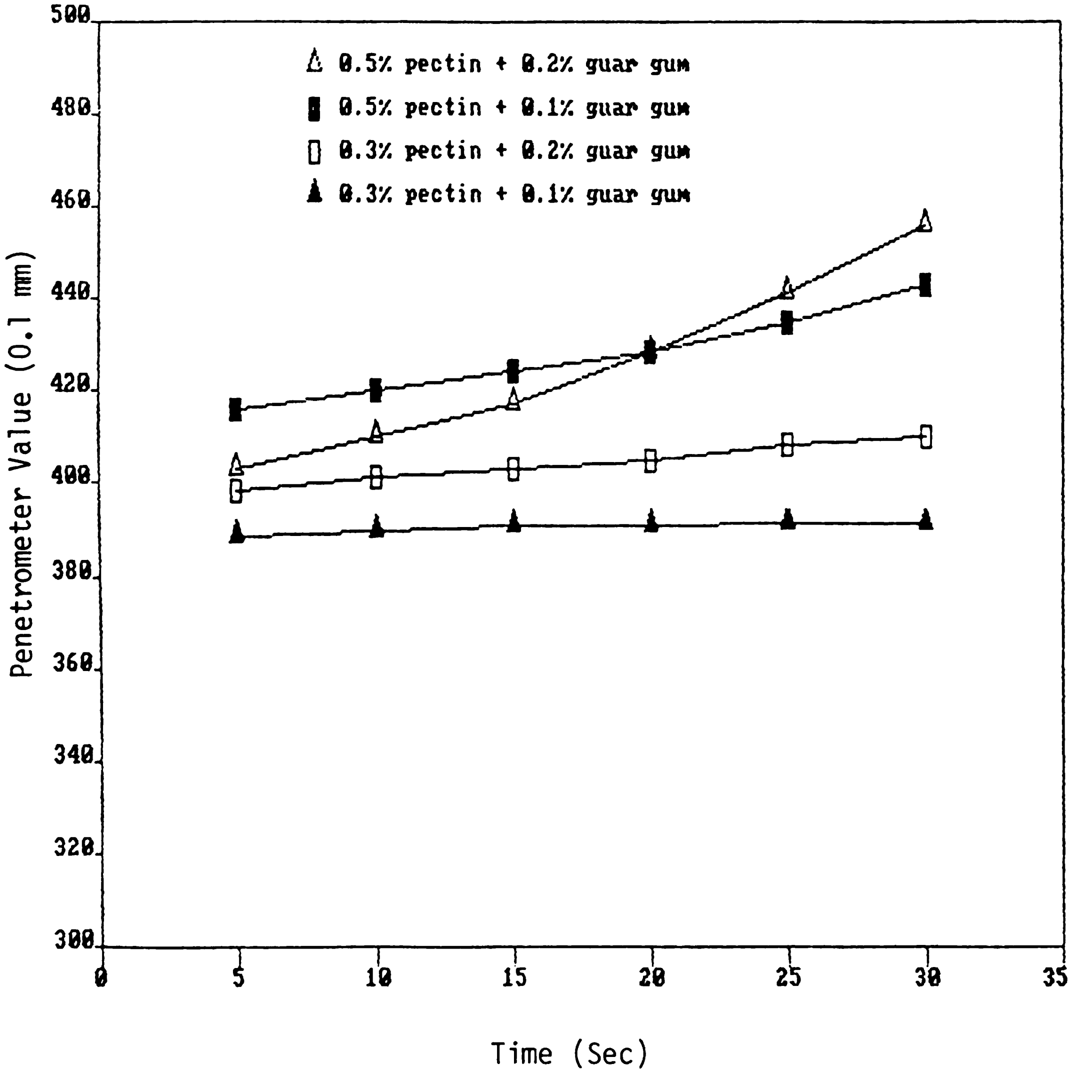


Figure 9. The effect of stabilizer blends on the gel firmness of freeze-dried direct set yogurt (Milk standardized to 2.9% fat, 15.5% SNF)

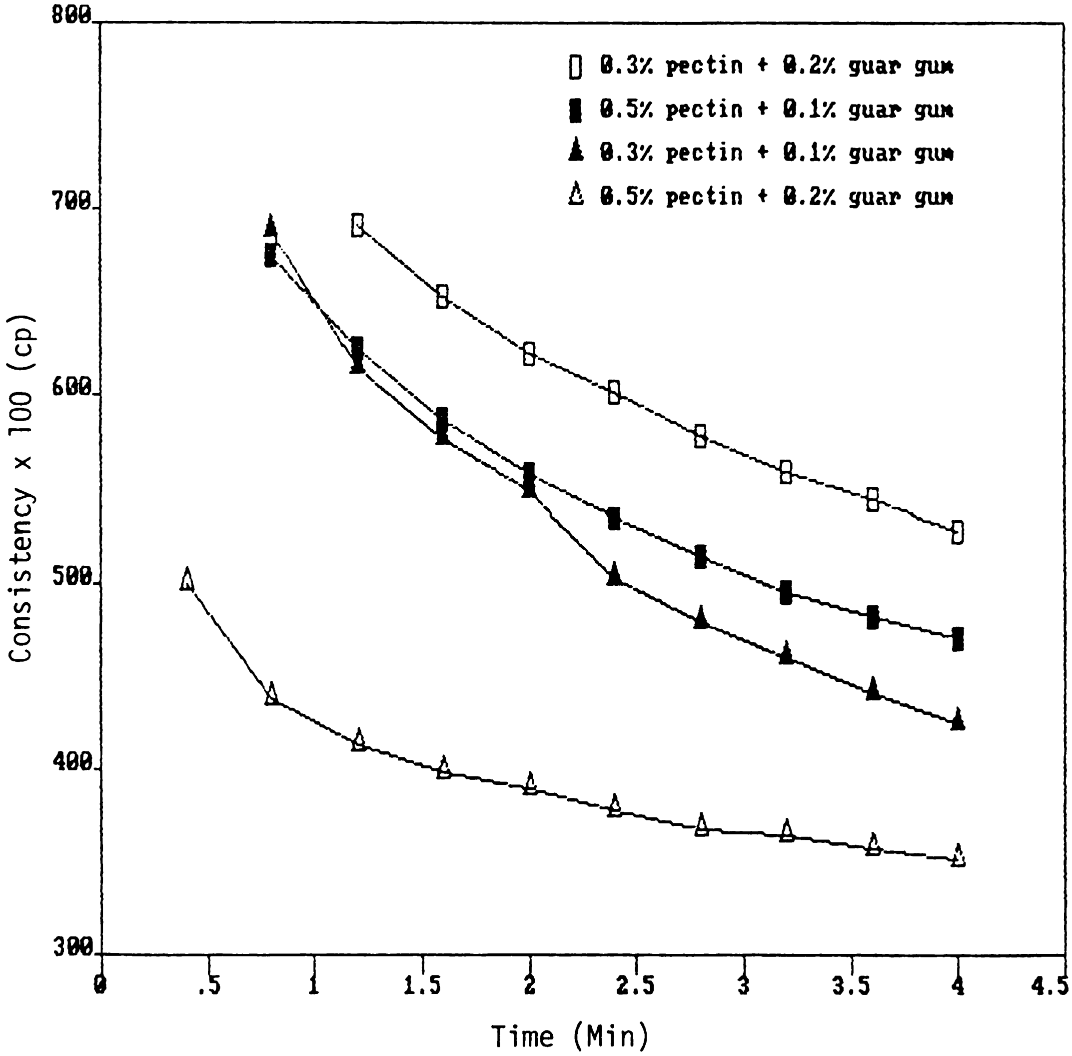


Figure 10. The effect of stabilizer blends on the consistency of freeze-dried direct set yogurt (Milk standardized to 2.9% fat, 15.5% SNF)

body in such combinations. This may be due to reduction in coagulation or matrix structure when high levels of stabilizer are used. Their interaction with the milk proteins may actually weaken the tendency to clot at the isoelectric point.

From the effect of stabilizer combinations on gel firmness and consistency it appears that 0.3% pectin in combination with 0.1% or 0.2% guar gum yields better physical properties.

This conclusion is substantiated by observations of the loss of gel firmness through freeze-drying which indicates that 0.4% - 0.5% stabilizers added to yogurt mix yielded superior properties (Figure 11).

Effect of Total Solids Content on Physical Properties of Freeze-Dried Direct Set Yogurt

Yogurt produced by a mix containing 10.3% SNF (13.4% TS) has a very weak body even when fortified with stabilizer.

The solids not fat (SNF), and especially casein, is very important in the formation of a firm gel structure. This is true of yogurt reconstituted from freeze-dried powder. In such a system, SNF has an important function as a structural contributor and as a water-binding material for gelation when the powder is hydrated. For this reason higher levels of SNF are necessary to obtain optimal body.

Sodium caseinate, which might be considered to have basically the same function as SNF on the physical properties in yogurt except for properties related to salt balance, was evaluated as a possible means of avoiding high SNF and TS content. The effect of added sodium caseinate on the body of direct set yogurt (Figure 12) is contrary to

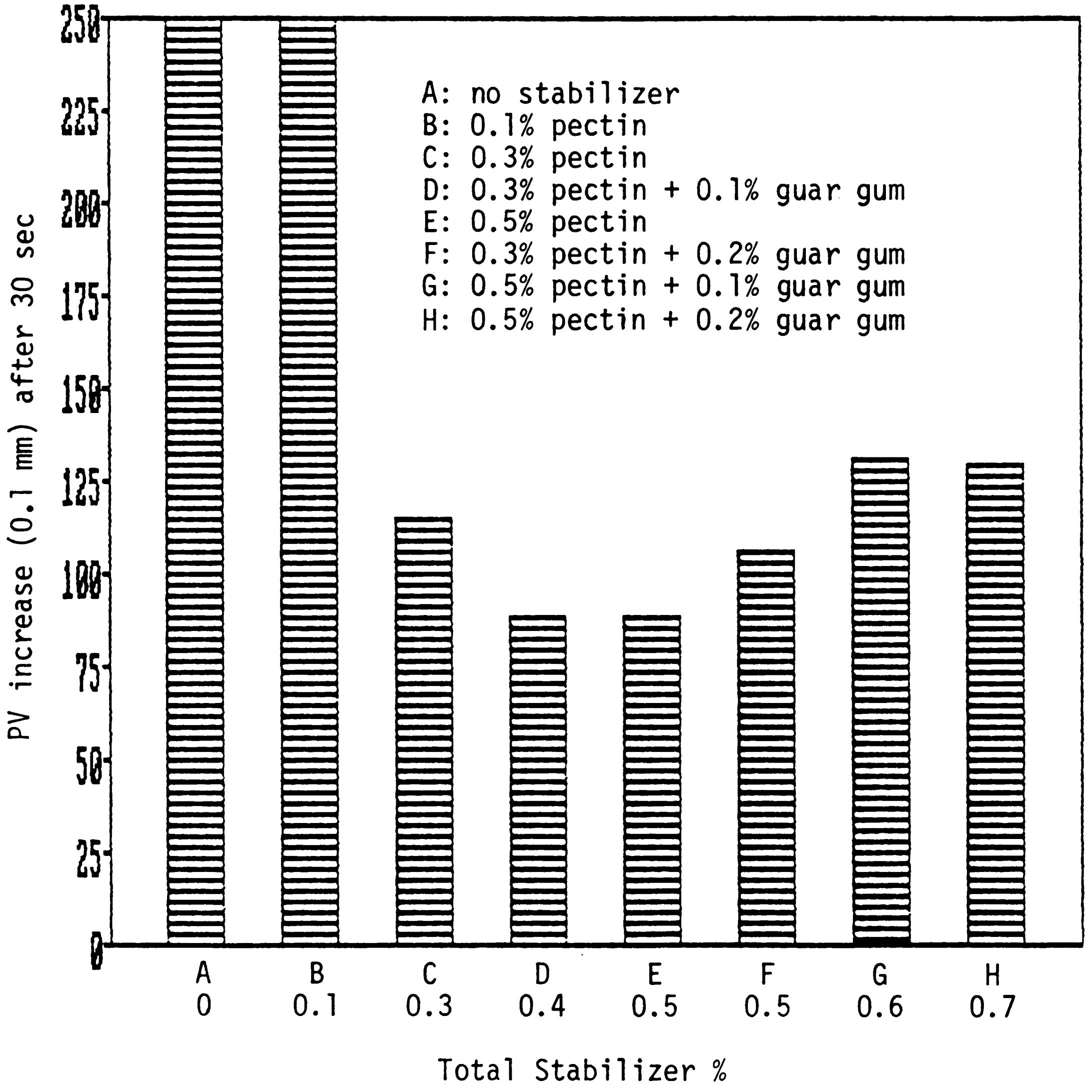


Figure 11. The loss of gel firmness of direct set yogurt by freeze-drying (Milk standardized to 2.9 - 3.0% fat, 15.5% SNF)

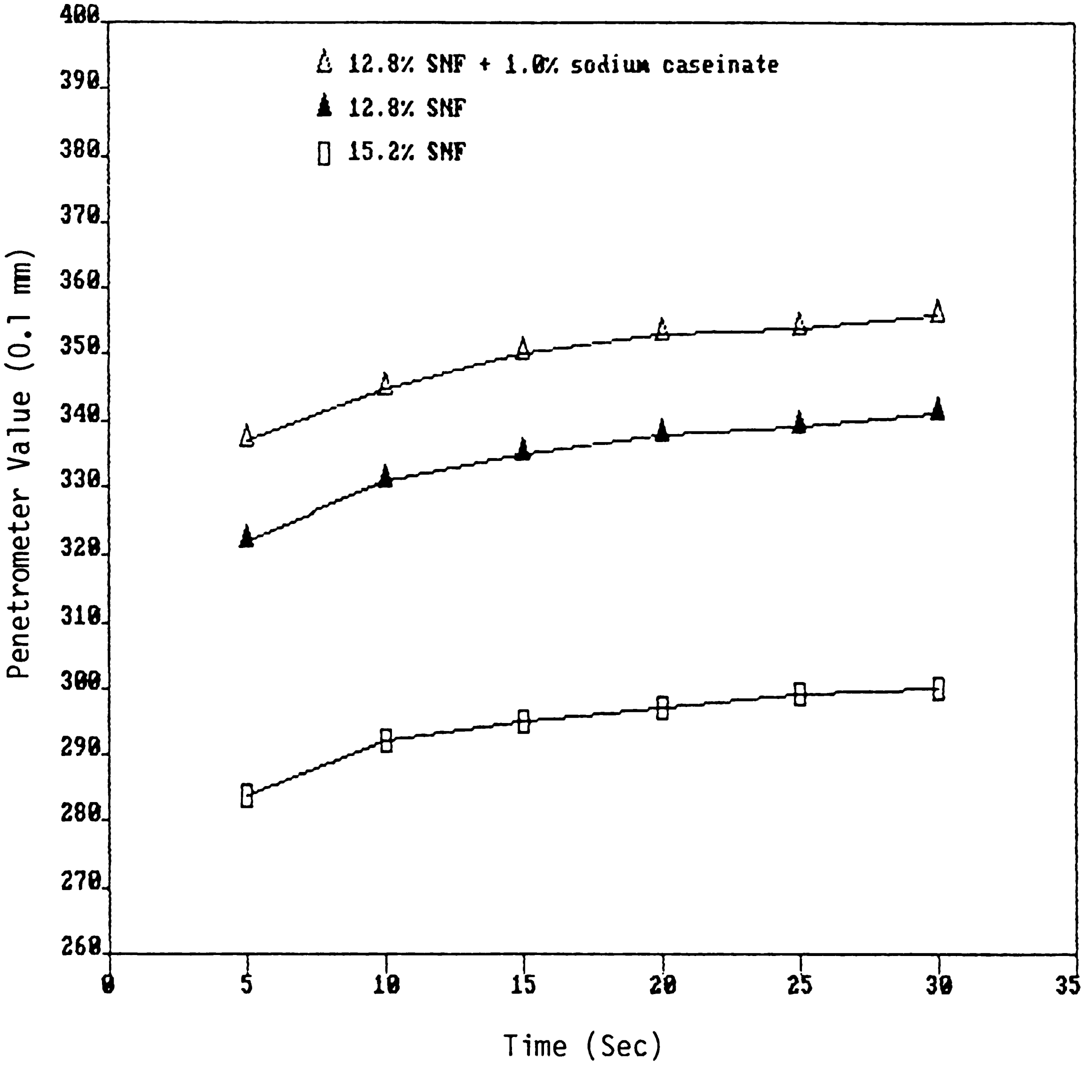


Figure 12. The effect of varying total solids content on the gel firmness of fresh direct set yogurt (Milk standardized to 3.1% fat containing 0.3% pectin and 0.1% guar gum)

observations of Gennip (1973). The data show no beneficial effect of fortification with sodium caseinate.

