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Ice-cream cone baking: dependence of baking performance on flour and batter viscosity

V.T.Huang, J.B.Lindamood[1] and P.M.T.Hansen[1,2]

Pillsbury Corporate R&D, Minneapolis, MN 55414 and [1]Department of Food Science and Nutrition, The Ohio State University, Columbus, OH 43210, USA

[2]To whom correspondence should be addressed

Abstract. Effects of flour quality, batter formulation and batter viscosity on baking performance of rolled ice cream cones were examined by response surface methodology. The results showed batter viscosity to be inversely related to temperature and salt and water content. An empirical relationship was developed to optimize batter viscosity by adjustment of any given combination of these factors. The variable batter viscosity due to flour quality and chlorination could, to a large extent, be controlled by adjustments of salt and other electrolytes. Control of processing conditions, including agitation speed, time and temperature, was important for maintaining batters within a given viscosity range.

Introduction

Rolled ice cream cones (sugar cones) are customarily manufactured by baking a batter in the form of flat waffles, and then rolling them into conical shapes while still hot and pliable. When automated equipment is used, the release of the baked waffles from the baking plates is one of the critical factors for uninterrupted operation and may be related to the rheological properties of the batter. Batter ingredients for rolled sugar cone production include flour, water, sugar, shortening, lecithin, salt, colorant and flavoring materials. Certain batters tend to produce wafers that adhere to the baking plates, making tedious and troublesome manual removal necessary. In severe cases, production must be discontinued until a satisfactory batter can be prepared. Sticking problems are often associated with thin batters while thick batters may cause difficulties in the uniformity of batter application. Thus, batter quality and the associated tendency for adhesion become controlling factors for satisfactory baking performance.

In this study, investigations were conducted to evaluate the effect of flour quality, batter formulation and batter viscosity on baking performance.

Materials and methods

Evaluation of baking performance

Typical failures in continuous baking relate to difficulties with baked wafers sticking to the bottom plates and to the associated problem of weakened cone strength. The baking performance was assessed subjectively by plant personnel evaluating the average performance for any batch on any day according to a 3-

point scale: good (100), fair (50), poor (0). Performance was judged primarily in relation to the time an operator was required to spend on manually releasing the baked wafers from the plates. The following guidelines were used: if more than ⅔ of the operator time was used for manual release assistance the baking performance was rated 'poor'; if less than ⅓ of operator time was required, the performance was rated 'good'. Baking performance requiring intermediate manual assistance was rated 'fair'.

Analyses of flours

Moisture, ash and protein contents as well as pH of flour samples were analyzed by AACC methods (1). Apparent viscosity of flour was measured by a modification of the AACC method (1). The sample was prepared by placing 80 g (dry wt basis) of flour into 400 ml of double distilled water, shaking the dispersion for 2 min in an Erlenmeyer flask and incubating the sample at 30°C. A no. 1 spindle (Brookfield, RVT) was used at 100 r.p.m. The reading was taken after five revolutions. After each measurement, 5 ml of 1 N lactic acid was added to the slurry and the measurement repeated until the reading was constant. The final reading was used for reporting the apparent viscosity.

Scanning electron microscopic study of flour samples

Two flour samples were selected on the basis of good and poor baking performance. Each sample was placed on an aluminum stub with graphite cement adhesive, coated with carbon and gold and examined on a Cambridge model S4-10 Scanning Electron Microscope.

Amylograms of flour samples

Visco-amylograms of flour samples were obtained by a modification of the AACC method (1). Sixty grams (dry wt basis) of flour were dispersed in 460 ml of phosphate/citrate buffer (pH 5.35). The slurry was transferred quantitatively into the Brabender amylograph bowl. Temperature programming was set for start at 30°C with 1.5°C/min increase, then stopped and held at 90°C for 15 min. After that, the slurry was cooled rapidly to 70°C.

Batter formulation

Batters were prepared in a mixing tank, then held in a holding tank before being pumped to the baking plates. The following procedure was used.

In a 100 gal mixer, 135 lb brown sugar, 1.5 lb NaCl, 0.188 gal caramel colorant, 0.09 lb sodium benzoate and 15 gal of water were mixed for 30 s. Next, 150 lb of flour was added to the mixer and mixed for 1 min. Another 150 lb of flour was then added to the tank and stirred for an additional 5 min. Any adhering batter was scraped from the wall of the mixer. Two and one-half lb of lecithin and 10 lb of melted shortening were added to the batch and mixed for

30 s. A predetermined amount of water, usually 15 gal, was added followed by mixing for 5 min. The batter was then released into the holding tank.

