

/THE USE OF CHEMICAL LEAVENING IN FROZEN DOUGHS/

by

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TABLE OF CONTENTS

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Page

ACKNOWLEDGMENTS	v
INTRODUCTION.....	1
LITERATURE REVIEW.....	2
Frozen Doughs	2
Commercial and Consumer Use	2
Stability	3
Rheology	5
Chemical Leavening	6
Leavening Reaction	7
Leavening Mechanism	7
Leavening Rate	8
Neutralizing Value	9
Applications	10
MATERIALS AND METHODS	11
Ingredients	11
Straight Dough Method	11
pH Determination	13
Gassing Power Determination	13
Resistance Oven	13
Remix Procedure	14
Preparation of Chemical Leavening and Reaction Salts	17
Mixograph	17
No-Time Dough Method	18
Freezing	18
Thawing	27
Addition of Chemical Leavening to Frozen Doughs	27
RESULTS AND DISCUSSION	31
Effect of pH on Gas Production	31
Effect of pH on Loaf Volume	34
Effect of Leavening Acids on Loaf Volume	36
Effect of Reaction Salts on Loaf Volume	39
Frozen Dough Freeze/Thaw Studies	54
Study of Short-Time Fermentation Formula and Process	59
Addition of Chemical Leavening in Frozen Doughs	64
SUMMARY	68
LITERATURE CITED	70

LIST OF TABLES

Page

Table I.	Straight Dough Bread Formula	12
Table II.	Baking Results at Certain Dough pH Values	35
Table III.	Comparison of Control and Remixed Dough.....	37
Table IV.	Effect of Chemical Leavening on Dough pH and Bread	38
Table V.	Effect of Leavening Acids on Loaf Volume	42
Table VI.	Effect of Reaction Salts on Loaf Volume	46
Table VII.	Effect of NaCl Plus Reaction Salts on Loaf Volume	47
Table VIII.	Mixograph Study Results on Specific Ions of the Lyotropic Series	52
Table IX.	Effect of the Amount and Type of Reaction Salt on Gassing Power and Loaf Volume	53
Table X.	Optimizing Freeze/Thaw Conditions for Frozen Doughs	56
Table XI.	Storage Study for Frozen Doughs	57
Table XII.	Higher Temperature Thawing/Proofing of Frozen Doughs	58
Table XIII.	Addition of Chemical Leavening in Frozen Doughs	67

LIST OF FIGURES

	Page
Fig. 1. Scheme for Remix Procedure	16
Fig. 2. Mixograms of the Salt Concentration Series for Sodium Sulfate	20
Fig. 3. Specified Curve Type for Mixograph Study on Lyotropic Ion Series	22
Fig. 4. No-Time Fermentation Procedure	24
Fig. 5. Short-Time Fermentation Scheme Used for Frozen Doughs	26
Fig. 6. Procedure for the Addition of Leavening Acids Plus Soda in Frozen Doughs	29
Fig. 7. Effect of pH on Yeast Activity	33
Fig. 8. Resulting pH After Heating SALP Plus Soda in Water	41
Fig. 9. Effect of NaCl on Loaf Volume	45
Fig. 10. Effect of Levels of Reaction Salts on Loaf Volume	49
Fig. 11. Effect of NaCl on Loaf Volume in a No-Time Fermentation System	61
Fig. 12. Addition of NFDM to No-Time Doughs	63
Fig. 13. Addition of SAS in a No-Time Fermentation System..	66

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INTRODUCTION

In spite of the fact that they generally suffer from variable performance, frozen doughs are gaining acceptance in the baking industry. As reported by many investigators (Hsu et al 1979, Kline and Sugihara 1968, Merritt 1960) the major problem with frozen doughs is the performance of the yeast. Yeast is necessary to provide proper gas production for dough leavening. In any yeast-leavened dough the aroma, taste and texture of the final product are dependent on the yeast fermentation and its development action (Merritt 1960). When frozen dough is thawed, yeast's viability and capacity to produce gas is decreased, resulting in bread with lower loaf volume and inferior quality.

Leavening gives dough a cellular structure that improves the texture, edibility, and appearance of the finished product. Carbon dioxide produced either by yeast fermentation or chemical reaction is a major leavening gas. Chemical and yeast leavening sources are rarely used together in the same product. Their combination apparently has not been studied.

The objective of this study was to examine the feasibility of using a combination of chemical and yeast leavening to produce a frozen dough product that is comparable to a freshly baked yeast-leavened bread. With the beneficial effects of yeast and additional leavening from the chemical leaveners it was hoped more acceptable bread products could be produced from frozen doughs.

Frozen Doughs

Commercial and Consumer Use. Refrigeration and freezing technology were introduced to the baking industry in the 1920's, first for air-conditioning and fermentation control and soon thereafter for product freezing. In the baking industry, freezing technology made possible such products as frozen baked goods and frozen doughs (Drake 1970). In recent years, frozen doughs have increased in popularity and acceptance. Reasons for this increased interest include the important advantages frozen doughs provide for both the consumer and the food manufacturer (Vetter 1979). For the consumer, the prospect of baking at home fascinates many people and entices them to try their skill at the art of breadmaking. A strong attraction is the delicious aroma of bread fresh from the oven. Another is the expectant satisfaction and pride of being able to serve one's own product. There are, however, several difficulties and inconveniences associated with home breadmaking. These include obtaining a suitable yeast supply and the time and effort necessary to complete the task. The purchase of a fully prepared frozen dough at a local store removes those difficulties and enables the home breadmaker to concentrate on the proofing and baking of the dough (Marston 1978).

Production of frozen doughs has increased in the past decade, partly because of consumer sales but mostly as a result of the growing number of in-store bakeries. Commercial bakers

find it convenient to freeze dough pieces which then can be held for short periods before being proofed and baked as required. This is particularly convenient for in-store bakeries where doughs can be ready for baking without the need for a dough mixer or other equipment. Also frozen doughs are an advantage economically to the commercial in-store baker. A complete bakery requires twice as much space as a bake-off facility (proofing and baking of frozen doughs done in-store) and six times as much as the cold spot (no baking done in-store). A complete bakery also requires a greater number of skilled workers (Vetter 1979). Further, frozen doughs are lower priced than baked products. Finally, frozen dough processors distribute their products over a wider geographical area. This, therefore, increases the efficiency of their distribution system (Lorenz 1974).

Stability. There are, of course, disadvantages with the frozen bread dough system. The major problem with marketing frozen doughs is deterioration in stability during storage (Varriano-Marston et al 1980). Stability of frozen dough is the ability of thawed dough to proof in an acceptable period of time and to bake into a loaf with normal volume and bread characteristics (Wolt 1984). Studies have shown that frozen dough stability is related to yeast quality, dough formulation and process, and freezing and thawing conditions (Davis 1981, Hsu et al 1979a, Hsu et al 1979b, Kline and Sugihara 1968, Lorenz 1974, Merritt 1960).

Yeast is the single most studied ingredient in frozen dough (Bruinsma and Giesenschlag 1984). The interest in yeast is because it is the ingredient that provides proper gas production

for dough leavening as well as the character and flavor of the finished bread product (Bruinsma and Giesenschlag 1984). Kline and Sugihara (1968) reported that the first problem which must be solved with frozen unbaked doughs is the retention of sufficient yeast viability and gassing power during frozen storage to avoid excessive proofing times or even a virtual loss of proofing power, after thawing the frozen product. Minor improvements in quality of the thawed product can be achieved by formulation changes, selecting type of yeast, using dough conditioners, decreasing absorption, using oxidizing agents or by re-working the dough after thawing (Bruinsma and Giesenschlag 1984, Davis 1981, Lorenz and Bechtel 1965, Lorenz and Bechtel 1964). A review of these improvements is detailed by Pizzinatto (1979). However, these are of little consequence if the yeast activity is not maintained at a pre-freezing level.