On the other hand, fortification with sodium caseinate results in improved firmness of reconstituted yogurt (Figure 13) and the data suggest that 2.4% SNF could be replaced by 1.0% of sodium caseinate. However, the texture of yogurt was found to be slightly impaired by sodium caseinate (Table 1). This observation was indicated earlier by Modler and Kalab (1983).

Another possible approach to improved body in the reconstituted yogurt would be dry blend solids in the dehydrated yogurt prior to packaging. Experiments were designed wherein instantized non-fat dry milk solids (Natural Non Fat Dry Milk, Carnation) were dry blended with the yogurt powder. There was no significant difference (Figure 14) between the fortified and non-fortified samples.

Possibly the freeze-dried powder has its own internal matrix as a result of process conditions and the mere addition of NFDM to the dried yogurt failed to achieve the desired increase in firmness. It would seem appropriate in future work to pursue this matter further possibly using lower pH in the dried yogurt to compensate for buffer effects of the added NFDM, and also, to evaluate low vs high heat NFDM for fortification.

Effect of Fat Content on Physical Properties of Freeze-Dried Direct Set Yogurt

There is a paucity of literature on the importance and role that fat plays on the physical properties of yogurt. In the data shown in

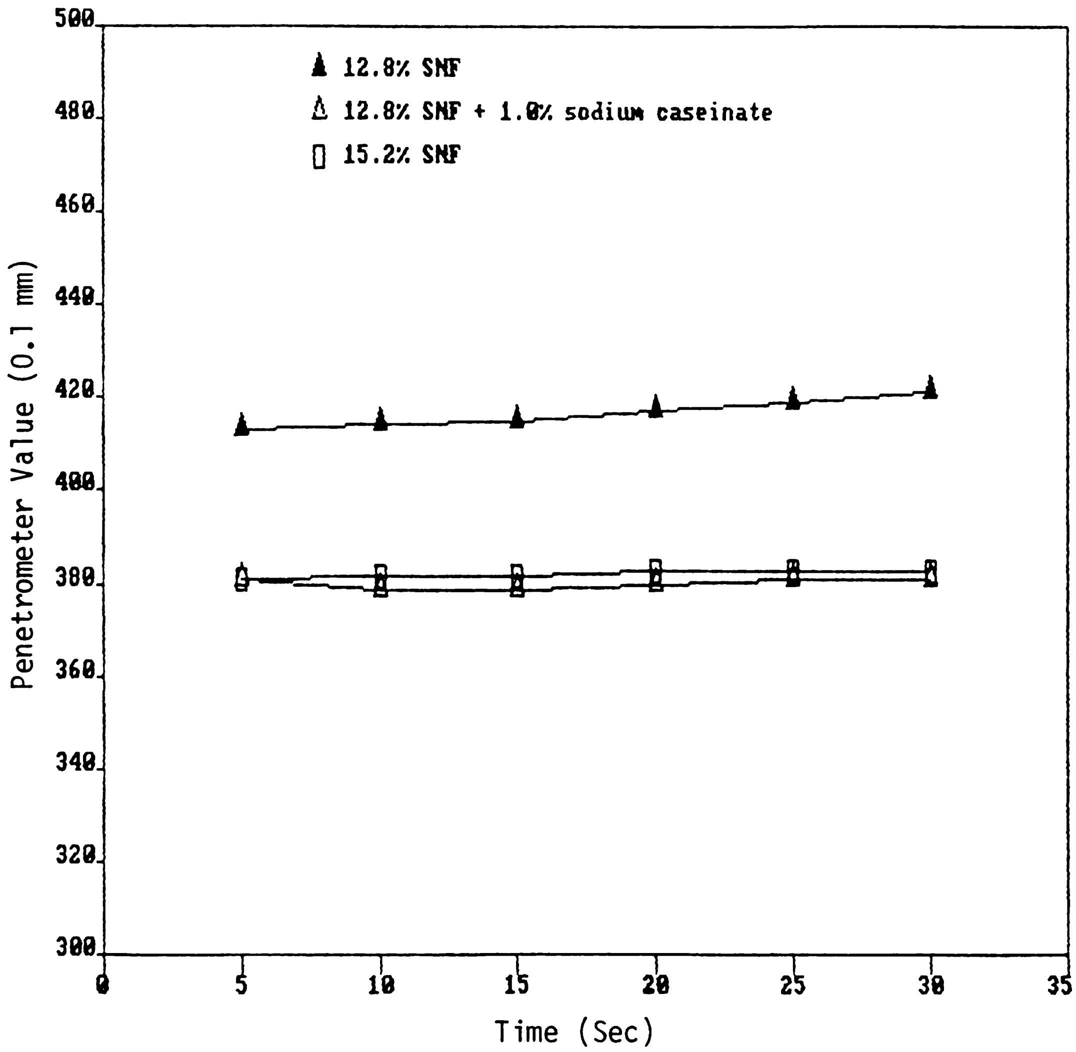


Figure 13. The effect of varying total solids content on the gel firmness of freeze-dried direct set yogurt (Milk standardized to 3.1% fat containing 0.3% pectin and 0.1% guar gum)

Table 1. Some physical properties of different types of freeze-dried direct set yogurt

Fat %	SNF %	Stabilizer pectin	% guar	Process	Body	Texture	Whey-Separation
3.0	15.5	0	0	normal*	soupy	smooth	-
		0.1	0	normal	soupy	smooth	-
		0.3	0	normal	sl. weak	smooth	-
		0.5	0	normal	sl. weak	smooth	-
2.9	15.5	0.5	0.1	normal	weak	smooth	-
		0.5	0.2	normal	weak	smooth	-
		0.3	0.1	normal	sl. weak	smooth	-
		0.3	0.2	normal	sl. weak	smooth	-
3.1	12.8	0.3	0.1	normal	weak	smooth	-
	12.8**			normal	sl. weak	sl. rough	-
	10.3			normal	liquid		+++
	10.3**			normal	liquid		+++
3.1	15.7	0.3	0.05***	normal	weak	smooth	+
2.0	15.7			normal	ex. weak	smooth	+
1.0	15.6			normal	soupy	smooth	-
0.5	15.4			normal	liquid		++
3.2	14.8	0.3	0.1	90C 30M	sl. weak	smooth	+****
				80C 15M	good	smooth	-
				normal	good	smooth	-
				70C 30M	sl. weak	sl. rough	++
3.1	15.2	0.3	0.1	2.7% GDL	sl. weak	smooth	+
				normal	sl. weak	smooth	-
				3.3% GDL	sl. weak	smooth	-
				3.6% GDL	sl. weak	smooth	-

* 80C 30M Heat Treatment, pH 4.0 - 4.1 (3.0% GDL)
** fortified with 1.0% sodium caseinate
*** carageenan rather than guar gum
**** browning was observed

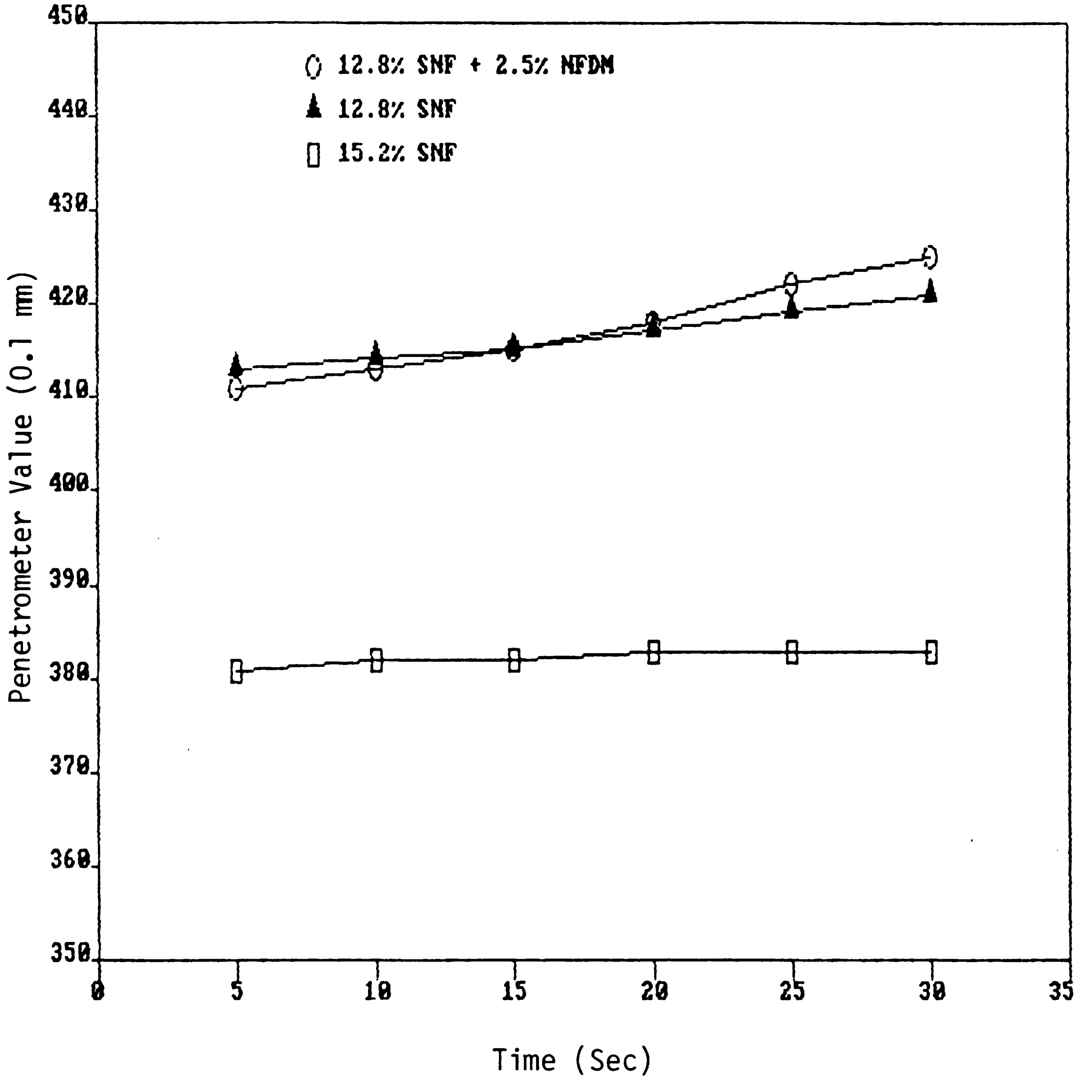


Figure 14. The effect of blending NFDM and yogurt powder on the gel firmness of freeze-dried direct set yogurt (Milk standardized to 3.1% fat containing 0.3% pectin and 0.1% guar gum)

Figure 15 one can see the major contribution fat makes to the body of fresh yogurt. As fat content was increased from 0.5% to 3.1%, there was a significant increase in firmness of the yogurt. The contribution to firmness is even more dramatic when one compares the PV of reconstituted yogurt (Figure 16). Yogurts produced by a mix containing less than 2% fat yielded extremely weak body, making it impossible to determine PV. In addition, the shape of PV curve of yogurt produced by a mix containing 2.0% fat is concave, which means low resistance of the body to the penetrating force and the rate of penetrating was accelerated after 45 mm penetration since the height of cone is 45 mm. The definite effect of milk fat can be observed for the consistency of the freeze-dried yogurt as well (Figure 17), as measured by viscometry.

Fat seems to be indispensable for desirable body in reconstituted yogurt, since lower levels of fat yield body too weak to determine by penetrometry or viscosimetrically. This may be due to the interaction between the fat globules and the coagulated protein filaments which affects the formation of solid gel structure. In addition, in yogurt of lower fat content and particularly, in the case of 0.5% fat yogurt, whey separation was readily observed on the surface of the yogurt (Table 1). This defect was noted earlier by Rasic and Kurmann (1978).