Batter viscosity

Batters with different combinations of salt (0, 0.7, 1.4 or 2.1 g) and water (81, 97 or 113 ml) were prepared and the apparent viscosity measured at three different temperatures (15, 23.5 and 30°C). The specified amounts of salt and water were placed in a mixer bowl and the contents were mixed until all salt was completely dissolved. Then 1.6 g lecithin, 6.7 g shortening, 200 g of flour and 135 g sucrose syrup (total solids 67.5%) were added. The mixture was stirred with a spatula, then agitated by a household mixer at low speed for 30 s and for another 30 s at high speed. The mixed batter was transferred to a 600 ml beaker and the apparent viscosities (V'_1 and V'_2) were measured at 10 r.p.m. and 20 r.p.m., corresponding to shear rates r_1 and r_2, using a model RVT Brookfield viscometer and no. 6 spindle. The plastic viscosity, V_P, was calculated by (2):

$$V_P = (V'_2 r_2 - V'_1 r_1)/(r_2 - r_1) \tag{1}$$

or

$$V_P = 2V'_2 - V'_1 \qquad \text{(valid for } r_2/r_1 = 2) \tag{2}$$

The value for plastic viscosity represents the slope of the flow curve between r_1 and r_2 and is a more representative expression for the viscous behavior of non-Newtonian systems than a single point determination.

Determination of flow profiles

The same batter formulation and procedure as above was used with the water level fixed at 97 ml. Salt levels were 0, 0.5, 1.0, 1.5 and 2.0 g. The apparent viscosity, V' (dyne s/cm^2), was measured at 21°C for 0.5, 1.0, 2.5, 5.0, 10, 20, 50 and 100 r.p.m. and the corrected plastic viscosity calculated by equation (1). Yield stress values, Y (dyne/cm^2), were obtained from shear stress readings after the rotation of the viscometer spindle was stopped and, therefore, correspond to the yield stress of a 'worked' sample rather than the yield stress to initiate flow (3). Determined in this manner, Y is not the true yield stress but, rather, a quantity which is proportional to the shear modulus of a viscoelastic substance at the cessation of flow. Hence, the flow profiles are not true flow curves, but for any given spindle a curve provides a shape which indicates the appropriate rheological classification. Corresponding flow equations were developed using the logarithmic transformation of the general power–law relationship:

$$\log (t - Y) = \log b + s \log (r^*k) \tag{3}$$

where t = shear stress, Y = yield stress, s = pseudoplastic constant, r = shear rate (r.p.m.) and k is a proportionality factor.

Results

Effect of flour types on baking performance

Flour samples of variable baking performance were obtained from cone baking plants for analysis. The results are shown in Table I. To evaluate these data several empirical models were tested. The following equation describes a model with a regression coefficient of 0.81.

$$\mathrm{BP} = 67.7 + 2.38\ U - 19.4\ M^{*}A \qquad (R = 0.81) \tag{4}$$

where BP = baking performance, U = flour viscosity, M = moisture content of flour (%) and A = ash content of flour (%) on the basis of 14% moisture content.

It is obvious that a 3-point scale for baking performance is not sufficient to explain fully the response of these variables; nevertheless, an important trend can be deduced in which flour viscosity is the most important factor ($P < 0.001$), and the product of ash and moisture content is another significant factor ($P = 0.002$). It should be noted that variation in pH-values was not a significant factor within the range represented by these flour samples. The contours of

Table I. Flour quality and baking performance (flours obtained from different plant locations)

Code no.	Moisture content (%)	Protein content (%)	Ash content (%)	Viscosity ('M)[a]	pH	Baking performance (score)[b]
01	12.60	7.05	0.500	38.5	4.90	0
02	12.10	8.90	0.468	22.0	4.90	0
03	11.70	8.33	0.530	22.0	4.60	0
I1	12.16	8.57	0.460	16.5	5.10	0
M1	10.70	9.55	0.536	47.3	4.45	50
O4	14.10	8.61	0.460	71.5	4.80	100
I2	12.75	8.33	0.445	45.6	4.89	50
P1	9.98	9.71	0.382	48.0	4.95	100
I3	12.29	9.25	0.476	45.4	5.03	100
O5	12.24	9.02	0.474	48.0	5.09	100
O6	10.94	8.74	0.349	44.5	4.87	100
G1	10.77	7.87	0.508	43.7	4.63	100
O7	11.37	8.83	0.376	45.5	4.95	100
O8	11.38	9.72	0.452	48.5	5.00	100
P2	10.87	7.29	0.354	52.0	4.93	100
A1	11.91	9.11	0.321	41.7	5.01	100
M2	9.91	9.95	0.416	45.0	4.61	50
P3	10.75	7.84	0.392	39.3	4.78	100
I4	9.87	7.59	0.373	41.4	4.75	100
O9	8.74	8.42	0.461	41.3	5.00	100
O10	11.03	8.08	0.463	45.2	4.98	100
M3	10.50	9.46	0.560	34.0	4.80	50
M4	9.68	9.91	0.523	48.0	4.83	100
M5	9.65	9.86	0.550	40.4	5.25	0
I5	10.74	8.07	0.354	46.0	4.45	100

[a]Degrees MacMichael.
[b]100 = good, 50 = fair, 0 = poor.