There appears to be a consensus that to achieve yeast stability during frozen storage one must minimize or eliminate yeast activity prior to moulding and freezing of the dough (Merritt 1960, Meyer et al 1956, Godkin and Cathcart 1949, McPherson and Lamb 1948). Merritt (1960) suggests that the greater stability of yeast in frozen doughs prepared with minimal fermentation is probably because the yeast is still in a dormant state. Short-time breadmaking processes such as the Chorleywood Bread Process or Activated Dough Development are, therefore, more suitable for the production of frozen dough (Cauvain 1982). The straight dough method with minimal fermentation time is recommended. However, stability achieved by abbreviated

fermentation time is at the expense of aroma, flavor, crumb grain, and to a lesser extent, loaf volume.

During fermentation yeast becomes active and thereby vulnerable to freezing damage. Consequently, as a result of the long fermentation time of the sponge, the sponge and dough method is not considered a viable process for the preparation of frozen doughs. However, Lorenz and Bechtel (1964, 1965) reported that, at least for short storage periods, doughs with full fermentation produced better bread than those without fermentation before freezing.

The rate of freezing and thawing also has an effect on yeast viability. Results show that freezing rate should be slow and thawing rate rapid (Pizzinatto 1979, Lorenz 1974). Slow freezing is generally believed to allow cells to adjust to the freezing environment by transferring intracellular water to external ice. Fast freezing, on the other hand, causes intracellular freezing because temperature changes are faster than the transport of water to the external environment. The small ice crystals formed during intracellular freezing are likely to recrystallize into larger crystals during warming and hence become lethal to the cells (Lorenz 1974). Another view proposed by Hsu et al (1979b) was that the lowest temperature reached had a greater effect on yeast survival than the freezing rate.

Rheology. Kline and Sugihara (1968) noted that dough rheology was altered when doughs were stored for long periods in the freezer or when subjected to freeze-thaw cycles. This is a problem. Frozen doughs, after thawing, are often slack and sticky. Those doughs retain gas poorly. The defect is possibly

associated with the release of reducing substances from yeast cells which died during frozen storage (Kline and Sugihara 1968). Wolt and D 'Appolonia (1984) refuted this idea with data that did not support the theory that reducing compounds are a factor in the gas retention of frozen doughs. Varriano-Marston et al (1980) stated that the phenomenon of ice recrystallization contributed to the weakening of the three-dimensional protein network responsible for gas retention in doughs.

The significance of much of the research on frozen dough stability is not totally understood. The future of the frozen dough industry depends upon the success of researchers in discovering ways to solve existing problems.

Chemical Leavening

The word "leavening" is derived from the Latin *levo* "to raise" and means raising or making light (Kichline and Conn 1970). The first known record of leavened products was the result of the use of yeast by the Egyptians as early as 2000 B.C. (LaBaw 1982). The baking powder principle resulted much later when it was patented in 1838 in England (Conn 1981).

Light, palatable bakery products are achieved by mixing air into dough or batter forming small bubbles. Bubbles are then inflated and the product "set" by heat so it structurally supports itself without the help of trapped gas. Chemical leavening provides a quick way of inflating the bubbles (Conn 1965, Conn 1981). The resulting cellular structure in the baked product adds a pleasing appearance and contributes to the texture.

Leavening Reaction. Carbon dioxide (CO_2) is the principle leavening gas and is produced by one of three mechanisms: fermentation, where yeast ferments sugar and produces alcohol and carbon dioxide, decomposition, where ammonium bicarbonate in the presence of heat produces ammonia, water, and carbon dioxide, and the reaction of an acidic salt and sodium bicarbonate in the presence of moisture and heat to form a salt, water, and carbon dioxide. The popularity of the third mechanism is based upon sodium bicarbonate's low cost, lack of toxicity, ease of handling, tasteless end products, and high purity (Conn 1965).

Leavening Mechanism. Chemical leavening occurs in stages: 1) during mixing 2) while the product awaits baking (bench action) and 3) during baking. Carbon dioxide must be released at just the right time during dough preparation and subsequent baking to obtain optimum properties in the baked product. The initial or nucleating gas comes from the incorporation of air into the dough or batter during mixing. This is followed by the formation of CO_2 from the reaction of the leavening acid with soda. Thus, the small bubbles (containing air and CO_2) are finely dispersed during the mixing and retained in the system. The greater the number of bubbles and the more stable the dispersion, the finer the grain and the thinner the cell walls in the final product. Ideally, no carbon dioxide evolution should occur during bench action.

During the expansion or baking stage, CO_2 must be released at the proper time. Most of the available CO_2 must be released before the product reaches its set-point temperature. If CO_2 production is complete before the structure sets, a coarse or

collapsed structure may result. If CO_2 production is still occurring when the structure sets, a smaller volume can result or structural rupturing can occur.

Leavening Rate. Depending upon the type of baked product, different amounts of chemical leavening are needed at each stage of the process (Anonymous 1983). A baker must select a leavening system with the rate of leavening that suits the type and form of the end product, taste, texture, and color desired.

Because soda dissolves almost immediately, the leavening acid's rate of dissolution determines the rate of CO_2 release. Leavening acids therefore are characterized by leavening rate. There are two classifications of leavening rates. Fast acting acids liberate as much as 80 percent of the leavening gas during mixing and standing (Anonymous 1983). An example of a fast acting acid is monocalcium phosphate (MCP). MCP's leavening reaction produces most of its gas within 2 min after mixing. There is virtually no gas produced on standing. The remaining gas is evolved during baking. The other type, slow acting, produces the major portion of CO_2 as the temperature of the product rises during baking (Anonymous 1983). An example of a slow acting acid is sodium aluminum phosphate (SALP). SALP has a relatively slow reaction rate during mixing and minimal CO_2 production during standing. Maximum reaction potential is retained for baking. Other examples of fast and slow acting acids are described by Conn (1965, 1981) and LaBaw (1982).

Leavening rates are generally determined in doughs. The volume or pressure of released carbon dioxide is measured as a

function of time and expressed as percentage of carbon dioxide added as soda (Kichline and Conn 1970).

LaBaw (1982) reported that the temperature of the system and certain interactions between soluble materials in the formula influence the rate of reaction. The temperature of the system affects the solubilities of both the acid leavening agent and the bicarbonate. Generally, the lower the temperature, the slower the rate of solubilization of the acidic component and the slower the rate of reaction. Also, soluble salts such as the calcium ions present in milk or hard water will decrease the rate of solubilization of certain leavening acids and, thereby, influence its reaction rate.

Neutralizing Value. The concept of neutralizing value (N.V.) was developed to compare both the available acidity (CO₂ releasing power) of various leaveners and, more important, to calculate the correct level of usage (Conn 1981, Kichline and Conn 1970, Conn 1965). Neutralization value is defined as the parts by weight of sodium bicarbonate which will neutralize 100 parts by weight of an acid leavener so as to convert the bicarbonate to carbon dioxide. The following formula is used to calculate the neutralizing value of an acid leavening agent:

$$\text{N.V.} = \frac{\text{Soda (g)}}{\text{Leavening Acid (g)}} \times 100$$

Weights can be expressed in any units as long as the same units are used for both the soda and the acid (LaBaw 1982). The practical value of knowing this figure is in determining the amount of leavening acid required to neutralize a known quantity

of sodium bicarbonate. Normally, the proportions of soda and acid used are calculated so that little unused soda remains after baking. The soda and acid are balanced to give a neutral pH in the baked product except when particular effects such as color and flavor related to the pH of the final product are desired.

Applications. Chemical leavening has been applied to a variety of baked products. The largest use of chemical leavening is in prepared mixes (Reiman 1977). Products such as cakes, muffins, quick breads, waffles and pancakes, cookies, brownies and bar mixes contribute to this usage. Other uses include self-rising flour, pretzels, doughnuts, crackers and refrigerated doughs. The opportunity for other applications continues to be studied.

Ingredients

Two shipments of a commercial bread flour (Flours A and B) from Ross Mills, Wichita, Kansas, were used in the preparation of the bread doughs. Flour A contained 12.29% protein and 0.472% ash. Flour B contained 11.85% protein and 0.462% ash. A hydrogenated vegetable shortening (Crisco, Proctor & Gamble, Cincinnati, Ohio) was also used in the bread formula. Fermipan instant dry yeast (Gist-Brocades, Delft, The Netherlands) was used.