In this experiment about varying fat content of yogurt mix (Figure 15 - 17), 0.05% carageenan was used rather than guar gum. However, guar gum can be considered better from the viewpoint of solubility because carageenan is difficult to dissolve in milk and causes very viscous milk, which does not necessarily produce firm body of yogurt. For this reason, the blends of pectin and guar gum was used

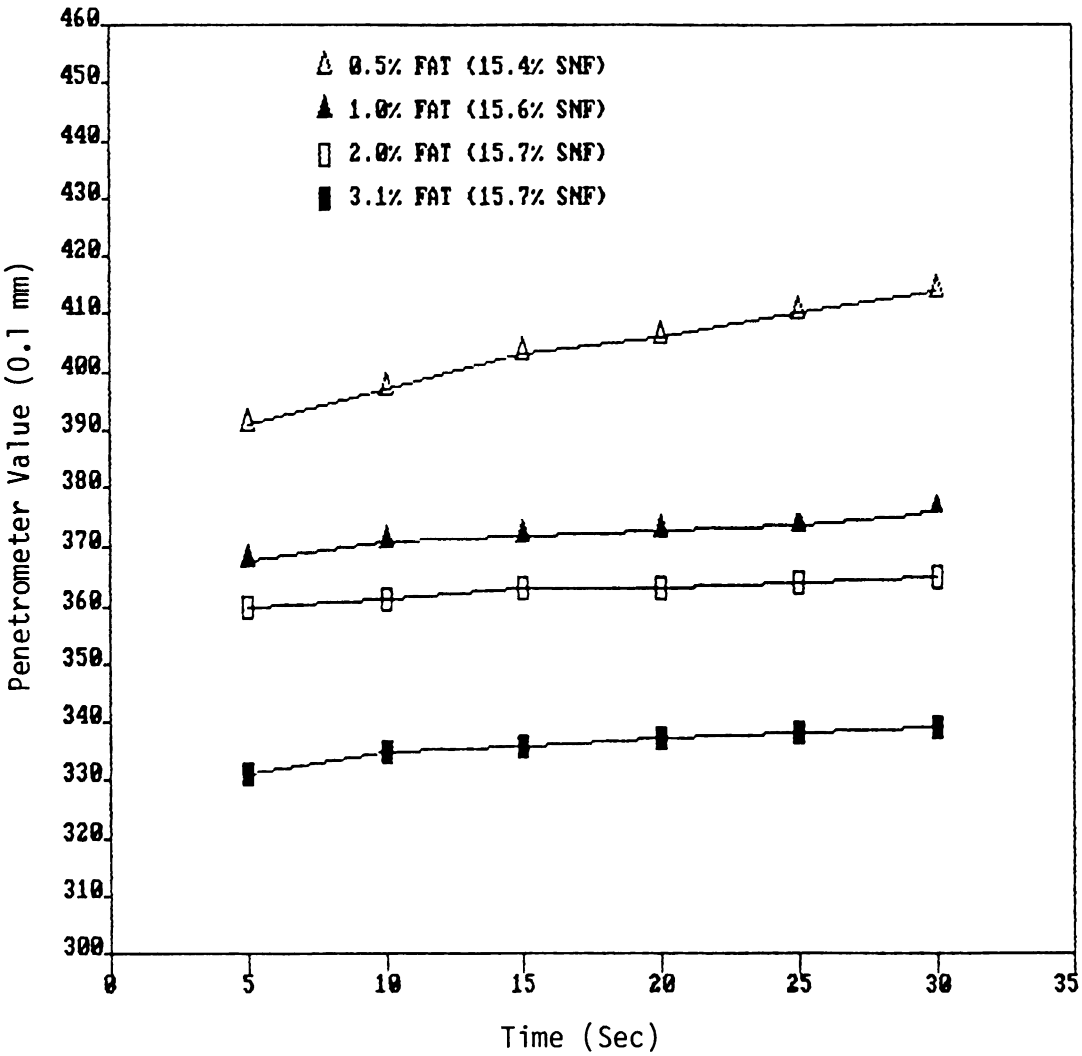


Figure 15. The effect of varying fat content of mix on the gel firmness of fresh direct set yogurt (Milk standardized to 15.4 - 15.7% SNF containing 0.3% pectin and 0.05% carageenan)

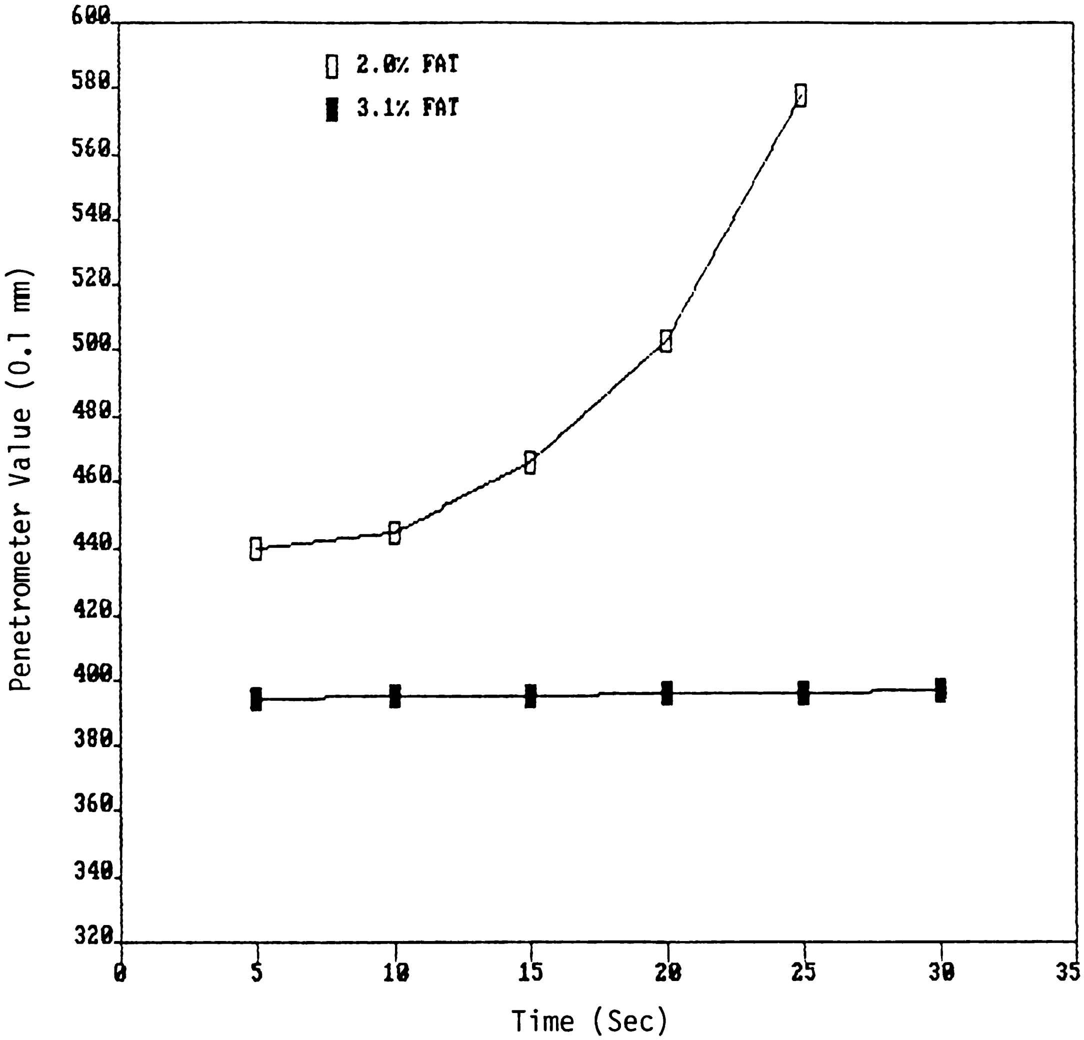


Figure 16. The effect of varying fat content of mix on the gel firmness of freeze-dried direct set yogurt (Milk standardized to 15.7% SNF containing 0.3% pectin and 0.05% carageenan)

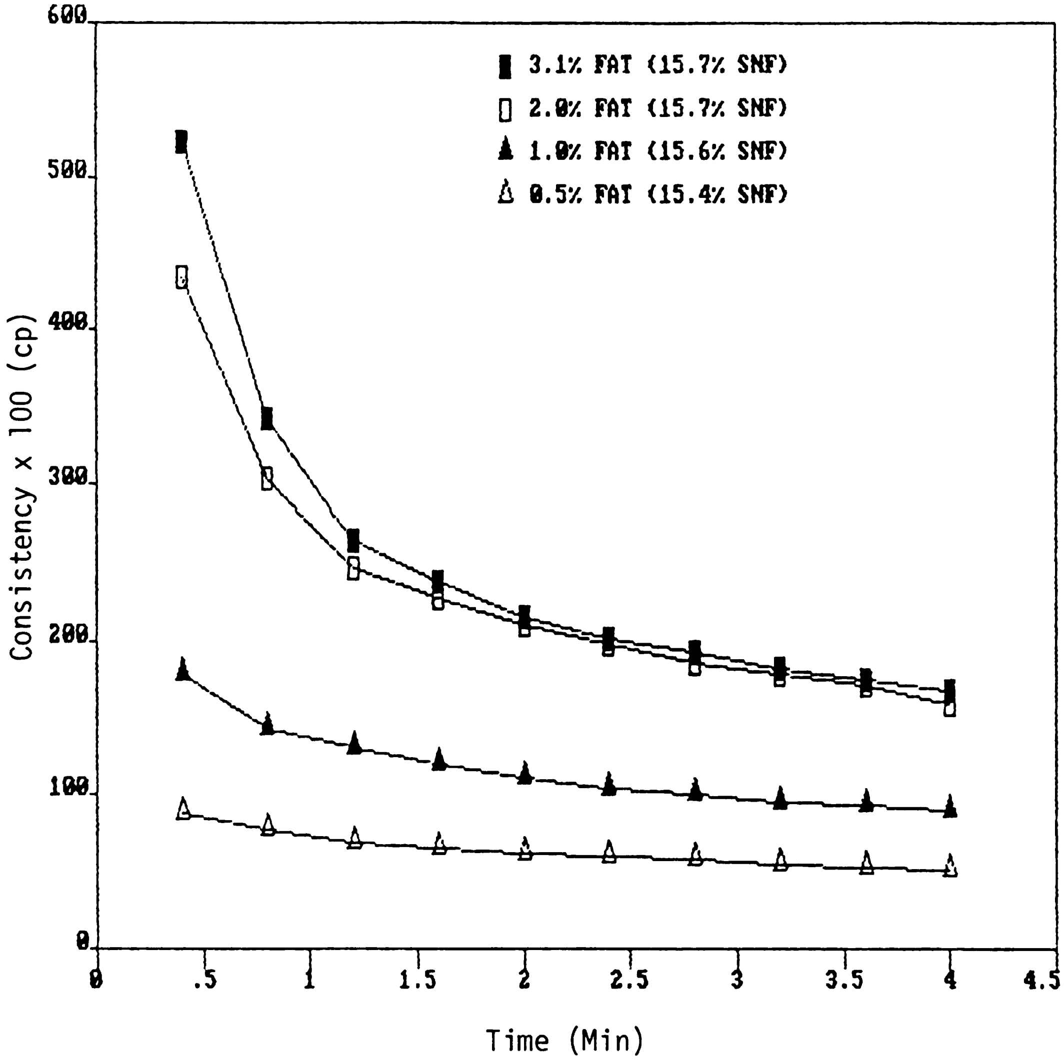


Figure 17. The effect of varying fat content of mix on the consistency of freeze-dried direct set yogurt (Milk standardized to 15.4% - 15.7% SNF containing 0.3% pectin and 0.05% carageenan)

for yogurt production in the following study.

Effect of Heat Treatment on Physical Properties of Freeze-Dried Direct Set Yogurt

Four different heat treatments were employed to study the effects of various heat treatments. The treatments used were 70°C/30 min; 80°C/30 min; 90°C/30 min; and 80°C/15 min. In regard to gel firmness, there were no significant differences except that the 70°C/30 minute treatment resulted in weaker body in both fresh yogurt (Figure 18) and reconstituted yogurt (Figure 19).

Browning, however, was very apparent in the yogurt heated to 90°C for 30 minutes (Table 1). This color change is due primarily to caramelization of lactose and to a lesser extent, to the Maillard reaction between protein amino groups and lactose carbonyl.

With reference to the consistency of reconstituted yogurt (Figure 20), both 80°C heat treatment for 15 minutes and 30 minutes produced good results. Although Gilles and Lawrence (1981) and others have recommended heating milk to 80°C - 85°C for 30 minutes for yogurt manufacture, good body and texture of reconstituted yogurt in this study was obtained by heating milk to 80°C for 15 minutes, as well as for 30 minutes.

It is concluded that similar beneficial effects of heat treatment apply to the physical properties of reconstituted yogurt as well as those which have been reported for fresh yogurt (Schmidt et al., 1980).

Such effects may be related to the adsorption of denatured whey proteins to casein micelles. The hydrophilic properties of such

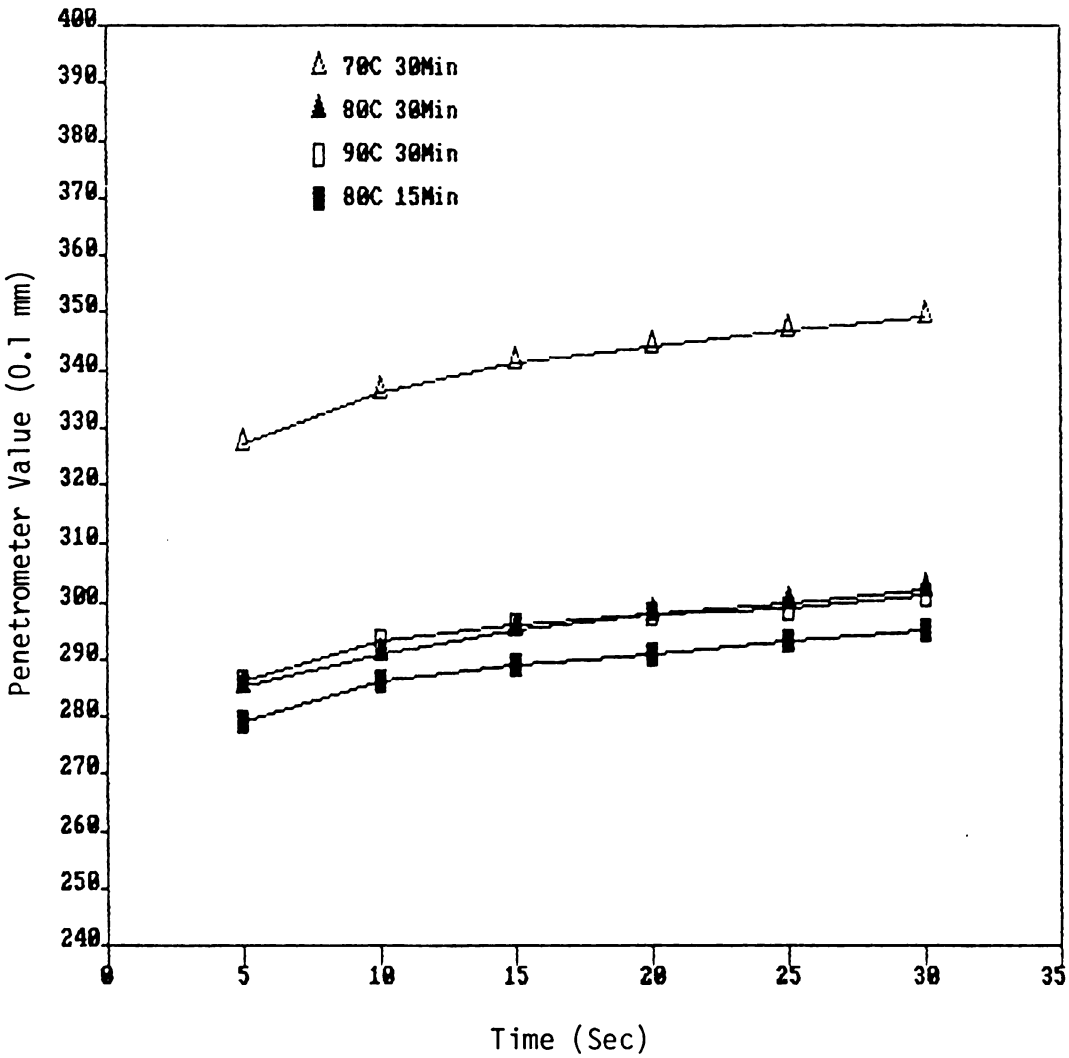


Figure 18. The effect of varying heat treatment of mix on the gel firmness of fresh direct set yogurt (Milk standardized to 3.2% fat, 14.8% SNF containing 0.3% pectin and 0.1% guar gum)