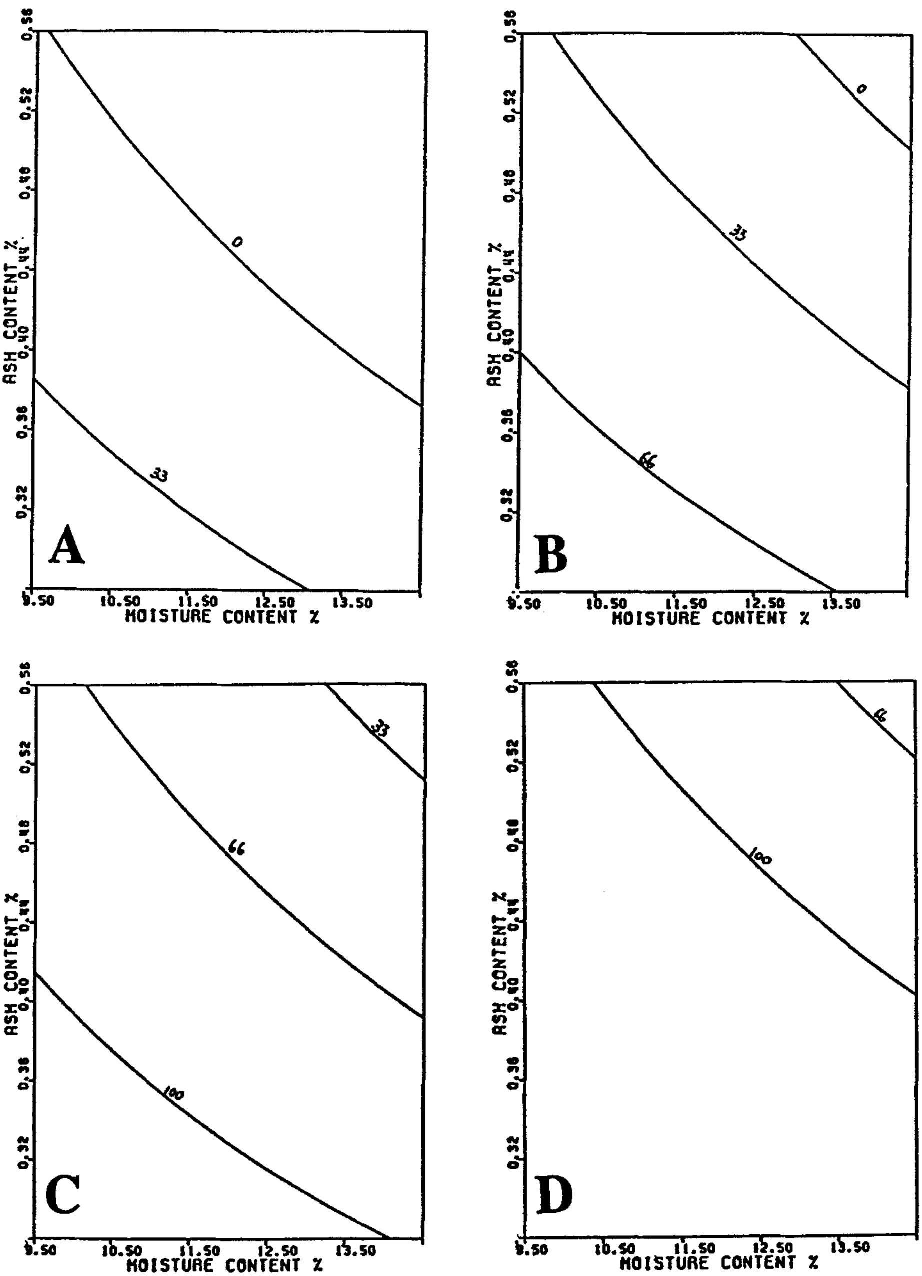


Fig. 1. Contour plots of baking performance for different flour viscosities. Contours are baking performance (100 = good, 0 = poor). (**A**) Viscosity = 15 '*M*; (**B**) viscosity = 30 '*M*; (**C**) viscosity = 45 '*M*; (**D**) viscosity = 60 '*M*.

baking performance for different flour systems are shown in Figure 1. The higher the viscosity the better the performance, while with higher moisture and ash contents the performance suffered.

Effect of flour composition on viscosity

Desirable wheat flour for cone baking is a flour which develops optimum viscosity for the application of batters to the baking plates and yet yields the desired cone texture.

Soft red winter wheat flour is used for cone baking and is usually of the straight flour variety, i.e. a combination of all streams without any exclusion. The data in Table II were obtained from a flour mill (Keynes Bros., Logan, Ohio) and details the chemical composition and viscosity values of the different streams of Ohio soft red winter wheat.