Sodium bicarbonate was obtained from the Church & Dwight Co., Inc., Princeton, N. J. The leavening acids were acquired from Stauffer Chemical Co., Westport, Connecticut, except for the sodium aluminum sulfate which was obtained from Allied Chemical, Morristown, New Jersey. The sodium and chloride salts of the cationic and anionic lyotropic series were purchased from Fisher Scientific Co., Fair Lawn, NJ. All chemicals were reagent grade.

Straight Dough Method

Doughs used for baking experiments were prepared using the straight dough procedure as described by Finney (1984). Table 1 shows the formula used. Doughs were mixed to optimum in a National 100 g pin mixer (National Mfg. Co., Lincoln, NE) and fermented at 30° C, 90-95% RH in a proof cabinet (National Mfg. Co., Lincoln, NE). A 180 min fermentation time was used with mechanical punches at 105 min and 155 min intervals. At the end of the fermentation, the dough was sheeted through the rolls set at 5/16" opening and moulded with a drum moulder (Thomson

Table 1. Straight Dough Bread Formula.

Ingredients	g ^a
Flour	100.0 ^b
Sugar	6.0
Salt	1.5
Nonfat Dry Milk (NFDM)	4.0
Shortening	3.0
Yeast	2.0
Potassium Bromate (KBrO ₃)	10 ppm
Water	optimum

^ag Based on Flour Weight

^b14% Moisture Basis

Co., Belleville, NJ). The moulded dough was panned and proofed at 30° C, 90-95% RH for 55 min. Baking was at 218° C (425° F) for 24 min. The weight and volume of the loaf were measured immediately after baking. Volume was determined by rape-seed displacement.

pH Determination

To determine the pH of dough, a 10 g sample was added to 100 ml of distilled water. The sample was then blended for 1 min at high speed in a blender. A Corning model 125 pH meter with electrodes which had been calibrated against known buffer solutions was used to determine hydrogen-ion activity. The sample was continuously agitated and the reading taken when the meter stabilized. Hydrogen-ion activity of bread samples was determined by using AACC method 02-52 (AACC 1976).

Gassing Power Determination

The Gasograph (DSI Gasograph 12) was used in all determinations of gassing power (Rubenthaler et al 1980). A 15 g sample of dough was placed in a gasograph vessel. The vessel was then placed in a 30° C water bath and allowed to stand two min before connecting the gas tube to the reaction vessel. This time-interval allowed for thermal expansion of the air in the reaction vessel which should not be considered as part of the total volume of evolved gas. Each sample was prepared as above and placed on the gasograph at regular intervals. Gas production in gasograph units (G.U.'s) was determined over 3 hr of fermentation time.

Resistance Oven

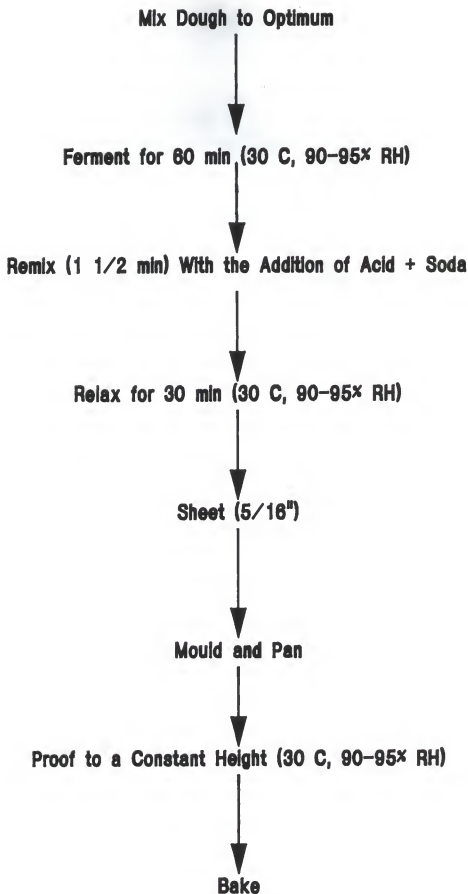
The resistance oven, as described by Junge and Hosney

(1981), was used. The same procedure as described by the straight dough method was used up to the panning step. Before panning a cut was made on the top side of the moulded dough (side opposite the seam) along its longitudinal axis to a depth of about 1/3 of the dough's diameter. The cut was made to reduce rounding of the top during proofing and baking and, thus, maximize dough contact with the electrodes. Doughs were then placed cut-side up in the bottom of the electrical resistance oven and proofed 55 min at 30° C, 90-95% RH. The dough was then baked using a constant 70 volt potential applied to the electrodes. This was sufficient to heat the dough at a rate to give "ovenspring" equivalent to a dough baked in a standard convection oven. Temperature measurements were obtained by a thermocouple inserted into the dough through a small hole in the end of the resistance oven, 3 cm above the base. Time, temperature, and height data were recorded until the height readings stabilized. Because the other dimensions were fixed, loaf volume was a function of dough height.

Remix Procedure

The scheme for remixing to incorporate the chemical leavening into the dough is shown in Fig. 1. Doughs were mixed to optimum development in a National 100 g pin mixer and fermented for 60 min at 30° C, 90-95% RH in a proof cabinet. These doughs were then remixing for 1 1/2 min to incorporate the acid and soda and fermented at 30° C, 90-95% RH for another 30 min to relax the dough. The optimum relaxation and remix times were determined so as to achieve uniform incorporation of the leaveners without overmixing. At the end of the relaxation time,

Fig. 1. Scheme for Remix Procedure.



doughs were processed as outlined above. In doughs where subsamples were taken for pH determinations, the loaf volumes were normalized to bring the values into conformity with the 100 g standard flour basis.

Preparation of Chemical Leavening and Reaction Salts

Various amounts of soda were weighed. The amount of acid added was determined by calculating the acid needed to neutralize the soda. The following equation was used in the calculations:

$$\text{Acid (g)} = \frac{\text{Soda (g)}}{\text{Neutralization Value}} \times 100$$

Specific neutralization values for the various leavening acids were supplied by the manufacturer.

The reaction salts from the above combinations were produced by adding 10 ml of distilled water to the acid and soda. The sample was then heated and allowed to boil for approximately 1 min. The salts produced from the reaction were added as part of the water during the mixing of the dough.

Mixograph

A National Mfg. 10 g mixograph as described by Finney and Shogren (1972) was used to study the effects of various ions on mixograph curves. Flour (10 g, weighed on 14% moisture basis) was placed in the mixograph bowl. An optimum water absorption (58%) was determined for the control (flour and water). Various dilutions of different molar solutions of selected sodium salts of the anionic lyotropic series, citrate > tartrate > sulfate > acetate > chloride > nitrate > bromide > iodide > thiocyanate (Bull 1964), and selected chloride salts of the cationic lyotropic series, thorium > aluminum > hydrogen > barium >

strontium > calcium > potassium > sodium > lithium (Bull 1964), were added to bring the flour sample to the optimum 58% water absorption. Each sample was mixed for 8 min. An example of the salt concentration series for sodium sulfate is shown in Fig. 2. A similar series was produced for the other salts. A specific curve type (shown in Fig.3) was identified from each salt series. The grams and moles of salt needed to produce the curve type was determined for comparison.

No-Time Dough Method

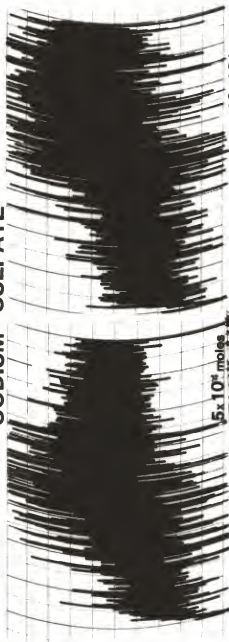
The formula for no-time doughs was the same as the straight dough formula except the sugar level was decreased to 3 g, nonfat dry milk was eliminated and 100 ppm ascorbic acid was used as an additional oxidizing agent. The most extreme case of a short-time fermentation, no fermentation time was used. The procedure is outlined in Fig. 4. Doughs were mixed to optimum development in a National pin mixer, immediately sheeted through rolls set at 5/16" opening, moulded and panned. Panned dough was proofed to constant proof height (73 mm) and the proof time recorded. Baking weight and volume were determined as previously described.