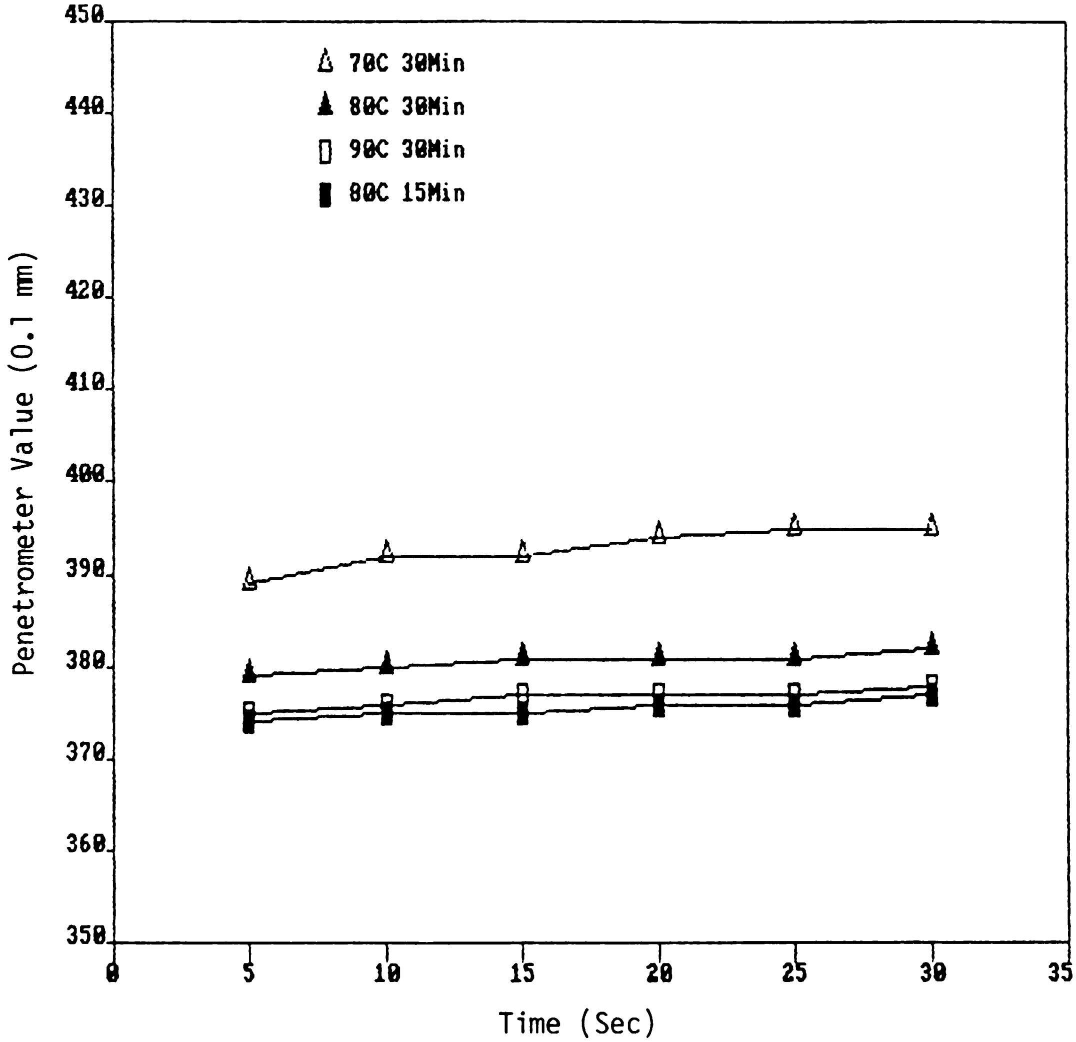


Figure 19. The effect of varying heat treatment of mix on the gel firmness of freeze-dried direct set yogurt (Milk standardized to 3.2% fat, 14.8% SNF containing 0.3% pectin and 0.1% guar gum)

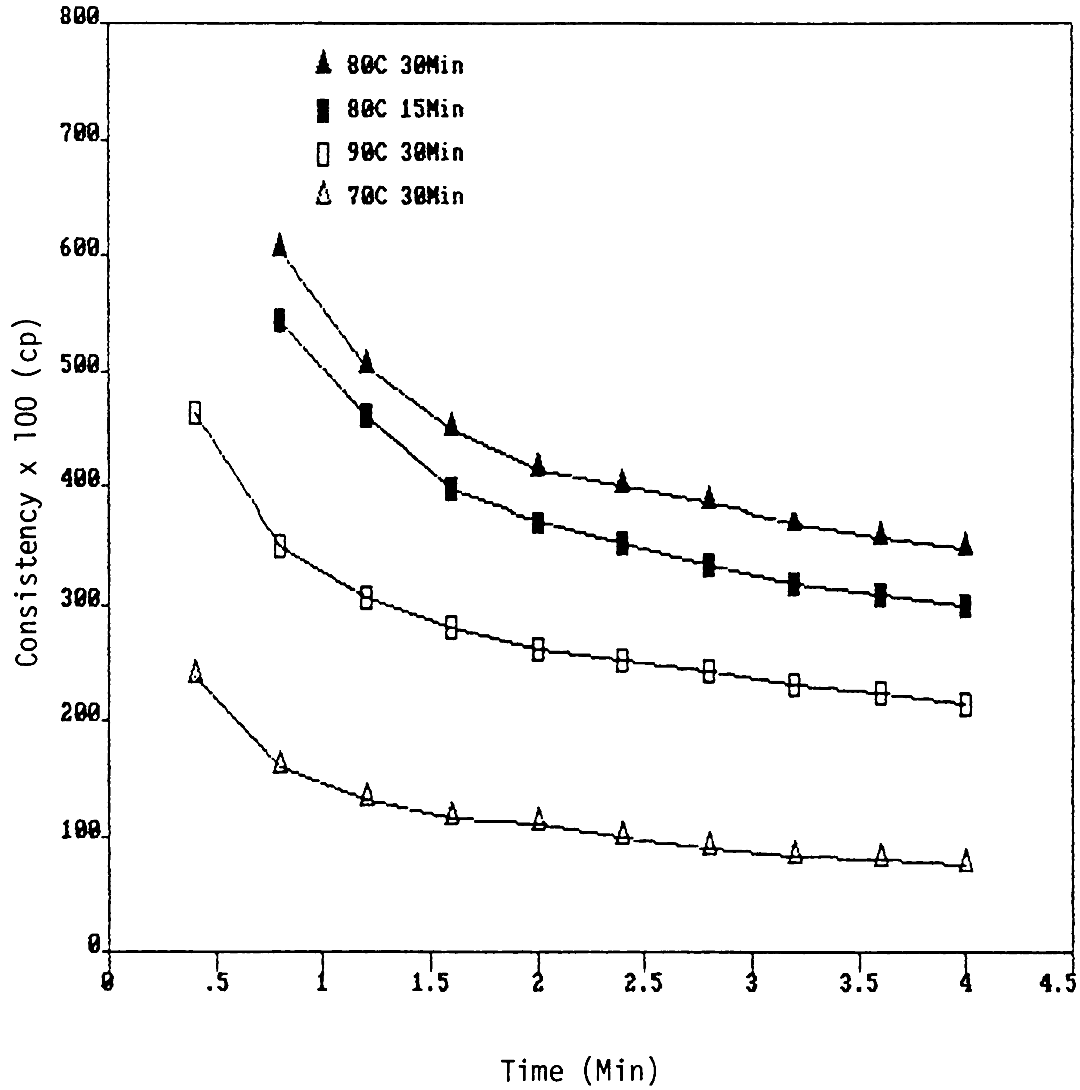


Figure 20. The effect of varying heat treatment of mix on the consistency of freeze-dried direct set yogurt (Milk standardized to 3.2% fat, 14.8% SNF containing 0.3% pectin and 0.1% guar gum)

aggregates may improve the gel firmness and consistency of yogurt.

Effect of pH on Physical Properties of Freeze-Dried Direct Set Yogurt

The pH range of commercial yogurts is generally 3.7 - 4.3 (Richmond, 1982). Other factors related to desired pH such as tartness and the type of yogurt (plain or flavored yogurt) are of importance, but pH is functionally vital as a factor influencing the physical properties of yogurt.

The final pH of a product can naturally be controlled by the amount of GDL added, as was evident from this, and earlier research studies.

Within practical limits the lower the pH, the firmer will be the body of fresh yogurt (Figure 21) and that of reconstituted yogurt (Figure 22).

The effect of hydrogen ion concentration on consistency (Figure 23) parallels the effects previously noted for gel firmness. pH has definite effects on the physical properties of freeze-dried direct set yogurt between pH 3.8 - 4.2 and the lower pH results in better body of the yogurt.

Coagulation occurs near the isoelectric point of caseins as a result of minimal stabilizing charge on the casein micelles in this range of pH. In addition, acidification to a pH of 4.6 and below tends to increase the hydration and solubility due to strong protonation of the micelle of protein. This may have a bearing on the physical properties noted.

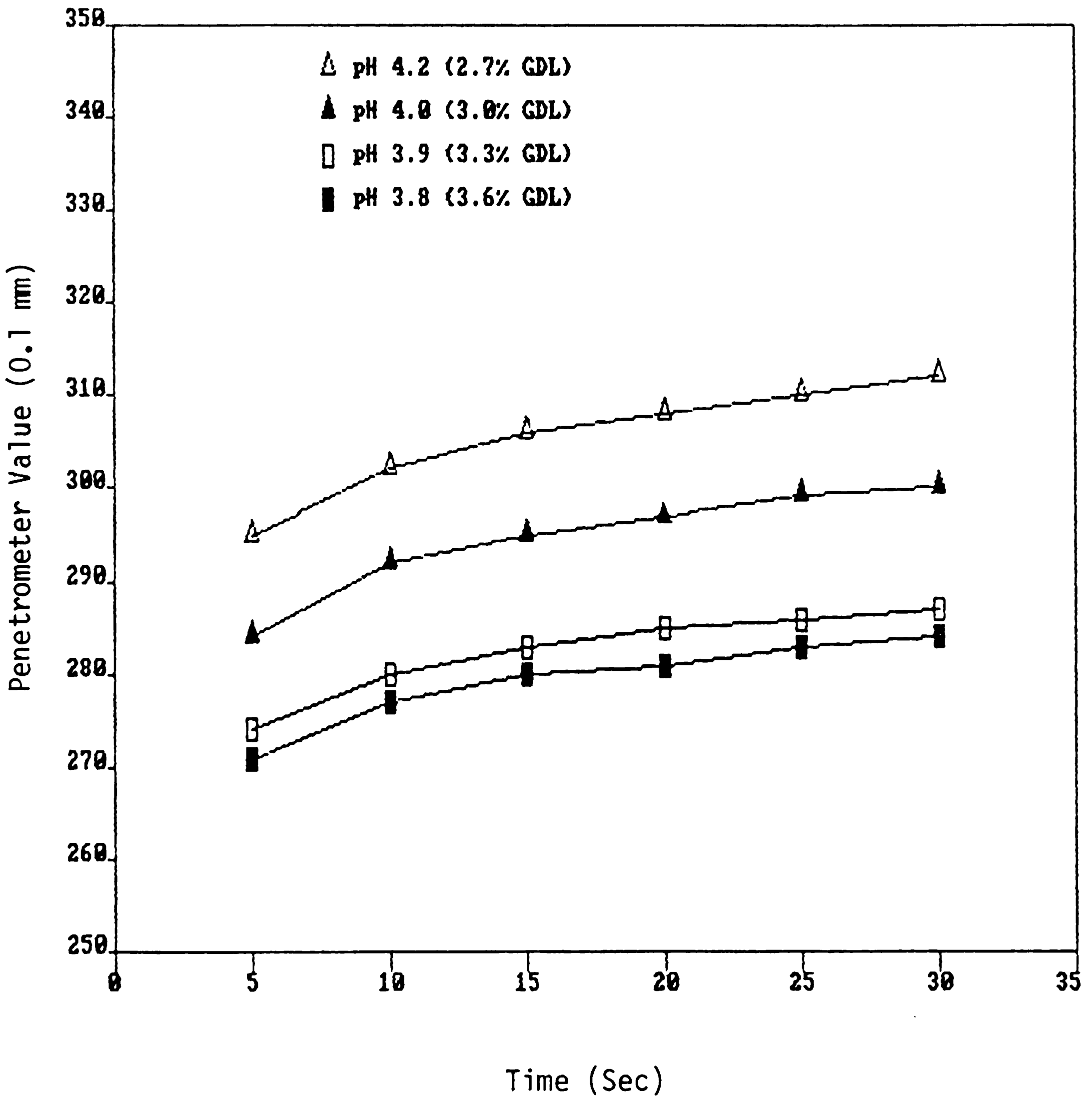


Figure 21. The effect of varying pH (GDL content) of mix on the gel firmness of fresh direct set yogurt (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