Statistical analysis was conducted on the data in Table II in which the viscosity of the flours was correlated with the chemical composition. The following equation was derived with a coefficient of correlation of 0.84.

$$U = -115 + 4.15\,M + 20.0\,P - 129\,A \qquad (R = 0.84) \tag{5}$$

where U = viscosity value (degree MacMichael), M = moisture content, P = protein content on the basis of 14% moisture content and A = ash content on the basis of 14% moisture content.

Analysis of variance of this model showed that protein and ash content were the two important factors which affected the viscosity values of the flours, while the moisture term was not significant. However, combining the data in Tables I and II again leads to a model for flour viscosity, U(overall), of the same form in which all terms, including moisture, are significant ($P < 0.01$):

$$U(\text{overall}) = -123 + 6.43\,M + 16.2\,P - 105\,A \qquad (R = 0.77) \tag{6}$$

It is apparent that a linear model fits and that, within limits, flour viscosity can be predicted from the terms of the equation. The plot of ash content versus protein content with viscosity as the contours is shown in Figure 2. A general pattern emerges in which a high protein content and a low ash content yield flour of the highest viscosity.

Microstructure of flours

Studies were conducted to evaluate the surface structure of flour samples exhibiting a difference in baking performance. Figure 3 shows that acceptable flour may be less aggregated than its counterpart. Bulk density measurements showed the acceptable flour to be somewhat more dense than the 'poor' flour, with values of 0.42 g/ml and 0.40 g/ml respectively. It is possible that the difference in structure results from differences in milling technique or the dispersive effect of chlorine used as a maturing agent on the protein matrix. Data on chlorination at the mill was not available, but it is possible that the

Table II. Ohio soft red winter wheat stream analysis[a]

Code no.	Moisture (%)	Protein (%)	Ash (%)	Viscosity ('M)[b]
1	13.5	6.50	0.306	37
2	13.3	7.45	0.300	51
3	12.7	9.45	0.405	66
4	11.7	12.05	0.940	15
5	12.7	6.25	0.277	30
6	12.7	7.20	0.287	52
7	12.4	7.20	0.290	43
8	12.3	8.30	0.300	65
9	13.1	8.35	0.298	73
10	13.2	9.00	0.310	93
11	12.3	9.00	0.305	89
12	12.2	10.60	0.356	119
13	12.4	8.15	0.440	38
14	11.7	9.35	0.460	64
15	11.4	10.55	0.538	107
16	11.1	10.90	0.740	23
17	11.0	11.50	0.840	30
18	10.1	10.80	1.120	15
19	10.6	11.40	1.080	19
20	13.7	7.30	0.270	45
21	13.4	8.90	0.362	73
22	13.1	7.30	0.302	40
23	13.1	8.05	0.324	57
24	12.9	9.30	0.514	52
25	13.2	8.85	0.328	66
26	12.9	9.00	0.304	70
27	12.8	9.25	0.336	84
28	12.6	9.75	0.332	96
29	12.4	9.85	0.362	97
30	12.8	10.85	0.460	116
31	12.0	9.20	0.616	12
32	12.6	13.10	1.208	29
33	12.6	10.40	0.498	93
34	12.1	12.20	0.670	77
35	12.3	12.50	1.416	32
36	11.7	13.90	1.410	40
37	11.8	12.15	1.264	30
38	12.2	13.50	1.300	38
39	12.8	9.75	0.602	15

[a] Analyzed at the flour mill.
[b] Degrees MacMichael.

acceptable flour may have received more intensive chlorine treatment than the other flour because the viscosity values were different (48 '*M* versus 16 '*M*).

Flour rheology

The results have shown that flour viscosity is the most important analytical parameter for assessing its potential performance in ice cream cone baking. Studies were conducted with two flours giving poor and acceptable baking performance to determine rheological differences. The Brookfield flow profiles

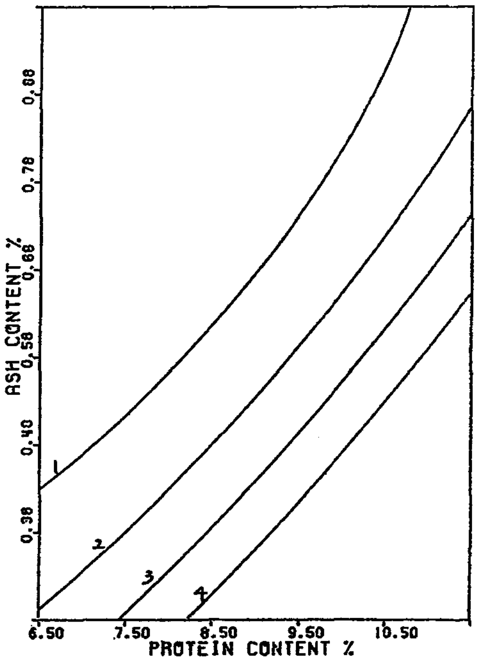


Fig. 2. Contour plot of flour viscosity at different ash and protein content. (**1**) Viscosity = 15 '*M*; (**2**) viscosity = 35 '*M*; (**3**) viscosity = 55 '*M*; (**4**) viscosity = 75 '*M*.