Freezing

The procedure used for freezing was described by Hsu et al (1979a). The short-time dough procedure was employed (Fig. 5). The formula was the same as the no-time fermentation doughs. Doughs were mixed to optimum in a National pin mixer and fermented for 40 min at 30° C, 90-95% RH in a proof cabinet. Doughs were frozen either in rectangular slabs (approximately 7 1/2" x 3" x 1/2") or moulded before freezing. The slab was

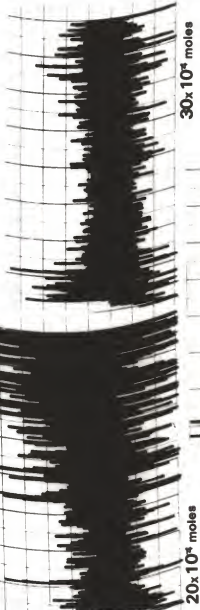
Fig. 2. Mixograms of the Salt Concentration Series for Sodium Sulfate.

SODIUM SULFATE



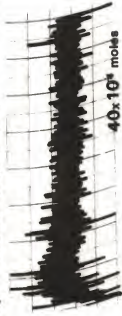
10×10^4 moles

5×10^4 moles



30×10^4 moles

20×10^4 moles



40×10^4 moles

Fig. 3. Specified Curve Type for Mixograph Study on
Lyotropic Ion Series.



Fig. 4. No-Time Fermentation Procedure.

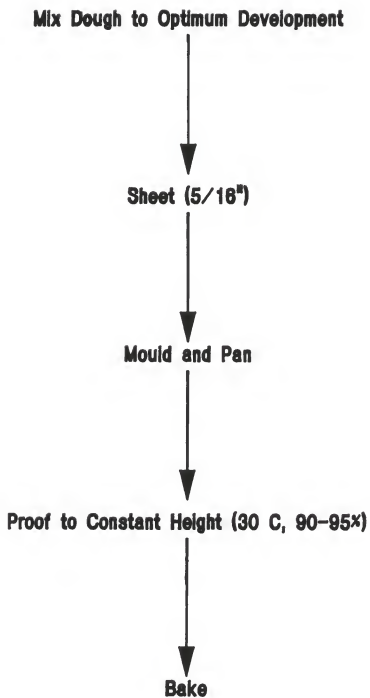
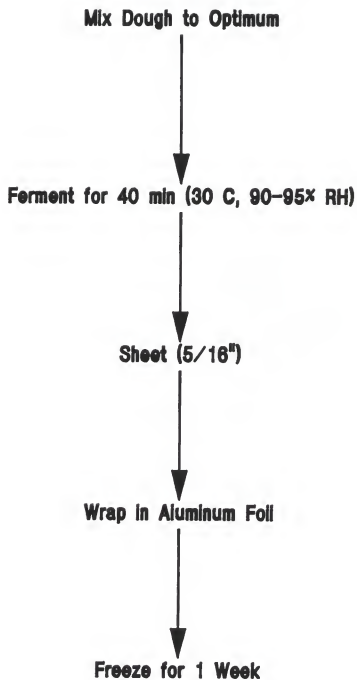


Fig. 5. Short-Time Fermentation Scheme Used for Frozen Doughs.



obtained by passing the dough through sheeter rolls set at 5/16" opening. The doughs were moulded on a drum moulder. All doughs were wrapped in aluminum foil before being placed directly on the freezer shelf of a home-style, upright freezer (-15° C). Unless otherwise specified, the doughs were frozen for a 1 week time period.

Thawing

The frozen doughs were subjected to one of four methods of thawing:

- 1.) Place in a proof cabinet (30° C, 90-95% RH) for 1 hr.
- 2.) Place at room temperature (25° C) for 1 hr.
- 3.) Place in the refrigerator (10° C) for 12 hr.
- 4.) Place in the refrigerator (10° C) for 24 hr.

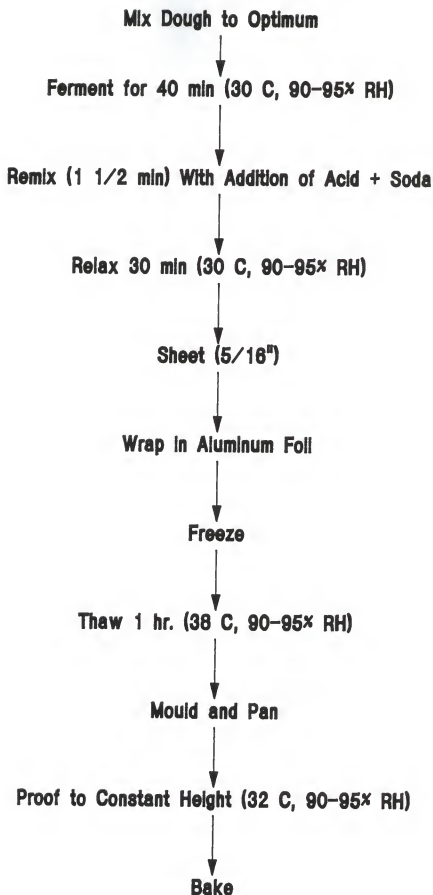
The thawed dough was then processed as described previously in the no-time procedure starting at the sheeter.

Frozen doughs were also thawed and proofed at various temperatures. Thawing and proofing temperatures included 32° C, 38° C and 43° C. A combination of a 38° C thaw temperature and 32° C proof temperature was also tested.

Addition of Chemical Leavening to Frozen Doughs

The procedure used to incorporate leavening acids plus soda into frozen doughs was a combination of the remix and freezing procedures. The procedure is shown in Fig. 6. Doughs were mixed to optimum development in a National 100 g pin mixer and fermented for 40 min at 30° C, 90-95% RH. The fermented doughs were remixed for 1 1/2 min to incorporate the chemical leaveners and fermented for an additional 30 min at 30° C, 90-95% RH to relax the dough. Doughs were sheeted through the rolls set at

Fig. 6. Procedure for the Addition of Leavening Acids
Plus Soda in Frozen Doughs.



5/16" and the resulting slab was wrapped in aluminum foil and frozen as previously described. Frozen doughs were thawed for 1 hr at 38° C, 90-95% RH, moulded, panned and proofed to constant height (73 mm) at 32° C, 90-95% RH. Baking and volume measurements were taken as previously described.

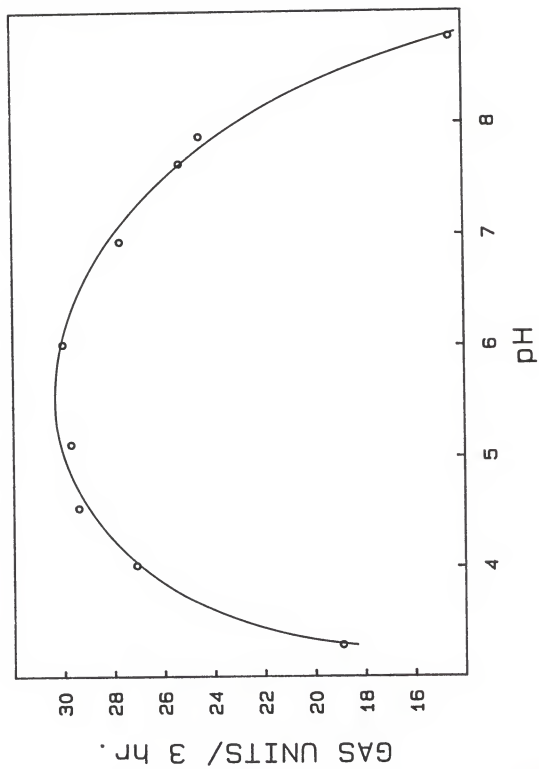
Effect of pH on Gas Production

Preliminary work was designed to study the combination of yeast and chemical leavening agents in bread doughs. The optimum pH for yeast activity (gas production) is known to be approximately 5.5 (Pyler 1973). However, it was not clear from the literature how tolerant yeast was to changes in pH. Therefore, gas production was determined as a function of pH (Fig. 7). The figure shows that yeast is tolerant to changes in pH, with a substantial rate of gas production (24 G.U./3 hr or better) between pH 3.7 and pH 8.0.