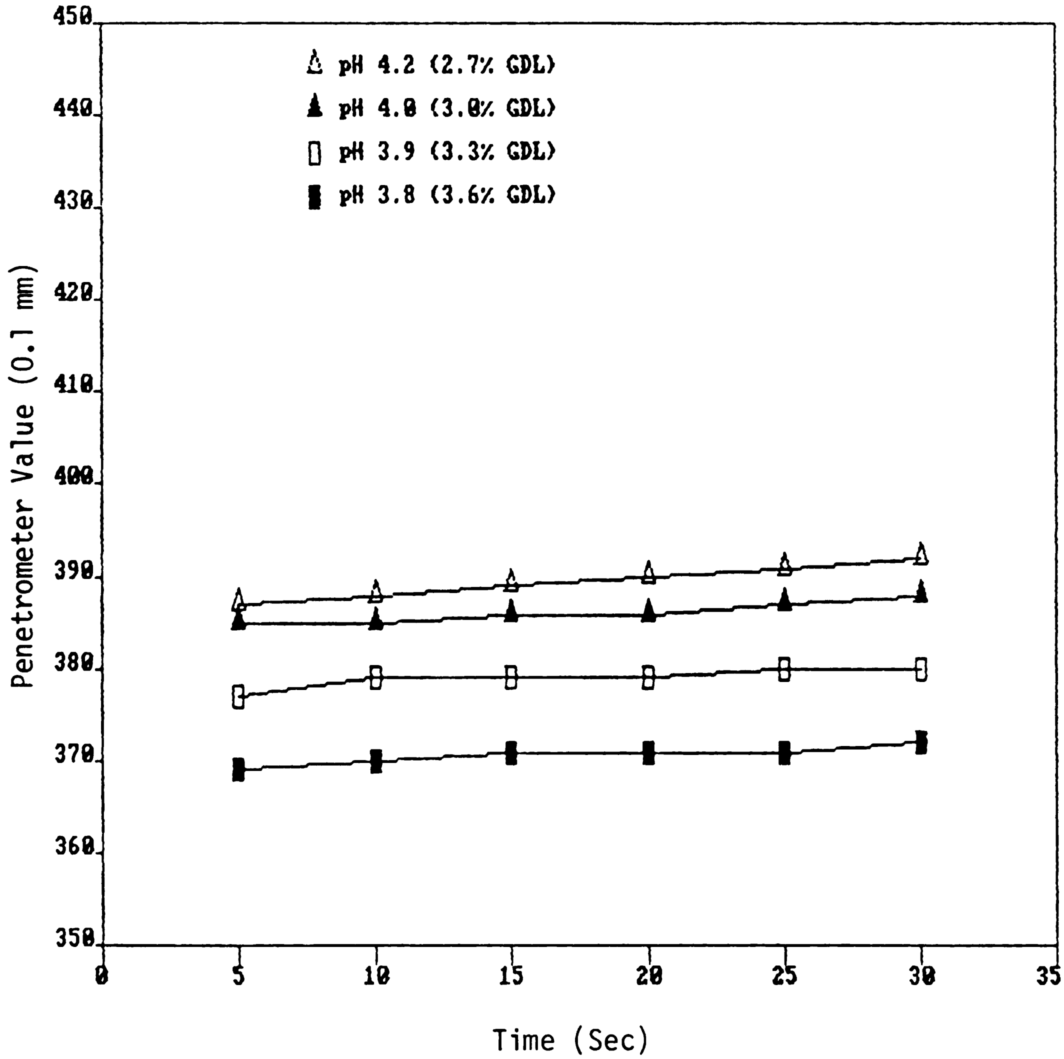


Figure 22. The effect of varying pH (GDL content) of mix on the gel firmness of freeze-dried direct set yogurt (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

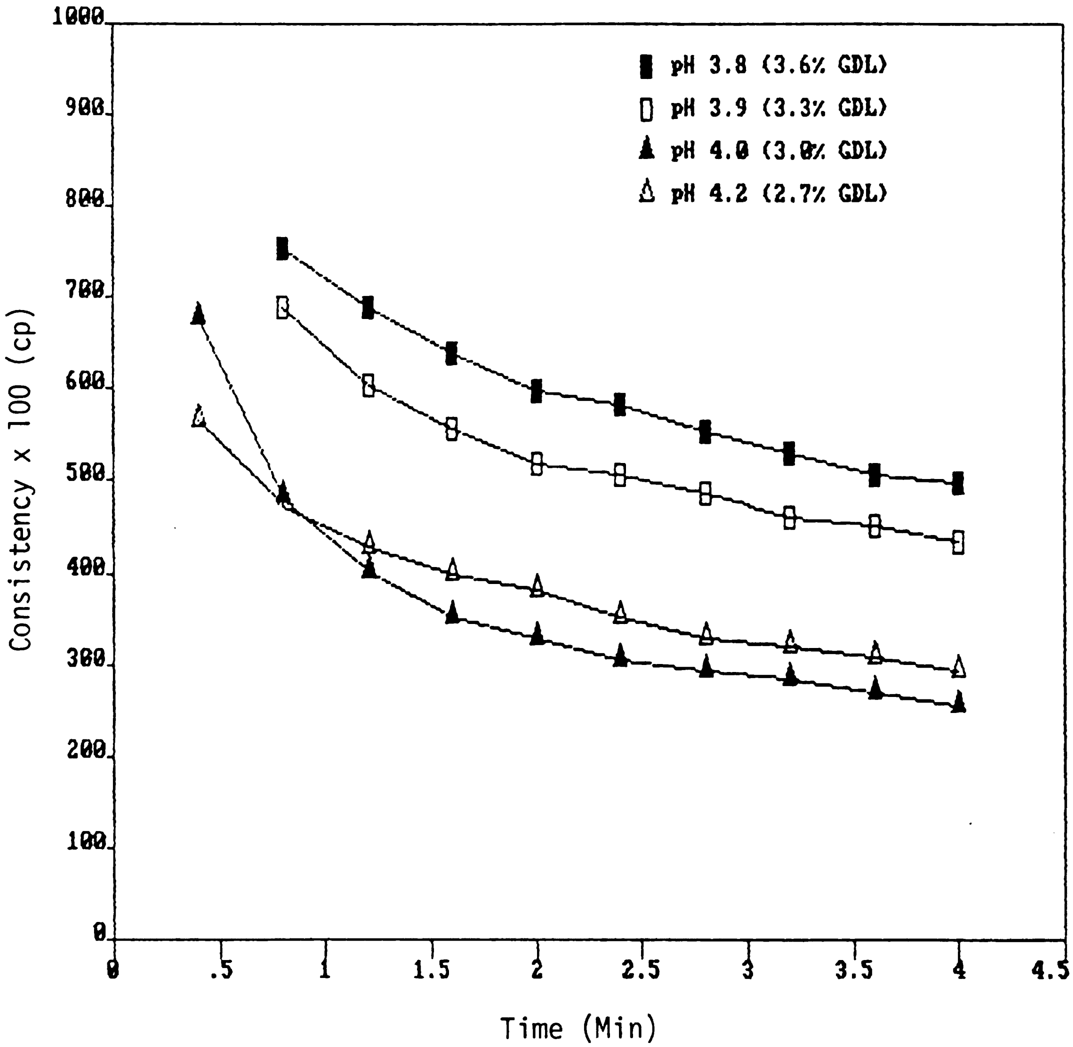


Figure 23. The effect of varying pH (GDL content) of mix on the consistency of freeze-dried direct set yogurt (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

An experiment was also designed to study the effect of dry blending additional GDL to direct set freeze-dried yogurt. The intent of this experiment was the possibility of compensating for loss of yogurt structure through freeze-drying by providing additional acidity upon reconstitution. It was contemplated that GDL might have the ability to contribute to reforming the matrix structure which was partially destroyed during the process. However, no positive effect was noted in the characteristics of blended yogurt powder and GDL powder (Figure 24). Apparently the coagulum strength could not be intensified when the mixture was hydrated with water. Additionally, GDL is not as readily hydrolyzed at the low temperature used for reconstitution.

Effect of Cold Storage on Physical Properties of Freeze-Dried Direct Set Yogurt

The storage of yogurts in the refrigerator after reconstituting the freeze-dried powder has definite influence on the physical properties as well as sensory improvements. Apparently, the changing temperature of products during storage affects the firmness of coagulum in yogurt (Figure 25). The low temperature and extended storage at refrigerator temperature ($5^{o}C$, $41^{o}F$) enhanced body, since it has long been noted with proteins such as gelatin that hydration occurs to a greater extent in the cold. This phenomenon may occur due to the hydration of milk protein and solidification of the gel structure of yogurt during cold storage (Kurmann, 1978).

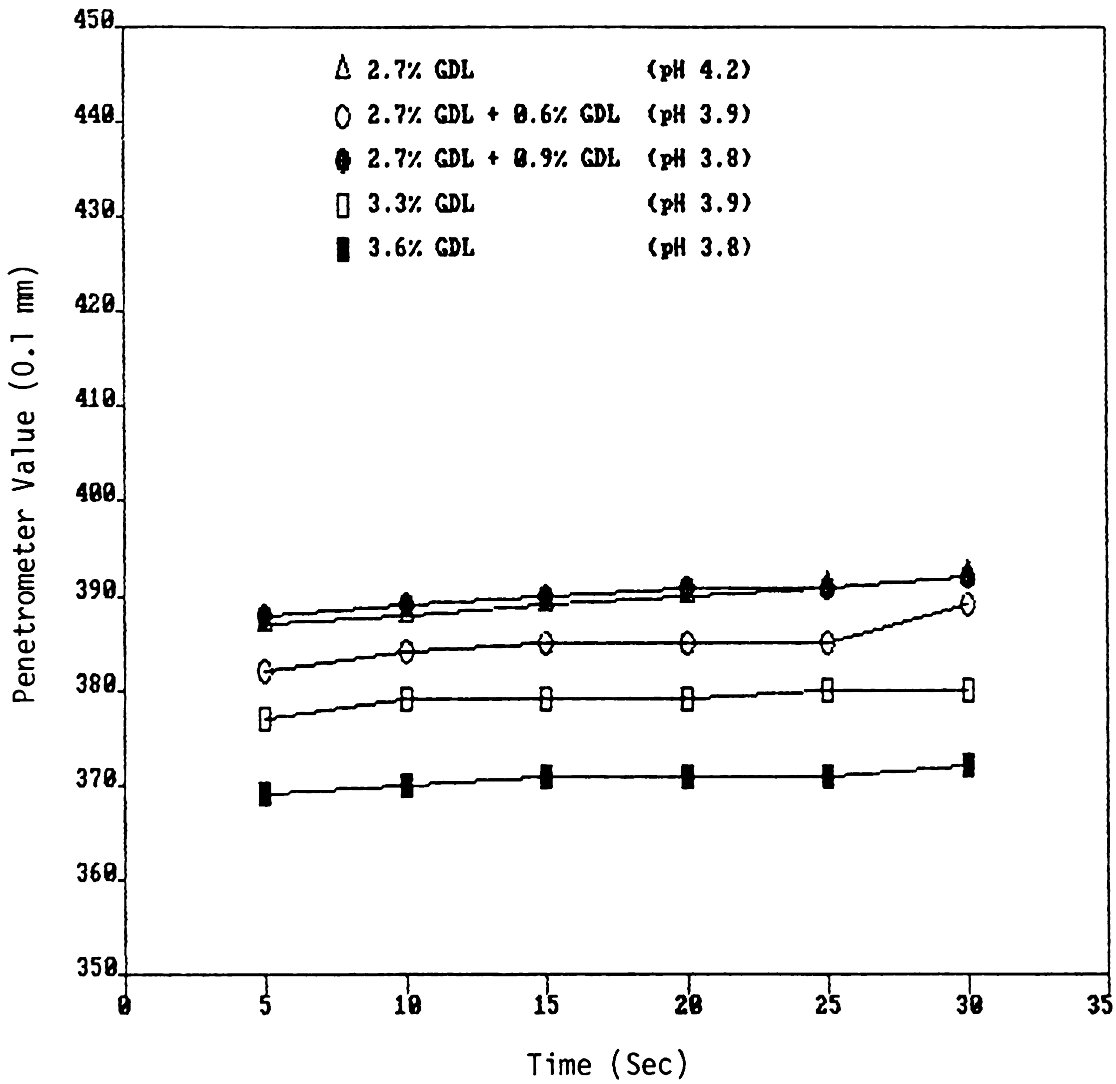


Figure 24. The effect of blending GDL powder and yogurt powder on the gel firmness of freeze-dried direct set yogurt (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

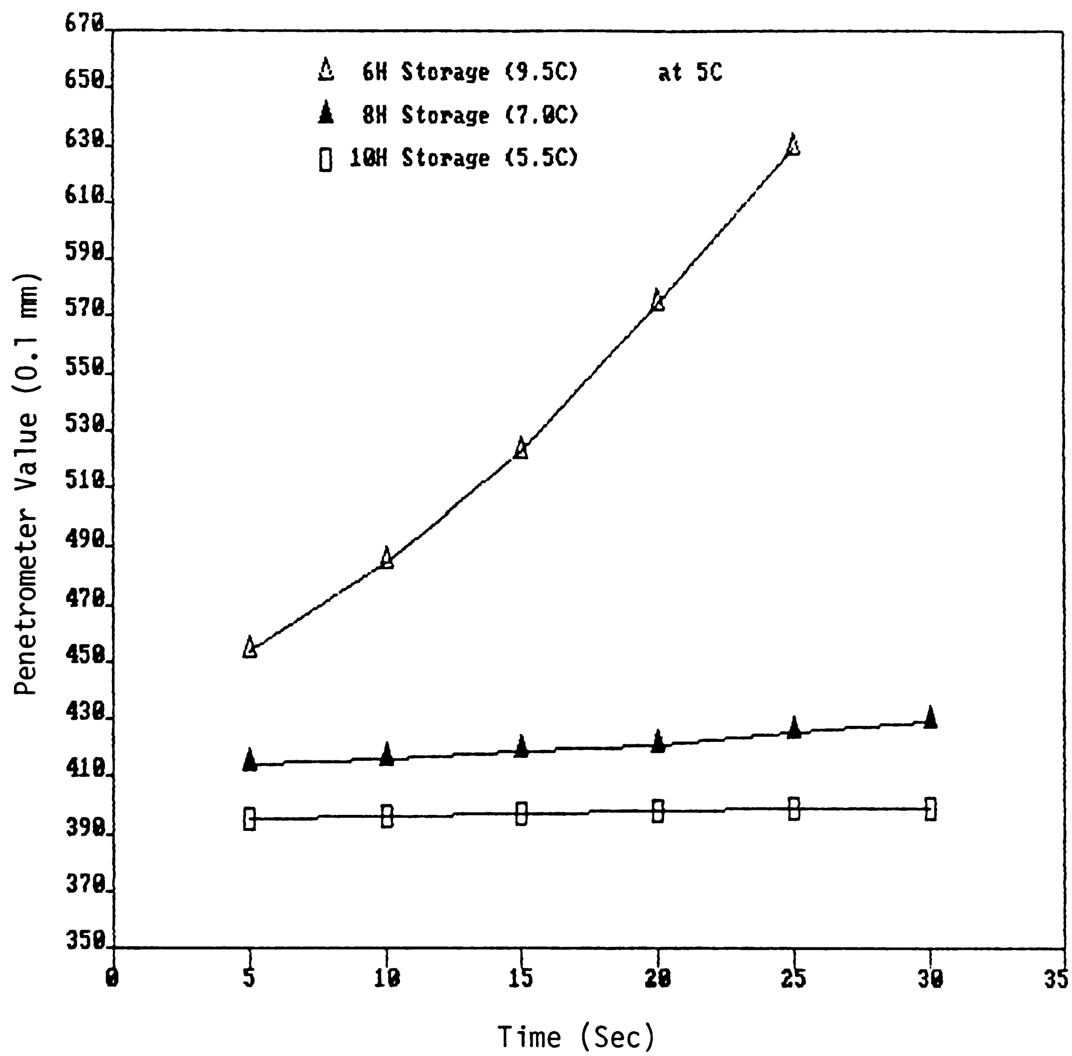


Figure 25. The effect of cold storage (5°C, 41°F) on the gel firmness of freeze-dried direct set yogurt (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

The required storage time to achieve reasonable physical properties are also dependent on other factors such as cooler capacity, total solids of yogurt, the volume of the vat or package and the heat conductivity of the vessel. Storage times up to 24 hours or longer are often empolyed.