are shown in Figure 4. Flour represents a pseudoplastic system exhibiting both a yield value and a high shear-rate-dependent apparent viscosity. The results from amylograph measurements are shown in Figure 5. The flour rated as 'good' with respect to baking performance exhibited a higher Brabender reading than the 'poor' flour. No difference in gelatinization temperatures between these two samples was recorded. These observations support the speculation that the two flours differ in extent of chlorination (4,5).

Batter rheology

The rheological properties of cone batters reflect the presence of flour as the dominant ingredient. Thus, the flow profile of a typical batter is similar to that of flour. The system shows the properties of a thixotropic fluid with a time-dependent behavior as shown in Figure 6. It is apparent that too long a holding time and excessive agitation will result in batters of low viscosity. This finding is consistent with the observation by Matz and Matz (6) that it is not desirable to hold batters for more than 30 min. It is also advisable not to use pipes of too small diameter for delivering batters, since this increases the stress on the batter and reduces viscosity.

Effect of temperature, water and salt content on batter viscosity. Since batter viscosity has been shown to be the most critical factor in cone baking, it becomes

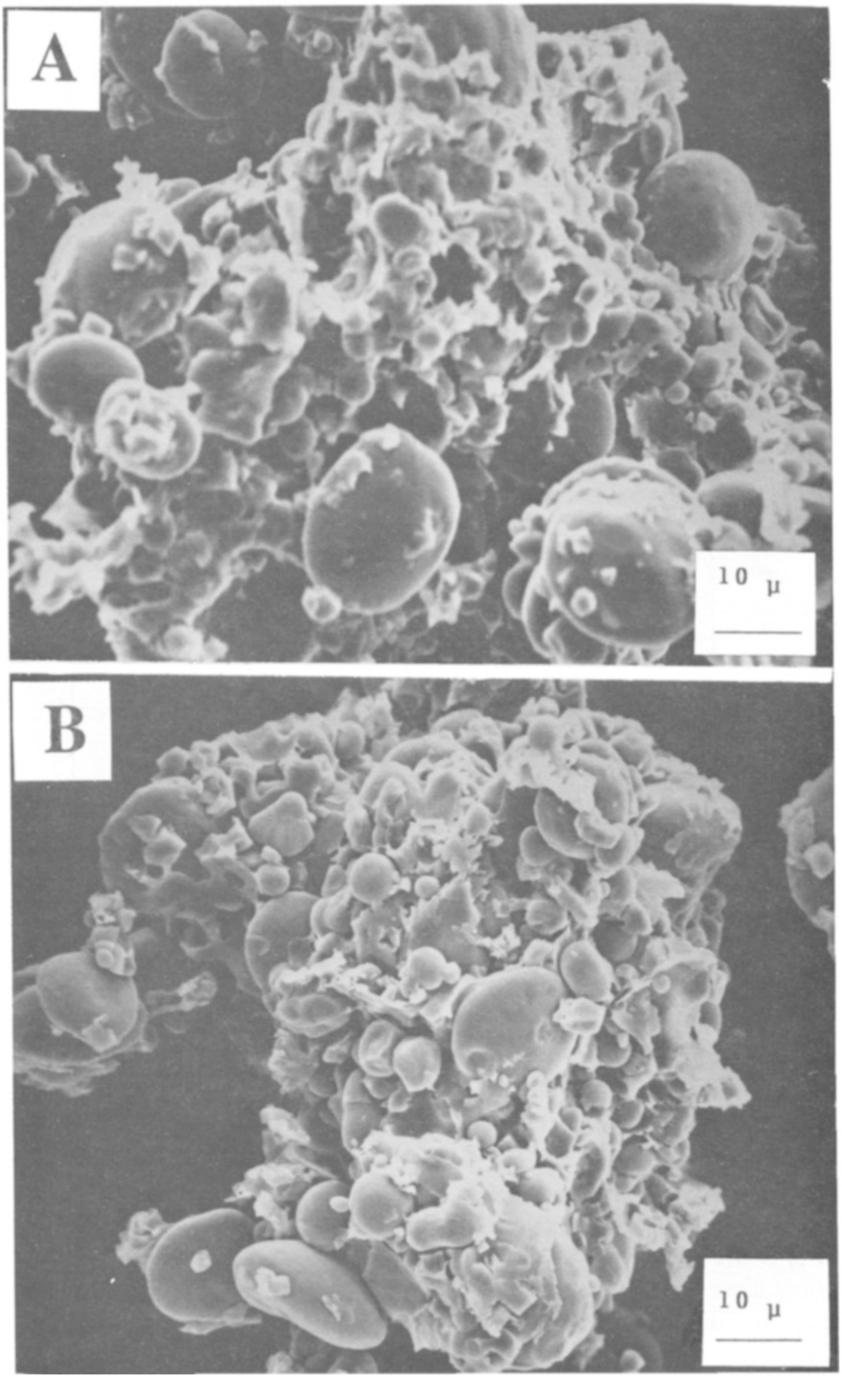


Fig. 3. SEM micrographs of flour samples. (**A**) 'Good' flour; (**B**) 'poor' flour.

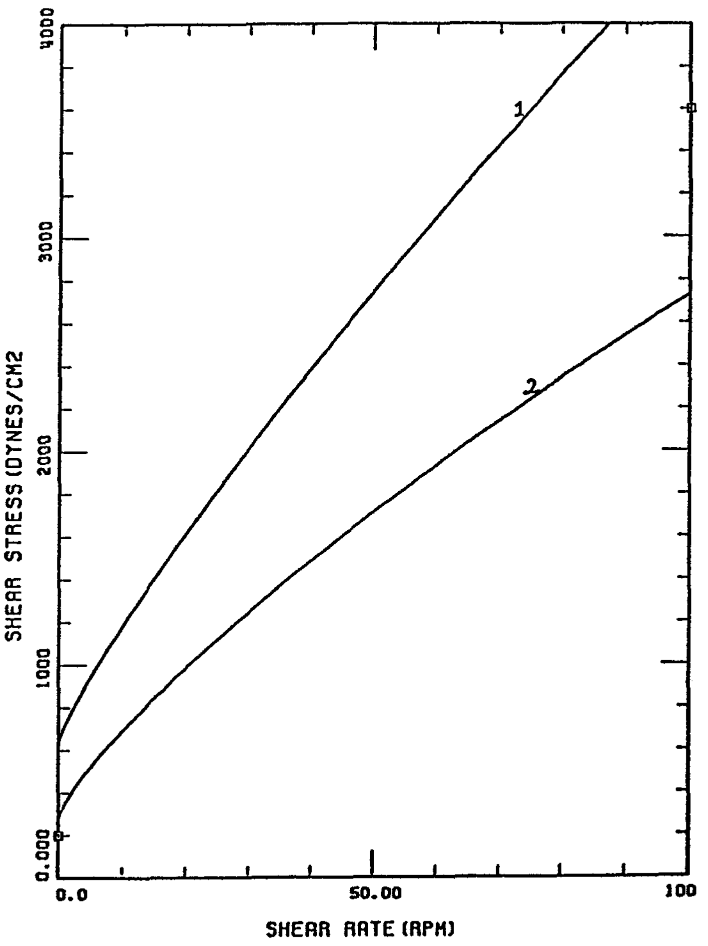


Fig. 4. Flow curves of flours. (**1**) 'Good' flour; (**2**) 'poor' flour.

necessary to monitor batter viscosity for any given composition of flour at any given temperature. Table III gives the viscosity value of a typical batter with different salt and water contents at different temperatures. The data were analyzed by analysis of variance. The results show, as expected, that viscosity increases when solid concentration is increased and when temperature is lowered. More importantly, the results show that viscosity drops when the salt content is increased, even at moderate levels. A derived empirical model which satisfactorily describes the system is the following, in which all terms are significant ($P < 0.001$):

$$\ln U = 13.6 - 0.221\ W - 0.281\ S - 0.064\ T \qquad (R = 0.95) \qquad (7)$$

where $\ln U$ = natural logarithm of plastic viscosity (poise), measured at 10 and 20