Those results were encouraging. If yeast had been more sensitive to pH, then the possibility of using combinations of yeast and chemical leavening would be remote. The fact that we could obtain substantial gas production at alkaline pH's was particularly critical as sodium bicarbonate (NaHCO_3) would adjust the dough pH into this range.

The effect of higher pH values on yeast was also studied. At higher pH values it was not clear if the yeast was killed by the higher pH or if it was just dormant and would become active if the pH was adjusted to a more favorable range. In an attempt to answer the above question, a dough was adjusted to pH 9.7 with sodium carbonate. At that pH the yeast produced very little gas. After exposure to pH 9.7 for 5 min, the pH was adjusted to pH 5.7 with lactic acid. The gassing rate (17.5 G.U./3 hr) was much lower than that for the control unadjusted dough (pH 6.1 and 27 G.U./3 hr). Since yeast had lost a great deal of activity by

Fig. 7. Effect of pH on Yeast Activity.



being subjected to the higher pH it was concluded from the data that when yeast is subjected to high pH (≥ 9.7) its gas producing ability is permanently impaired.

Effect of pH on Loaf Volume

Although it was clear that substantial gas production was obtained over a wide range of pH values, the question of what type of bread would be produced at the various pH values was still unanswered. To answer that question doughs were prepared at five pH's; 4.65 and 5.30 (lactic acid), 6.15 (control) and 6.86 and 7.72 (NaHCO_3). Mixing time for the doughs varied with the pH. All the doughs were proofed to a constant height and baked. The loaf volume was affected by the dough pH (Table 2) even though the doughs were all proofed to the same size. In addition to the effects on loaf volume, the texture and crumb grain of the bread were affected by the dough pH (Table 2). In these experiments no leavening acid was used. Therefore, the only gas produced was from the yeast and thermal decomposition of the soda.

Also of interest was why the acid (more acid than the control) and alkaline doughs had lower loaf volumes even though they were proofed to equal heights. In an attempt to answer this question, doughs were baked in an electrical resistance oven. Because this oven heats the dough mass at the same rate it allows us to speculate on the mode of volume loss during baking. Specifically, it allows us to investigate whether the dough rheology is changing or the gas is being lost by diffusion. Preliminary results suggested that both the acid and alkaline

Table 2. Baking Results at Certain Dough pH Values.

Dough pH	Mixing Time (min)	Proof Time (min)	Loaf Volume (cc)	Crumb Grain
4.65	3 5/8	60±3	742±10	Tight
5.30	3 5/8	58±2	860±5	Sl. Tight
6.15 (control)	3 7/8	55±0	938±21	Normal
6.86	4	69±2	905±30	Sl. Open
7.72	5 1/8	75±4	816±20	Open

doughs lost carbon dioxide to a greater extent during baking than did the control dough. We can hypothesize that gas is being lost by diffusion. More work is necessary to confirm this finding.

Effect of Leavening Acids on Loaf Volume

A way to incorporate the leavening acids and soda into the dough needed to be developed. Therefore, the feasibility of remixing dough was studied. To study remixing, a control dough and a remixed dough (processed as outlined in Fig. 1 without the addition of the acid and soda) were prepared. The results (Table 3) show that the loaves were comparable and that remixing was not detrimental to loaf volume.

Although it was clear that remixing dough was feasible, the effect of chemical leaveners on dough still needed to be established. Doughs were prepared with two leavening acids. The first, sodium aluminum phosphate (SALP), is slow acting and triggered by heat. The second acid, monocalcium phosphate (MCP), is a fast acting acid which will dissolve at room temperature. Thus its effect will be more immediate (Conn 1981). The loaf volume was decreased by the addition of the chemical leaveners (Table 4). This was an unexpected result because the additional CO₂ supplied by chemical leaveners was expected to boost the loaf volume. It was not clear why there was no change in pH of the dough containing SALP between the remix stage and the baked product. A difference would be expected because the SALP would dissolve at oven temperatures and, therefore, should lower the pH.

To understand the effect of SALP + soda on a dough, the experimental system was simplified. The pH of SALP plus soda in

Table 3. Comparison of a Control and Remixed Dough.

Sample	Proof Time (min)	Loaf Volume ^a (cc)
Control	55±0	956±15
Remixed	58±2	972±18

^aNormalized to 100 g of Flour

Table 4. Effect of Chemical Leavening on Dough pH and Bread.

Sample	pH After Mix	pH After Remix	pH of Baked Loaf	Loaf Volume ^a (cc)
Control	6.02	5.60	5.51	1025±15
Remixed	6.08	5.62	5.50	1038±21
SALP+soda (1g:1g)	6.13	7.01	7.04	798±18
MCP+soda (1.25g:1g)	6.00	6.71	6.83	831±19

^aNormalized to 100 g of Flour.

water as a function of temperature was determined (Fig. 8). The data shows that as the system was heated the acid dissolved rapidly and lowered the pH. The solution then maintained a constant pH until gaseous CO_2 was driven off and the system again became more alkaline. We proposed that the baked loaf was removed from the oven at the point on the curve that is equivalent to the pH at the remix stage. More work is necessary to confirm this hypothesis.

With the understanding obtained from the study of the simplified system, the question of the importance of the pH throughout the breadmaking process and especially the pH immediately before baking was addressed. Doughs were prepared with various ratios of soda to acid in order to vary the pH during mixing, fermentation, and baking. The goal was to produce a pH immediately before baking comparable to the control pH at the same step. However, even with the adjustment in pH, the loaf volume was much lower than the control (Table 5). In fact, when additional leavening acid was added to lower the pH to a level comparable to that of the control, the loaf volume decreased with each addition of acid. From the data it was concluded that pH is not the factor affecting loaf volume.

Effect of Reaction Salts on Loaf Volume

Since pH was not the factor affecting loaf volume, other possibilities needed to be investigated. The salts produced by the chemical leavening system were considered. The effect of the salts produced as a result of the leavening reaction was studied. First, loaf volume as a function of salt (NaCl) level

Fig. 8. Resulting pH After Heating SALP Plus Soda
in Water.

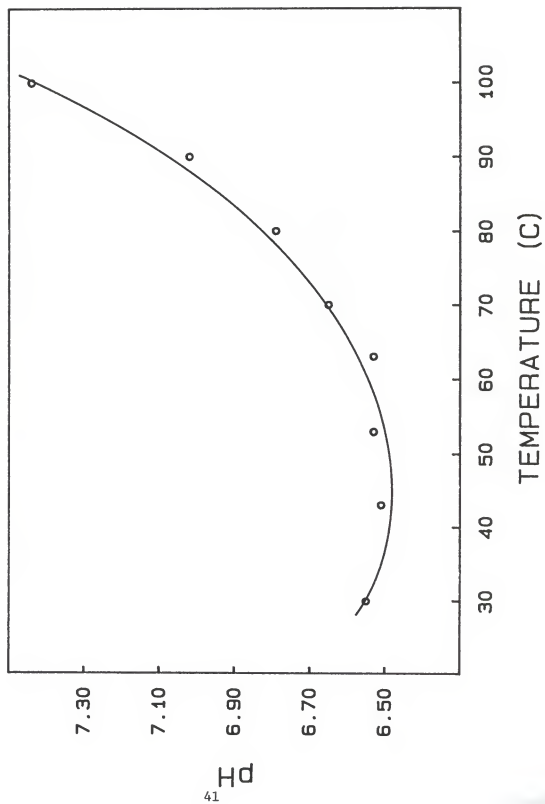


Table 5. Effect of Leavening Acids on Loaf Volume.

Sample	pH After Mix	pH After Remix	pH Before Oven	pH of Baked Loaf	Loaf Volume ^a (cc)
Control	6.01	5.56	5.33	5.56	1064±10
Remixed	5.97	5.50	5.29	5.57	1043±12
SALP+soda (1g:1g)	5.99	6.76	6.73	6.81	893±16
MCP+soda (1.25g:1g)	5.95	6.68	6.56	6.81	857±21
MCP+soda (2.25g:1g)	6.02	6.26	6.10	6.19	829±18
MCP+soda (3.25g:1g)	5.90	5.80	5.71	5.67	721±17
MCP+soda (4.25g:1g)	5.87	5.39	5.32	5.19	679±25

^aNormalized to 100 g of Flour

was determined. The optimum NaCl level was 1.5 to 2.0% (Fig. 9). This was in agreement with the findings of Finney (1984). A substantial decrease in loaf volume occurred above and below that level. Doughs were then prepared with the salts produced from the MCP + soda and the SALP + soda reaction. A substantial decrease (200 cc) in loaf volume resulted with both leavening acids (Table 6).