It is concluded that a temperature of less than $7^{o}C$ is indispensable for reconstituted yogurts from the viewpoint of their body as well as their taste (Figure 25).

Effect of Mechanical Force on Physical Properties of Direct Set Yogurt

In yogurt manufacture, mechanical or physical forces which greatly affect the physical properties of yogurt can not be avoided. This is obvious in the case of stirred yogurt which has been coagulated in bulk in tanks and is subsequently agitated or blended to incorporate flavoring components prior to packaging. Processing steps resulting in flow through the plate cooler, pumps and pipes and filling into retail containers as well as incorporation of fruit can all be detrimental to structure of the yogurt. Therefore, consideration of mechanical effects is very important when the physical properties of the final yogurt is to be considered.

In this research work, the mechanical force was derived by stirring fresh or reconstituted yogurts slowly with a teaspoon for approximately five seconds, at which time the samples were again stored in the refrigerator before testing.

The comparison of gel firmness on quiescent yogurt and stirred yogurt of different pH (Figure 26 - Figure 29) indicates a large effect of mechanical treatment in only fresh yogurt. The data in the bar graph (Figure 30) show this tendency more clearly. The data suggest that the firm coagulum structure in fresh yogurt is much stronger, perhaps due to apolar bonding of the micelles, whereas the coagulum structure in reconstituted yogurt is weaker and elastic. The characteristic difference comes mainly from the difference in process handling with or without reconstituting process. Reconstituted yogurt which has already received mechanical treatment while being hydrated has a relative stability against additional mechanical force. This observation suggests that reconstituted yogurt would be suitable for stirred yogurt products which are subjected to the additional mechanical force.

Regardless of the relative stability of reconstituted powders is the fact that they are apparently weaker in structure than their fresh counterparts.

Effect of Moisture Content of Freeze-Dried Powder on Physical Properties of Reconstituted Direct Set Yogurt

The moisture content of freeze-dried powder must be considered from the standpoint of reconstitutibility as well as the effect of moisture on storage stability and physical and chemical properties.

According to the study of storage stability on cultured cream (Hamilton, 1970), the effect of level of moisture content and storage temperature are critical for some of the physical and chemical properties of the freeze-dried product.

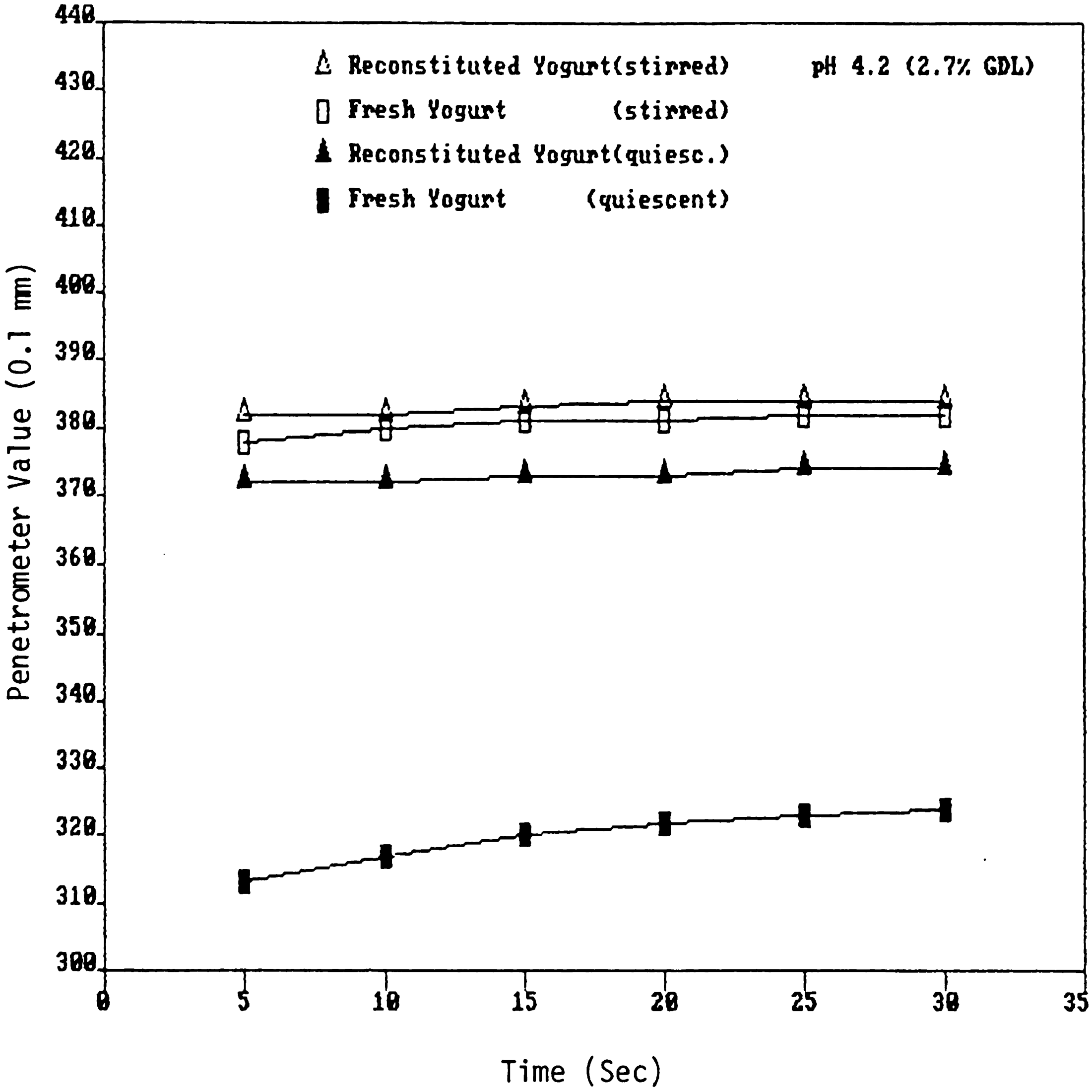


Figure 26. The effect of mechanical force on the gel firmness of direct set yogurt; pH 4.2 (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

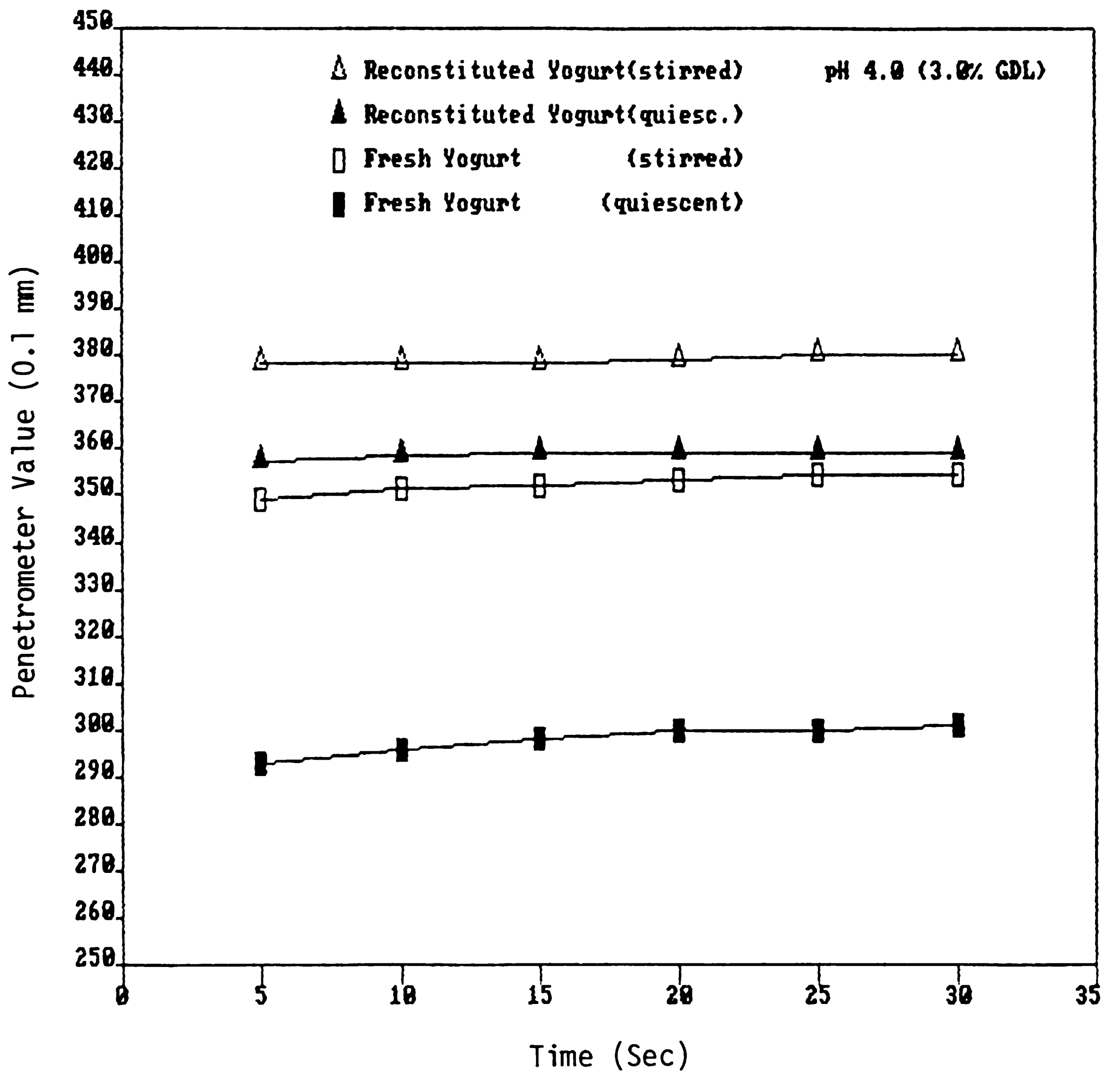


Figure 27. The effect of mechanical force on the gel firmness of direct set yogurt; pH 4.0 (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

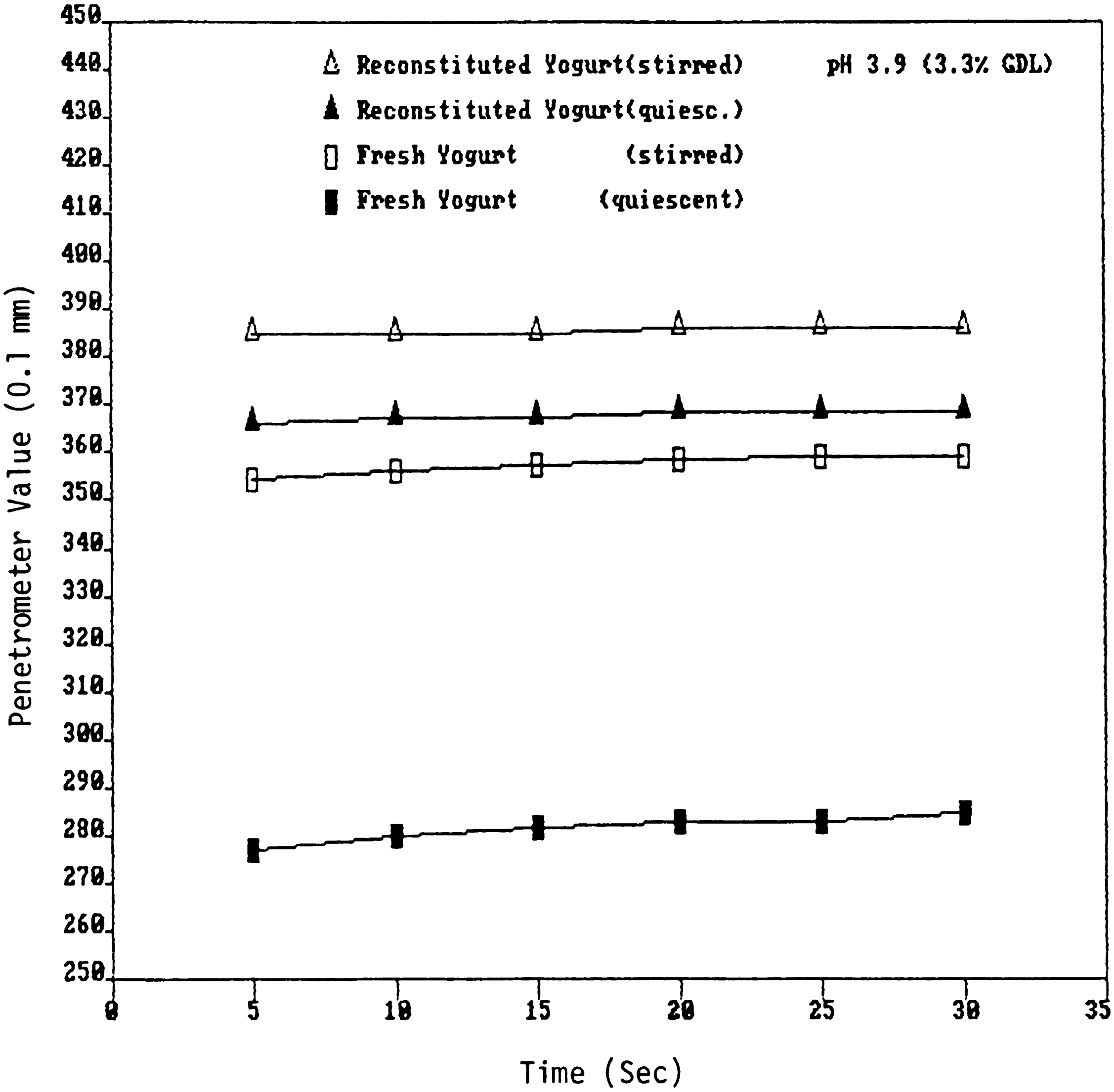


Figure 28. The effect of mechanical force on the gel firmness of direct set yogurt; pH 3.9 (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