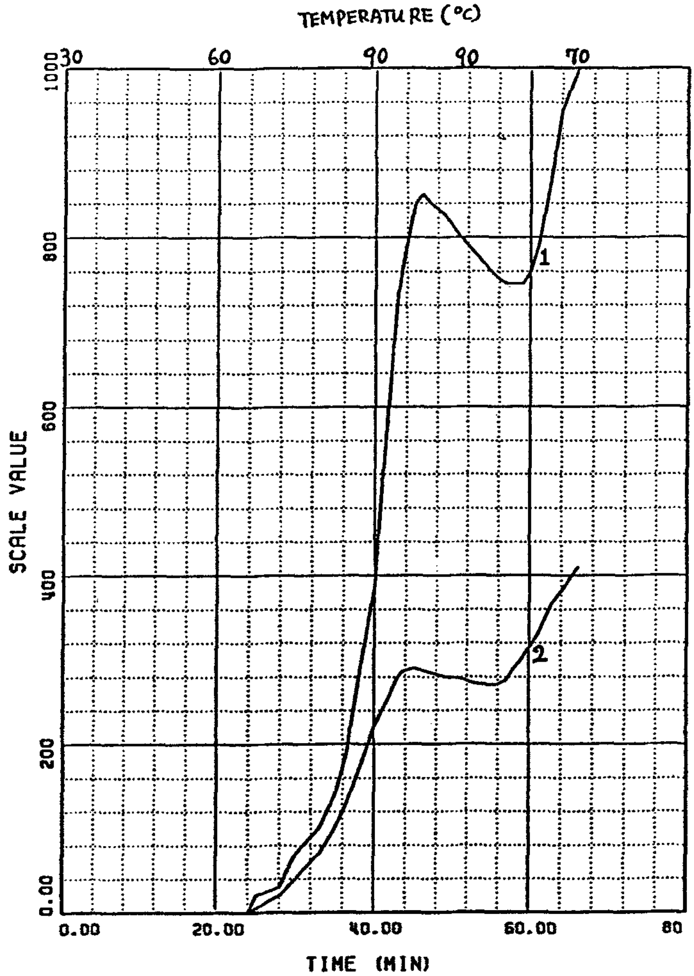


Fig. 5. Amylogram of flour samples. (1) 'Good' flour; (2) 'poor' flour.

r.p.m., W = weight percent of water in batter, S = weight percent of salt in liquid phase and T = temperature (degree Kelvin).

While the coefficients of this equation are valid only for the specific batter used in the experiment, the general form of the equation provides a guideline for adjusting batter viscosity for any flour by manipulating the salt and water content. Figure 7 shows the contours of viscosity varying with water and salt content at different temperatures.

Effect of salt content on flow curve of batters. Table IV shows the apparent viscosity of batters with different amounts of salt at 21°C at different shear rates. Flow curves generated from these data show that plastic viscosity and apparent recovery yield stress decrease as the salt content increases. The recovery yield

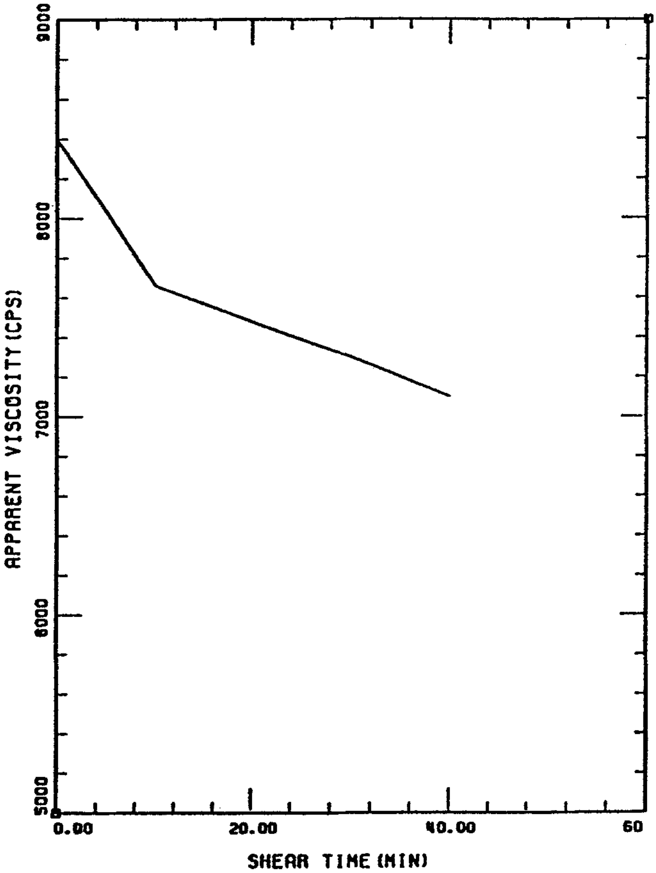


Fig. 6. Time dependency of viscosity of batter.

Table III. Effect of salt and water content on batter viscosity at different temperatures

Sample no.	Additions		Composition		Temperature (°C)		
	Salt (g/batch)[b]	Water (g/batch)[b]	Salt (% of water)	Water[a] (% of batter)	15.0	23.5	30.0
					Batter viscosity (poise)		
1	0.0	81	0.00	29.5	820	209	160
2	0.0	97	0.00	32.0	234	153	120
3	0.0	113	0.00	34.4	115	82	55
4	0.7	81	0.56	29.5	797	176	124
5	0.7	97	0.50	32.0	210	120	90
6	0.7	113	0.45	34.4	120	75	53
7	1.4	81	1.12	29.5	277	158	111
8	1.4	97	1.00	32.0	161	114	75
9	1.4	113	0.90	34.4	120	73	50
10	2.1	81	1.68	29.5	248	152	120
11	2.1	97	1.50	32.2	145	102	65
12	2.1	113	1.35	34.4	110	71	50

[a] Added water plus liquid in syrup.
[b] Batch of 200 g flour, 6.7 g shortening, 1.6 g lecithin and 135 g syrup (67%).