We proposed two hypotheses to explain why loaf volume decreased when leavening acids were added to dough. First, the total level of salt was too high and reduced the volume as previously indicated in Fig. 9. The second hypothesis was that specific ions present in the leavening acid were detrimental to loaf volume. To determine whether either or both of the two hypotheses were correct, a constant level of reaction salts (produced from 1 g leavening acid and 1 g soda) from several acids (all the acids used had a N.V. of 100) was added to doughs while the level of NaCl varied from 0 to 1.5%. From Table 7 it is clear that as the NaCl level decreased the loaf volumes of the products made from all three acids increased. Thus, with the level of chemical leavening used in these experiments the optimum level of NaCl is zero.

Next, various levels of different reaction salts were added to doughs that contained no added sodium chloride. Figure 10 shows that the amount and type of salt affects the loaf volume. There was an optimum level (1 g) of sodium aluminum sulfate (SAS) that produced a loaf volume comparable to the control. Above that level the loaf volume was significantly lower. On the other hand, sodium aluminum phosphate (SALP) and potassium aluminum

Fig. 9. Effect of NaCl on Loaf Volume.

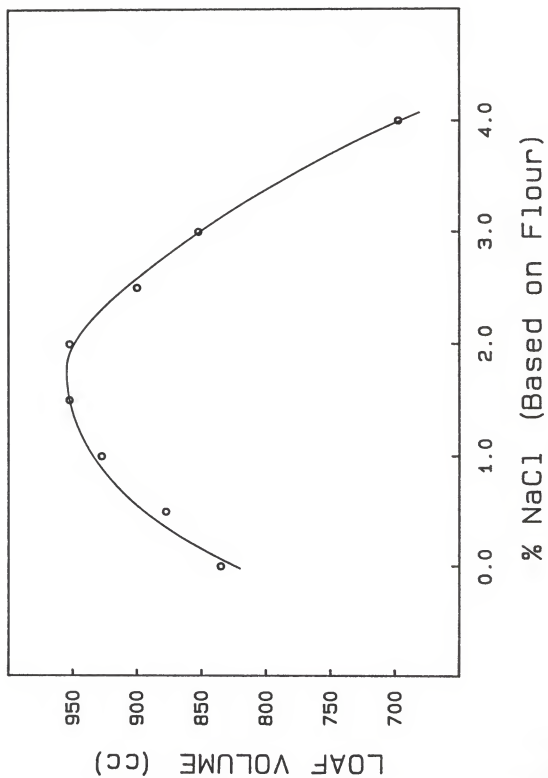


Table 6. Effect of Reaction Salts
on Loaf Volume.

Sample	Loaf Volume ^a (cc)
Control	915±5
MCP+soda (1.25g:1g)	705±9
SALP+soda (1g:1g)	713±10

^aBased on 100 g of Flour

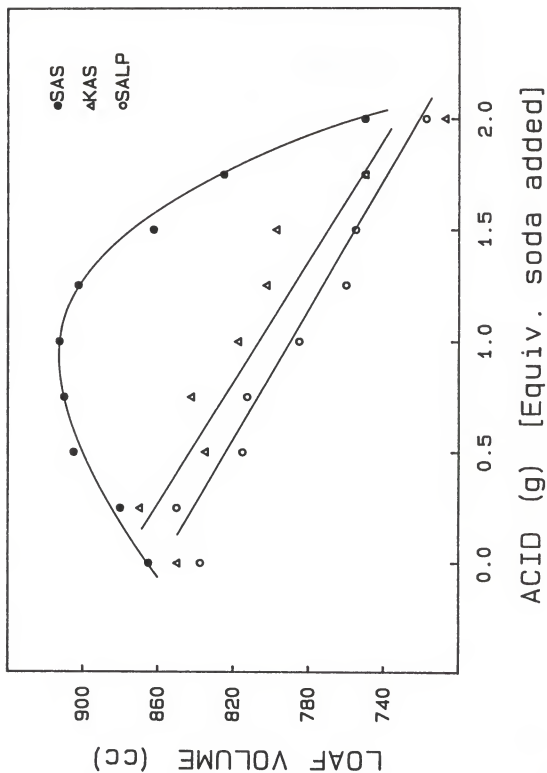
Table 7. Effect of NaCl Plus Reaction Salts on Loaf Volume.

NaCl Level ^a	SAS Loaf Volume (cc) ^b	SALP Loaf Volume (cc) ^b	KAS Loaf Volume (cc) ^b
1.50	795.0±5	652.5±25	777.5±4
1.25	837.5±38	637.5±18	822.5±38
1.00	817.5±11	687.5±4	825.0±21
0.75	865.0±2	702.5±31	825.0±2
0.50	865.0±2	707.5±11	837.0±4
0.25	892.5±11	740.0±2	817.5±4
0.00	917.5±25	752.5±4	817.5±32

^a Based on 100 g Flour

^b 1 g acid to 1 g soda was added for each chemical leavening system (N.V. for all acids was 100)

Fig. 10. Effect of Levels of Reaction Salts on Loaf Volume.
N.V.= 100 for all the Acids.
● SAS
△ KAS
○ SALP



sulfate (KAS) produced products with lower loaf volumes than the control at acid amounts ranging from 0.25 g to 2.0 g. In both cases, the highest loaf volumes were obtained with 0.25 g acid and as the amount of acid increased the loaf volume decreased. It was speculated based on this data that specific ions were detrimental to loaf volume, particularly phosphate and potassium ions.

Salovaara (1982) reported that the effect of electrolytes on dough rheology was based on gluten protein aggregation. Theoretically, ions may enhance either protein association or dissociation. The stabilizing effect of sulfate on a native configuration of protein as compared to that of chloride is a well known phenomenon (von Hippel and Wong 1964). This effect was detected when only a part of the sodium chloride in dough was replaced with sodium sulfate. The strengthening effect of sodium sulfate on wheat dough as compared to sodium chloride was also reported by Guy et al (1967). Furthermore, Evans et al (1975) stated that phosphates caused a retraction of the protein matrix in spaghetti. This inhibited the development of a cohesive continuous matrix. Those results give support for our hypothesis that phosphate is detrimental to loaf volume. This is also consistent with our finding that 1 g SAS gives a loaf volume comparable to the control.

To better understand the effects of specific ions on gluten structure and loaf volume, mixograph curves were compared to characterize the ions. Kinsella and Hale (1984) reported that anions of the Hofmeister (lyotropic) series altered the classical

farinograph patterns of bread flour dough. We used a mixograph to confirm these findings. Table 8 shows the various lyotropic ions and their salt levels needed to produce a certain mixograph pattern. Results of the anionic ions corresponded with the anionic lyotropic series described by Bull (1964). The salt level needed to obtain the specified mixogram progressively increased as the series was followed.

When comparing the salt levels of sodium sulfate to sodium phosphate, half the amount of phosphate was needed to obtain the same mixograph pattern. We can speculate that this is the explanation for the baking results with SAS and SALP (Fig. 10). It took half the amount of phosphate to achieve the mixograph curve. In the baking results with SALP, even at minimal amounts the salt curve had a negative slope. With the sodium sulfate, which is closer in the lyotropic series to sodium chloride, more salt was needed to produce the mixograph pattern. In the baking results with SAS, a 1 g level produced an optimum loaf volume. The SALP doughs had surpassed the optimum loaf volume. Further baking results are needed to confirm this speculation.

The pattern was not seen with the cationic lyotropic series described by Bull (1964), however, the findings (sodium, potassium > lithium > magnesium > calcium) of von Hippel and Schleich (1969) do coincide with our results. More work is necessary to understand this concept.

The effect of the amount and type of reaction salt on gassing power was also studied. Compared to the control, it is evident from Table 9 that loaf volumes are reduced in doughs where SALP and KAS were added. This data indicates that gas was

Table 8. Mixograph Study Results on Specific Ions of the Lyotropic Series.