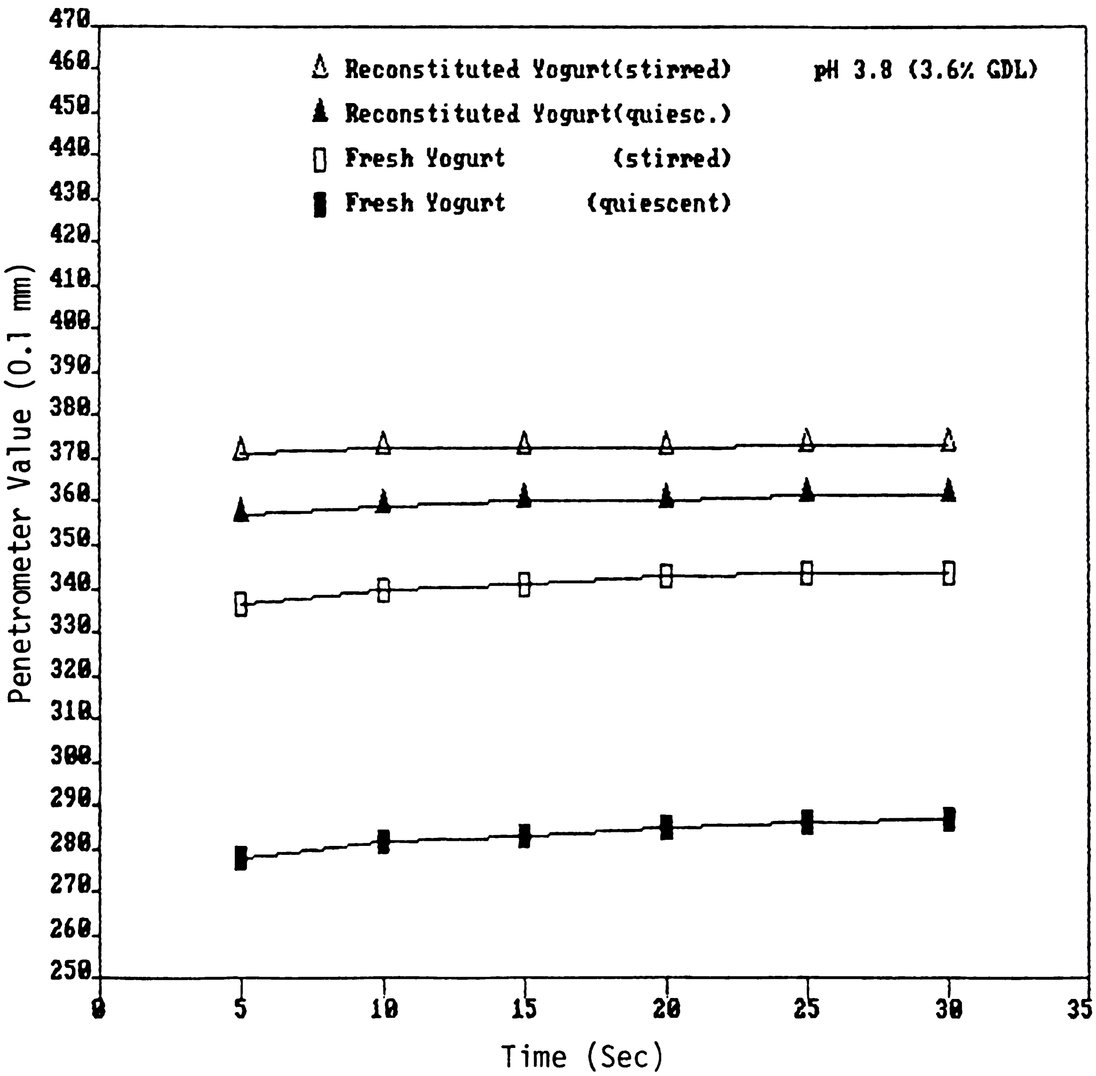


Figure 29. The effect of mechanical force on the gel firmness of direct set yogurt; pH 3.8 (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

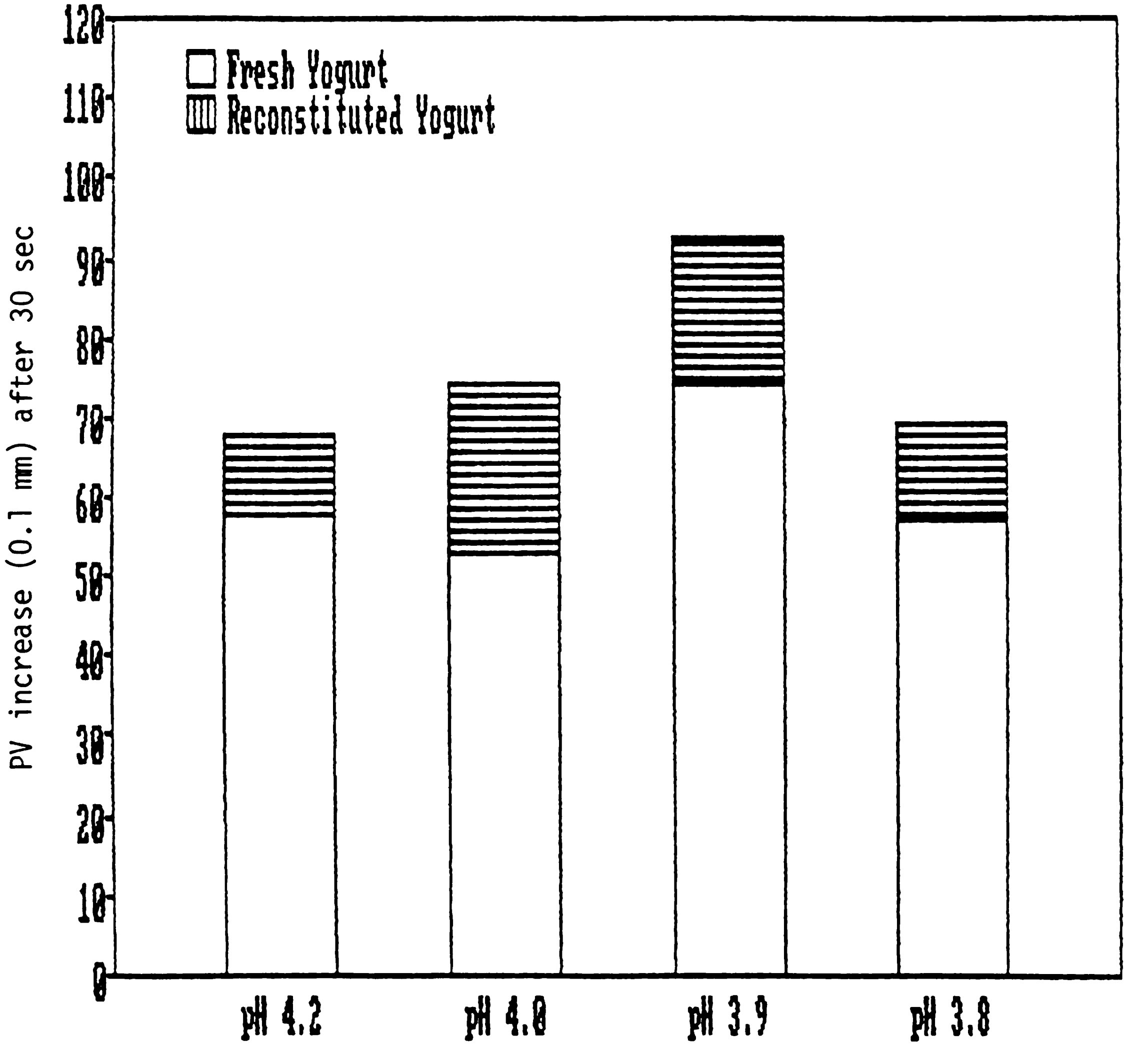


Figure 30. The loss of gel firmness by mechanical force for different pH direct set yogurt (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

In this research, a comparison of the gel firmness on two reconstituted yogurts prepared from powder of different moisture content was carried out. One of the freeze-dried powder samples was obtained through the normal process time (24 h) freeze-drying, on the other hand, the other powder sample was obtained through the shorter process time (approximately 19 h) freeze-drying. As a result, their moisture content was 3.78% and 5.10% respectively. Powder which was stored in screw top jars at room temperature ($24^{o}C$ - $26^{o}C$) for less than one month was used for this purpose to minimize stability loss during storage.

The data in Figure 31 indicate no effect of moisture content (at least in this range) on physical properties of freeze-dried reconstituted yogurt. Although this suggests that moisture content of powder within this range does not affect reconstitutibility of powder, one should also recognize that these are high moisture levels for optimal storage quality and additional data on samples of 1 - 3% moisture would be worth investigating.

In addition, no browning was observed in even high moisture freeze-dried powder during storage for four months at room temperature, in contrast to data of Hamilton and other researchers. Obviously, further investigation is necessary to study the effect of the moisture content of powder stored for longer times on the physical properties of reconstituted products.

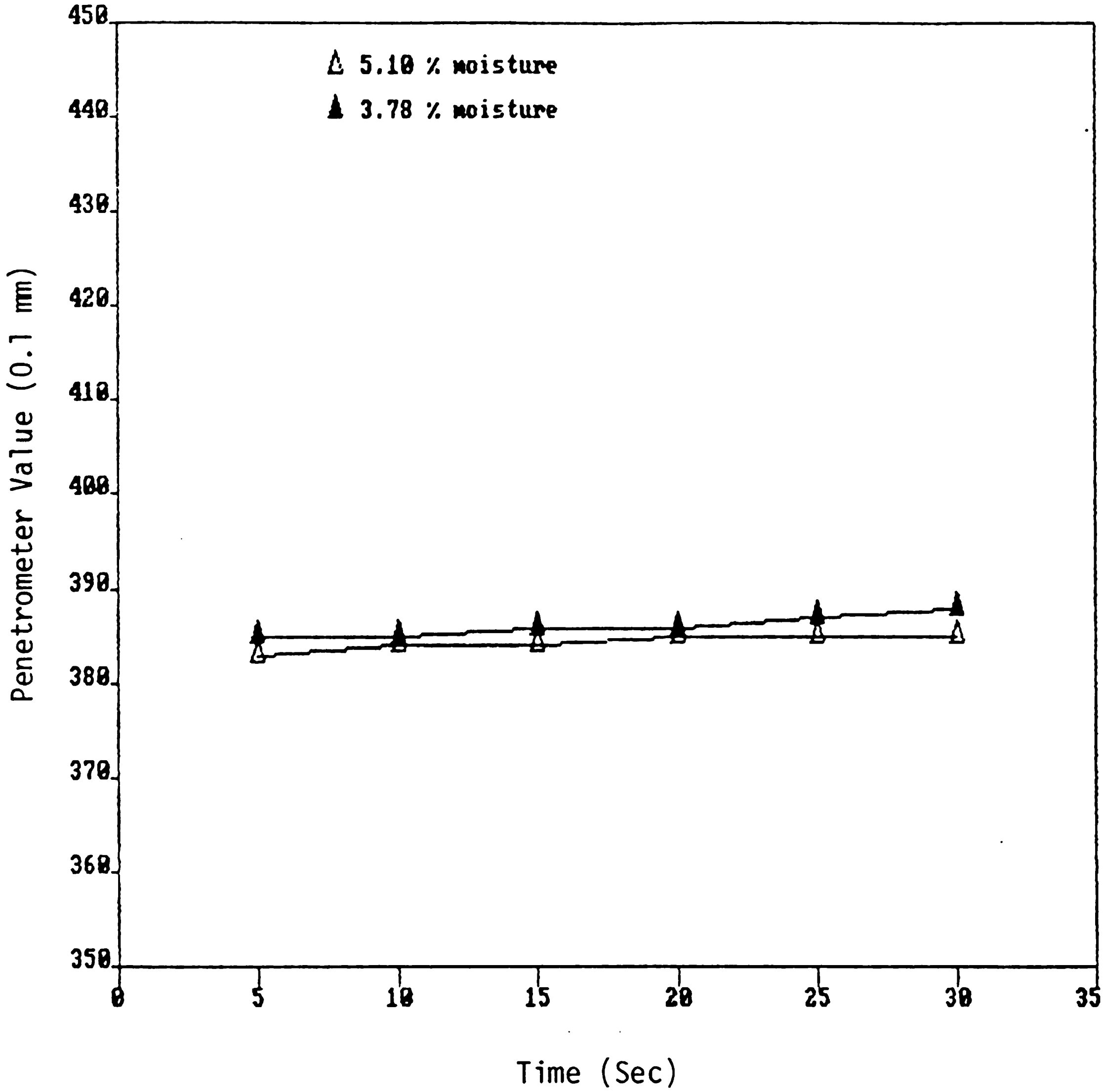


Figure 31. The effect of varying moisture content of freeze-dried powder on the gel firmness of freeze-dried direct set yogurt (Milk standardized to 3.1% fat, 15.2% SNF containing 0.3% pectin and 0.1% guar gum)

Sensory Evaluation

Fresh fermented yogurt (Dannon Plain Lowfat Yogurt), freeze-dried fermented yogurt, fresh direct set yogurt and freeze-dried direct set yogurt samples (all plain yogurts) were evaluated by the panel using a hedonic scale with a range of 1 - 7. Mean values show a significant difference between the fermented yogurt and the direct set yogurt (Table 2). The difference can be attributed mainly to the difference in flavor components of the two types of yogurt. The fermented yogurts tend to be evaluated as having higher quality, particularly on their freshness. This sensory tendency can be explained by the assumption that one of the major characteristics of plain yogurts is their typical fermented flavor and aroma due to acetaldehyde, acetone and diacetyl.

The loss of flavor components as a result of freeze-drying is not critical in judging for Freshness and Overall evaluation even though the score for Aroma decreases (Fresh vs Freeze-dried Fermented Yogurt).

The comparison of process difference between fresh and freeze-dried yogurts reveals the change of their physical properties. The mean value of the body evaluation on freeze-dried yogurts is similar to the results by analytical methods described before. On the other hand, the mean value of texture evaluation indicates the opposite results. This is due in part to psychological effect which causes people to evaluate elastic type materials as smooth.

The average of standard deviation values is related to the grade of sensory evaluation accuracy. According to the deviation values, the evaluation on Tartness and Body shows fair correctness; on the other hand, Freshness, Aroma and Overall evaluation results indicate a large

Table 2. Sensory evaluation of plain yogurt

	Fermented		Direct set		Average of S.D.
	Fresh	Freeze-dried	Fresh	Freeze-dried***	
Freshness	5.5*±1.78**	5.4±1.58	3.6±2.01	3.5±2.46	1.96
Aroma	5.3±1.77	4.3±2.00	4.1±2.08	4.0±2.16	2.00
Tartness	5.9±0.74	5.7±1.16	5.8±0.63	4.3±1.49	1.01
Body	6.3±0.82	4.4±1.17	4.9±1.45	4.2±1.32	1.19
Texture	5.1±1.79	6.0±0.82	4.7±1.77	5.6±1.51	1.47
Overall Evaluation	5.4±1.35	5.1±1.29	3.6±2.01	3.1±2.18	1.71

* Mean scores of ten judges based on Hedonic Scale 1 - 7 (Appendix 1)
** Standard Deviation (S.D.)
***Sample with additional 1.4% fat and 3.3% SNF

variation, which suggests the necessity of training judges for evaluating these categories.