Sample	Salt Level ^a (mg)	Moles x 10 ⁴
Anionic Series		
Sodium Citrate	129	4.99
Sodium Phosphate	142	9.98
Sodium Tartrate	194	9.98
Sodium Sulfate	284	20.00
Sodium Acetate	328	40.00
Sodium Chloride	339	58.00
Sodium Bromide	1646	159.96
Sodium Iodide	3477	232.00
Cationic Series		
Calcium Chloride	1932	174.00
Potassium Chloride	432	57.94
Sodium Chloride	339	58.00
Lithium Chloride	983	232.00

^aLevel needed to produce the specified mixograph curve (Fig. 3)

Table 9. Effect of the Amount and Type of Reaction Salt on Gassing Power and Loaf Volume.

Sample ^a	G.U.'s	Loaf Volume (cc)
Control ^b	32.0	935.0±12
0.25g SALP	39.7	850.0±2
0.50g SALP	36.5	815.0±21
0.75g SALP	35.7	812.5±18
1.00g SALP	33.5	785.0±14
1.25g SALP	31.2	760.0±3
1.50g SALP	31.1	755.0±14
1.75g SALP	30.2	750.0±14
2.00g SALP	28.8	717.5±38
0.25g SAS	39.4	880.0±14
0.50g SAS	34.7	905.0±28
0.75g SAS	35.0	910.0±14
1.00g SAS	34.2	912.5±11
1.25g SAS	33.0	902.5±25
1.50g SAS	32.0	862.5±4
1.75g SAS	30.9	825.0±21
2.00g SAS	30.8	750.0±3
0.25g KAS	----	870.0±7
0.50g KAS	35.5	835.0±7
0.75g KAS	35.2	842.5±25
1.00g KAS	32.8	817.5±17
1.25g KAS	32.8	802.5±4
1.50g KAS	33.2	797.5±38
1.75g KAS	31.3	750.0±5
2.00g KAS	31.0	707.5±4

^aAn equivalent amount of soda and acid was added to each dough

^bStandard formula

being produced (i.e. 0.5g SALP produced 36.5 G.U. compared to 32 G.U. produced by the control) but not retained by the loaves. In the doughs containing SALP and KAS, the lowest acid levels produced the highest gassing powers and loaf volumes. However, those loaf volumes were still substantially lower than the control. On the other hand, SAS at a 1 g acid level and with a slightly higher gassing power produced a loaf volume comparable to the control. This information supports the theory that the addition of the phosphate and potassium ions of SALP and KAS reduces the ability of the dough to retain gas, thereby decreasing loaf volume. However, at appropriate levels SAS does not impair the ability of the dough to retain gas. It was concluded from this work that sodium aluminum sulfate has the best potential to increase loaf volume in frozen doughs.

Frozen Dough Freeze/Thaw Studies

It was reported by Hsu et al (1979b) that freezing activated yeast and its fermentation products together was detrimental to yeast viability. Thus, if dough fermentation before freezing could be reduced or eliminated, yeast survival might be improved. However, the improved yeast viability after freezing could not be at the expense of bread quality.

A short-time dough process was developed that gave reasonably good quality frozen dough (Hsu et al 1979a). The short-time dough process using the regular straight dough formula suggested that some formulation changes were needed to overcome the weak structure and dark crust color of the bread. NFDM was eliminated to lower oxidant requirement. The sugar content was

reduced so the dough would be more elastic. This was necessary because sugar competes with the gluten and other dough components for available water (Hoseney et al 1979). The more sugar in the dough, the more that dough will flow. Also, less sugar results in decreased browning at the oven stage (Hsu et al 1979). The oxidant system, 10 ppm of bromate plus 100 ppm ascorbic acid, was used because of the increased oxidation requirement for a short-time dough system.

An optimum method for freezing and thawing frozen doughs had not been established. We attempted to optimize a method using the revised formula and procedure. The dough was sheeted into a slab and also moulded before freezing. The slab produced a higher loaf volume and lower proof time than did the moulded dough (Table 10). This was expected because of the relationship between the geometry of the dough and heat transfer.

The frozen doughs were subjected to one of four methods of thawing. As shown in Table 10, the highest loaf volume and shortest proof times were achieved with the 1 hr thaw at 30° C. Furthermore, as shown in Table 11, a storage study with thawing and proofing at 30° C, 90-95% RH indicated that as storage time increased the loaf volume decreased and proof time increased. This coincides with the findings of many investigators (Davis 1981, Hsu et al 1979a, Lorenz and Bechtel 1964, Merritt 1960).

The results showed that as the temperature of thawing was increased, loaf volume increased and proof time decreased. Frozen doughs were thawed and proofed at 32° C, 38° C and 43° C. Table 12 clearly shows that as temperature increased proof time decreased. Loaf volume was comparable with the 32° C and 38° C

Table 10. Optimizing Freeze/Thaw Conditions for Frozen Doughs.

Treatment	Proof Time (min)	Loaf Volume (cc)
Slab, 1 hr. proof box(30° C)	83±2	867±26
Moulded, 1 hr. proof box	87±5	826±17
Slab, 1 hr. Room Temp.(25° C)	143±11	731±25
Slab, 12 hr. Refrig.(10° C)	111±9	789±18
Slab, 24 hr. Refrig.(10° C)	118±4	816±16
Control	55±0	904±24

Table 11. Storage Study for Frozen Doughs.

Storage Time (weeks)	Proof Time (min)	Loaf Volume (cc)
Control(0)	55±0	935±10
1	82±1	905±17
2	109±5	877±17
3	124±2	835±26
4	129±7	833±10

Table 12. Higher Temperature Thawing/Proofing of Frozen Doughs.

Condition	Proof Time (min)	Loaf Volume (cc)
32° C, 90-95% RH (control)	91±5	882±11
38° C, 90-95% RH	72±6	878±20
43° C, 90-95% RH	60±2	843±16
38° C, 90-95% RH Thaw and 32° C, 90-95% RH Proof	102±5	913±25

conditions, however, a 40 cc decrease in loaf volume occurred with the 43° C temperature. Thawing for 1 hr at 38° C, 90-95% RH and proofing to constant height at 32° C, 90-95% RH were determined to be optimum thawing and proofing conditions for frozen doughs. Yeast's optimum rehydration temperature (38° C) explains the higher thawing temperature.

Study of Short-Time Fermentation Formula and Process

The reasons for changing the formula and procedure for the short-time fermentation system were logical, however, how those changes affected the system were not entirely understood. The most extreme case of a short-time fermentation, no fermentation time was used in this study. Because salt level was an important formula variable in the long-time fermentation, the effect of the salt level on loaf volume needed to be determined for the no-time fermentation. Fig. 11 shows that the optimum level of salt in the no-time fermentation is 0.5% based on the flour weight. This is a decrease in salt level compared to the 1.5 - 2.0% optimum salt level for the long-time fermentation. The reason for the change was because of the elimination of the NFDM from the no-time fermentation formula (Fig. 12). The figure shows a 2% optimum salt level when NFDM was included in the no-time fermentation formula. This 2% level is comparable to the optimum salt level in the long-time fermentation. More work is necessary to confirm why NFDM causes the change.

With the optimum salt level determined, the optimum level of chemical leavening (sodium aluminum sulfate and soda) needed to be established. Constant amounts of chemical leavening (0.25 g

Fig. 11. Effect of NaCl on Loaf Volume in a No-Time Fermentation System.

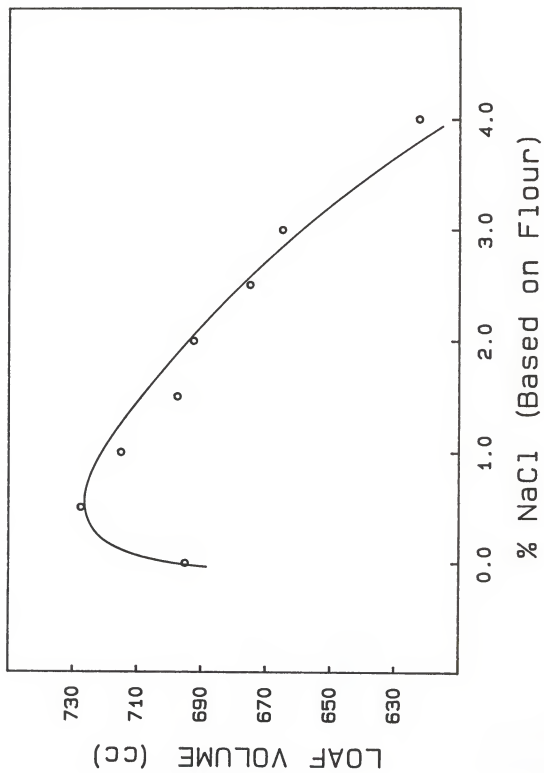
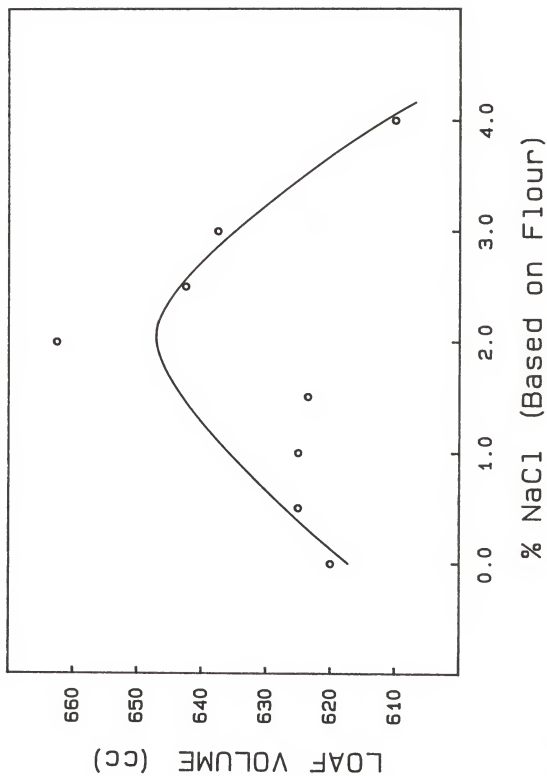


Fig. 12. Addition of NFDM to No-Time Doughs.



SAS: 0.25 g soda, 0.5 g SAS: 0.5 g soda, 0.75 g SAS: 0.75 g soda, 1 g SAS: 1 g soda) were added to doughs which varied in salt from 0 to 4%. Fig. 13 shows that the optimum bread was obtained with a combination of NaCl and chemical leavener of 0.5% NaCl and a 0.5 g SAS: 0.5 g soda ratio. This was the level of total salt that would be used in frozen doughs.

Addition of Chemical Leavening in Frozen Doughs

The question of the potential of chemical leavening in frozen doughs still was unanswered. The formula used was the same as the no-time fermentation formula except for the 0.5% salt level and the addition of the 0.5 g SAS plus 0.5 g soda. The formula did not contain NFDM. Table 13 shows that the addition of chemical leavening to frozen dough did not decrease proof time and did not increase loaf volume when compared to the mix/remix control. This preliminary work suggests chemical leavening has no positive benefit in frozen doughs.

Fig. 13. Addition of SAS in a No-Time Fermentation System.
NFDM was not added.
○ 0.25 g SAS
● 0.50 g SAS
△ 0.75 g SAS
▲ 1.00 g SAS

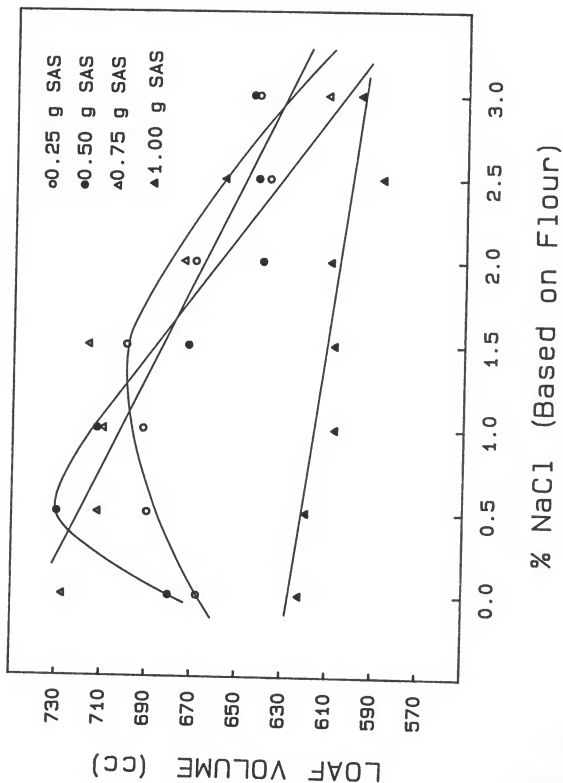


Table 13. Addition of Chemical Leavening in Frozen Doughs.

Sample	Proof Time (min)	Loaf Volume (cc)
Control	55±0	930±18
Remix Control (Long-time ferm.)	55±0	927±13
Remix Control (Short-time ferm.)	72±2	945±7
Mix/Remix Frozen Dough	92±4	919±9
Mix/Remix Frozen Dough with Chemical Leavening	95±3	842±20
Mix/Freeze Frozen Dough	94±2	831±25

SUMMARY

The objective of this study was to examine the feasibility of using a combination of chemical and yeast leavening to produce a frozen dough product that is comparable to a freshly baked yeast-leavened bread. With the beneficial effects of yeast and additional leavening from the chemical leaveners it was hoped more acceptable bread products could be produced from frozen doughs.

Results showed that yeast was tolerant to changes in pH, however, its gassing abilities were impaired when subjected to high pH (≥ 9.7). The loaf volumes, texture, and crumb grain of doughs at alkaline and acid pH's were of inferior quality compared to the control. A laboratory scale remixing scheme was developed to incorporate chemical leavening into doughs. Baking results indicated that pH was not the factor affecting loaf volume.

The salts produced from the leavening reaction were the major factor affecting loaf volume. Specific ions were detrimental to loaf volume. A mixograph study characterized anions in a pattern which corresponded to the anionic lyotropic series. This data substantiated the theory that specific ions had substantial effects on loaf volume and gluten structure. Sodium aluminum sulfate appeared to be the leavening acid that had the best potential to increase loaf volume in frozen doughs.

A short-time dough fermentation process was used for preparation of frozen doughs. Nonfat dry milk (NFDM) was eliminated from the formula to lower the oxidant requirement. Without the NFDM a lower salt level (0.5% based on flour weight)

was required for the short-time doughs. Thawing 1 hr at 38° C, 90-95% RH and proofing to a constant height at 32° C, 90-95% RH were determined to be optimum thawing and proofing conditions for frozen doughs. Preliminary work has not shown any positive benefits of chemical leavening in frozen doughs.

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THE USE OF CHEMICAL LEAVENING IN FROZEN DOUGHS

by

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ABSTRACT

Frozen doughs have enjoyed some success in the market but generally suffer from variable performance. A major problem with the performance of frozen doughs is the viability of the yeast after thawing. To avoid this problem, a combination of yeast and chemical leavening agents in frozen doughs was studied. Results showed that yeast was tolerant to changes in pH, however, its gassing abilities were impaired when subjected to high pH (≥ 9.7). A laboratory scale remixing scheme was developed to incorporate chemical leavening into doughs. Baking results indicated that pH was not the factor affecting loaf volume.

The salts produced from the leavening reaction were the major factor affecting loaf volume. Specific ions were detrimental to loaf volume. A mixograph study characterized anions in a pattern which corresponded to the anionic lyotropic series. Sodium aluminum sulfate had the best potential to increase loaf volume in frozen doughs.

A short-time dough fermentation process was used for preparation of frozen doughs. Nonfat dry milk (NFDM) was eliminated from the formula to lower the oxidant requirement. However, without the NFDM a lower salt level (0.5% based on flour weight) was required for the short-time doughs. Thawing for 1 hr at 38° C, 90-95% RH and proofing to a constant height at 32° C, 90-95% RH were determined to be optimum thawing and proofing conditions for frozen doughs. Preliminary work has not shown any positive benefits of chemical leavening in frozen doughs.