The evaluation on physical properties such as Body and Texture, which is relatively reliable, does not indicate any major problem regarding physical properties of all of the yogurt samples, since freeze-dried direct set yogurt was made from milk fortified with NFDM and stabilizers.

None the less, sensory evaluation indicates the need to improve flavor and aroma in direct set plain yogurts in order to insure consumer acceptance. The success of food products in the market is greatly dependent on the consumer preference and acceptance of a product. Accordingly, direct set yogurts might be utilized better in flavored yogurt or fruit yogurt, rather than plain yogurt.

Study of Correlation on Data Obtained by Different Methods

The comparison of two sets of physical analysis data obtained by different equipment, i.e. penetrometer and Brookfield viscometer, was carried out by calculating correlation coefficient (R) and coefficient of determination (R^2) (Table 3).

Since it is unquestionable that the gel firmness of yogurt increases as the consistency of the same yogurt increases, it is easy to understand the reverse relationship between Penetrometer Value (PV) and consistency. This relationship is shown as negative value of R. The grade of R is in a range of 0.78 - 0.93, but two physical analyses can be considered to be correlated with each other. This result brings

Table 3. Comparison of two analytical methods on physical properties of freeze-dried direct set plain yogurt

	Study 1 Heat Treatment		Study 2 pH Difference	
	PV*	Con.** $\times 10^3$ (cp)	PV	Con. $\times 10^3$ (cp)
Condition 1	37.8	21.52	39.2	29.44
Condition 2	37.7	30.00	38.8	25.60
Condition 3	38.2	34.80	38.0	43.60
Condition 4	39.5	7.52	37.2	49.60
Correlation Coefficient (R)	-0.78		-0.93	
Coefficient of Determination (R^2)	0.61		0.87	

* Penetrometer Value (mm) after 30 seconds
**Consistency (cp) after 4 minutes

about the reproducibility of analysis on physical properties of yogurt.

Furthermore, the investigation of correlation between physical analysis and sensory evaluation for the same sample was carried out. The results (Table 4) reveal the following tendency.

The body of yogurt is evaluated firmer as PV decreases (gel firmness increases) and consistency increases. On the other hand, the texture of yogurt is evaluated smoother as PV increases and consistency decreases. The grade of correlation is variable, but the body evaluation and the determination of consistency is correlated very well. This result indicates the appropriateness of the analytical method to relate to the sensory evaluation of the yogurt body.

Table 4. Comparison of physical analysis and sensory evaluation

	Body vs P V		Body vs Consistency		Texture vs P V		Texture vs Consistency	
	Body*	PV**	Body	Con.*** x 10^3 (cp)	Tex.*	PV	Tex.	Con. x 10^3 (cp)
Sample A	6.3	31.1	6.3	75.36	5.1	31.1	5.1	75.36
Sample B	4.4	53.2	4.4	10.80	6.0	53.2	6.0	10.80
Sample C	4.9	37.9	4.9	17.60	4.7	37.9	4.7	17.60
Sample D	4.2	38.2	4.2	19.20	5.6	38.2	5.6	19.20
R	-0.67		0.95		0.74		-0.36	
R^2	0.45		0.89		0.54		0.13	

* Mean scores of ten judges based on Hedonic Scale 1 - 7 (Appendix 1)
** Penetrometer Value (mm) after 30 seconds
***Consistency (cp) after 150 seconds
Sample A: Fresh Fermented Yogurt
Sample B: Freeze-dried Fermented Yogurt
Sample C: Fresh Direct Set Yogurt
Sample D: Freeze-dried Direct Set Yogurt

SUMMARY AND CONCLUSIONS

1. An acceptable, fresh direct set yogurt which has good physical properties can be prepared without cultures by using glucono delta lactone (GDL) as an acidogen.
2. An acidification of 3% GDL to fortified milk for 90 minutes at $30^{o}C$ brings about a good final product.
3. The loss of typical body and texture of yogurts through the freeze-drying process is readily observed.
4. The physical properties of freeze-dried reconstituted yogurt can be improved by fortification with NFDM and some stabilizers.
5. A reasonable range of stabilizer content was found when stabilizers were used for yogurt mix.
6. Higher SNF content of the yogurt mix is necessary to form a firm gel in freeze-dried reconstituted yogurt. Therefore, yogurt mix must be fortified with NFDM.
7. The milk fat content is an important factor for the formation of appropriate gel structure. The milk fat contributes to good body in reconstituted yogurt.
8. The addition of sodium caseinate results in an increase in gel firmness of reconstituted yogurt to the extent that 2.4% SNF could be replaced by 1.0% of sodium caseinate. However, the texture of final product seemed to be slightly rough.

9. The direct addition of instantized skim milk powder to the freeze-dried powder failed to contribute a firm matrix structure.
10. Good physical properties of freeze-dried reconstituted yogurt can be obtained with heat treatment of 80°C (176°F) for 15 or 30 minutes.
11. Lower pH produced a better body of reconstituted yogurt in the range of pH 3.8 - 4.2.
12. Direct supplementation of the dehydrated yogurt with dry GDL failed to improve the physical properties of reconstituted yogurt.
13. The physical properties of reconstituted yogurt are greatly affected by the temperature of the product. Lower temperature favors a firm body as well as good sensory response.
14. Mechanical force did not adversely affect the loss of physical properties of reconstituted yogurt as much as it did in fresh set yogurt.
15. The moisture content of freeze-dried powder (3.78% - 5.10%) did not affect the reconstitutibility of the powder.
16. Naturally fermented yogurts tended to be evaluated higher by the sensory panel than the direct set yogurts even though the physical properties did not differ greatly.
17. An improvement of flavor and aroma is required for the direct set yogurt to obtain consumer acceptance.
18. The two sets of physical analysis data obtained by different instruments indicate high correlation, which enables reproducibility of physical analysis.

19. The comparison of physical analysis and sensory evaluation reveals high correlation between the analytical determination and the evaluation of body, which indicates appropriateness of analytical methods on physical properties of yogurts.

APPENDIX

Appendix 1

Sensory evaluation of four plain yogurt

Name ______________________ Sample # ____________ Date ____________

Freshness	very fresh	moderately fresh	slightly fresh	neutral	slightly stale	moderately stale	very stale
Aroma	very pronounced	moderately pronounced	slightly pronounced	perceptible	moderately perceptible	slightly perceptible	imper-ceptible
Tartness (acidity)	very tart	moderately tart	slightly tart	perceptible	moderately perceptible	slightly perceptible	imper-ceptible
Body	very firm	moderately firm	slightly firm	neutral	slightly weak	moderately weak	very weak
Texture	very smooth	moderately smooth	slightly smooth	neutral	slightly rough	moderately rough	very rough
Overall evaluation	very desirable	moderately desirable	slightly desirable	neutral	slightly undesirable	moderately undesirable	very undesir-able

REFERENCES

REFERENCES

Abrahamsen, R.K. and Holmen, T.B., 1981. Goat's milk yoghurt made from non-homogenized and homogenized milks, concentrated by different methods. J. Dairy Research 48:457-463.

Bottazzi, V., Battistotti, B. and Montescani, G., 1973. Influence des souches seules et associees de L. bulgaricus et Str. thermophilus ainsi que des traitements du lait sur la production d'aldehyde acetique dans le yaourt. Le Lait 53:295-308.

Broussalian, J. and Westhoff, D., 1983. Influence of lactose concentration of milk and yogurt on growth rate of rats. J. Dairy Science 66:438-443.

Critchett, N. and Flack, E.A., 1977. The use of emulsifying and stabilising agents in the development of dairy desserts. Dairy Industries International. 42(10):21-25.

Dahle, C.D., 1941. Frozen cream -- a review. J. Dairy Science 24: 245-264.

Davies, F.L., Shankar, P.A., Brooker, B.E. and Hobbs, D.G., 1978. A heat-induced change in the ultrastructure of milk and its effect on gel formation in yoghurt. J. Dairy Research 45:53-58.

Desai, I.D., Nickerson, T.A. and Jennings, W.G., 1961. Stability of frozen milk. J. Dairy Science 66:215-221.

Desai, R.J., 1966. A study of some physical and chemical properties of dehydrated sour cream. M.S. Thesis, Michigan State University.

Desai, R.J. and Harper, W.J., 1968. Characteristics of direct acidified sour cream. J. Dairy Science 51:941.

Doan, F.J. and Baldwin, F.B., 1936. Observations on the freezing of milk and cream. II. The destruction of the fat emulsion in frozen cream. J. Dairy Science 19:225-233.

Dumont, J.P. and Adda, J., 1973. Methode rapide des composes tres volatils de l'arome des produits laitiers. Application au yoghourt. Le Lait 53:12-22.

Emmons, D.B. and Tuckey, S.L., 1967. Cottage cheese and cultured milk products. Pfizer cheese monographs. 3:130-141. Chas. Pfizer and Co., Inc., New York, N.Y.

Forss, D.A., 1979. Review of the progress of dairy science: Mechanisms of formation of aroma compounds in milk and milk products. J. Dairy Research 46:691-706.

Galesloot, T.E., 1958. Onderzoekingen over de consistentie van yoghurt. Netherland Milk Dairy J. 12:130-165.

Gennip, A.H.M. van, 1973. Milk proteins and their use in practical emulsions. Paper presented at the international symposium on emulsions and foams in Food Technology, Ebeltoft, Denmark.

Gilles,J. and Lawrence, R.C., 1981. The manufacture of cheese and other fermented products from recombined milk. New Zealand J. Dairy Science and Technology 16:1-12.

Gorner, F., Palo, V. and Seginova, M., 1973. Simulation of yoghurt flavour and aroma. Bratislava, Czechoslovakia; Slovenska Chemicka Spolocnost pri SAV. 124-130 (Original not seen; cited in Dairy Science Abstract 37:494, 1973).

Goldblith, S.A., 1965. Take pulse of freeze-drying. Food Engineering 37(4):45-48.

Green, M.L. and Manning, D.J., 1982. Development of texture and flavour in cheese and other fermented products. J. Dairy Research 49: 737-748.

Hamilton, M.O., 1970. Rheology and stability of freeze-dried cultured cream. Ph.D. Thesis, Michigan State University.

Hewitt, D. and Bancroft, H.J., 1985. Nutritional value of yogurt. J. Dairy Research 52:197-207.

Jensen, G.K. and Nielsen, P., 1982. Review of the progress of Dairy Science: Milk powder and recombination of milk and milk products. J. Dairy Research 49:515-544.

Kalab, M., Emmons, D.B. and Sargant, A.G., 1975. Milk-gel structure. IV. Microstructure of yoghurts in relation to the presence of thickening agents. J. Dairy Research 42:453-458.

King, C.J., 1970. Freeze-drying of foodstuffs. The Chemical Rubber Co. Critical Reviews in Food Technology 1(3):379-442.

Kozhev, A., Penelski, I. and Panova, V., 1970. Bulgarian sour milk production employing fermentation in bulk. Izv. nauchnoizsled. Inst. mlech. Prom. 4:127-136 (Original not seen; cited in Dairy Science Abstract 34:678, 1972).

Labropoulos, A.E., Palmer, J.K. and Tao, P., 1982. Flavor evaluation and characterization of yogurt as affected by ultra-high temperature and vat processes. J. Dairy Science 67:191-196.

Labropoulos, A.E., Collins, W.F. and Stone, W.K., 1984. Effects of ultra-high temperature and vat processes on heat-induced rheological properties of yogurt. J. Dairy Science 67:405-409.

Mabbitt, L.A., Chapman, H.R. and Berridge, N.J., 1951. Experiments in cheesemaking without starter. J. Dairy Research 22:365-373.

Marshall, V.M., Cole, W.M. and Mabbitt, L.A., 1982. Yoghurt made from single starter organisms using heat- or enzyme-treated milk or milk to which casein hydrolysate or sodium formate is added. J. Dairy Research 49:147-152.

Marshall, V.M., Cole, W.M. and Vega, J.R., 1982. A yoghurt-like product made by fermenting ultrafiltered milk containing elevated whey proteins with Lactobacillus acidophilus. J. Dairy Research 49: 665-670.

Mickle, J.B., 1966. Influence of emulsifiers and nonfat milk solids on physical stability of reconstituted lyophilized milk products. J. Dairy Science 49:1117-1119.

Modler, H.W., Larmond, M.E., Lin, C.S., Froehlich, D. and Emmons, D.B., 1983. Physical and sensory properties of yogurt stabilized with milk proteins. J. Dairy Science 66:422-429.

Modler, H.W. and Kalab, M., 1983. Microstructure of yogurt stabilized with milk proteins. J. Dairy Science 66:430-437.

O'Keeffe, R.B., Fox, P.F. and Daly, C., 1975. Proteolysis in cheddar cheese: Influence of the rate of acid production during manufacture. J. Dairy Research 42:111-122.

O'Neil, J.M., Kleyn, D.H. and Hare, L.B., 1979. Consistency and compositional characteristics of commercial yogurts. J. Dairy Science 62:1032-1036.

Rasic, J.L. and Kurmann, J.A., 1978. Yoghurt: Scientific grounds, technology, manufacture and preparation. Fermented Fresh Milk Products, Volume 1. Technical Dairy Publishing House, Copenhagen, Denmark.

Richmond, M.L., 1982. High performance liquid chromatografic analysis of natural fermented yogurt. Ph.D. Thesis, Michigan State University.

Schmidt, R.H., Sistrunk, C.P., Richter, R.L. and Cornell, J.A., 1980. Heat treatment and storage effects on texture characteristics of milk and yogurt systems fortified with oilseed proteins. J. Food Science 45:471-475.

Stein, M., 1966. Freeze-drying: The present position surveyed. Food Manufacture 41(2):51-54.

Storgards, T., 1964. Fermented milks. IDF Annual Bulletin 3:65-75, Bruxelles, Belgium.

Tamime, A.Y. and Deeth, H.C., 1980. Yogurt: Technology and Biochemistry. J. Food Protection 43:939-977.

Tamime, A.Y. and Robinson, R.K., 1983. Yoghurt: Science and Technology. Pergamon Press, New York, N.Y.

Towler, C., 1984. Sedimentation in a cultured milk beverage. New Zealand J. Dairy Science and Technology 19:205-211.

Trop, M., 1984. Simulation of bacterial fermentation of milk and possible acylation of its proteins by acidogen hydrolysis. J. Dairy Science 67:1381-1389.

Webb, B.H. and Hall, S.A., 1935. Some physical effect of freezing upon milk and cream. J. Dairy Science 18:275-286.

Wildasin, H.L. and Doan, F.J., 1951. Some additional influences affecting the stability of concentrated milk in frozen storage. J. Dairy Science 34:438-445.

Wong, N.P., Mcdonough, F.E. and Hitchins, A.D., 1983. Contribution of Streptococcus thermophilus to growth-stimulating effect of yogurt on rats. J. Dairy Science 66:444-449.