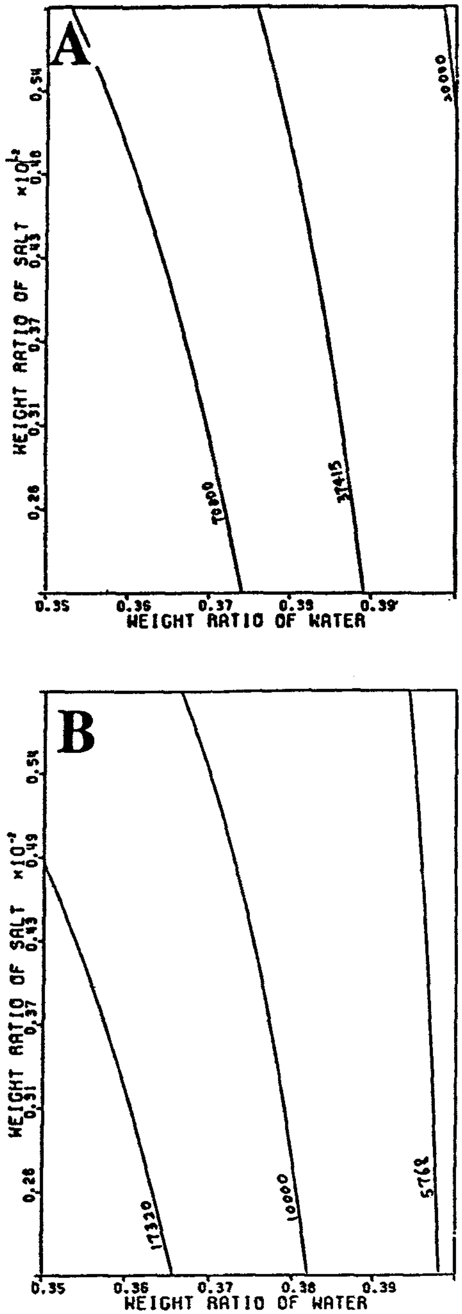
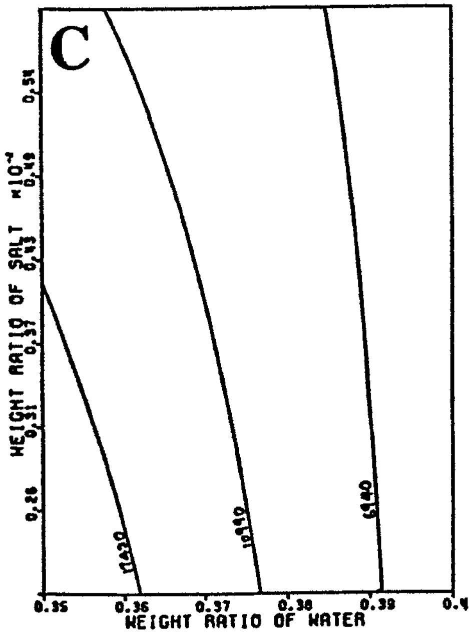

A
WEIGHT RATIO OF SALT
WEIGHT RATIO OF WATER
37415
B
WEIGHT RATIO OF SALT
WEIGHT RATIO OF WATER
17320
10000
5768

Fig. 7



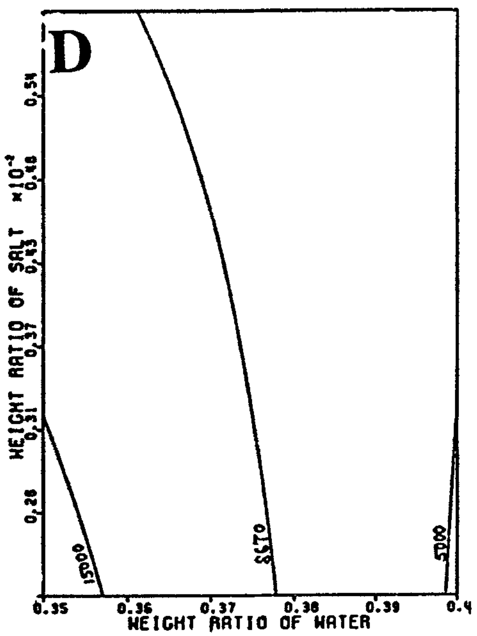


Fig. 7. Contour plot of batter viscosity at different temperature, water and salt content. Temperature = (**A**) 20, (**B**) 24, (**C**) 28, (**D**) 32°C.

Table IV. Effect of salt on batter viscosity at different shear rates

Shear rate (r.p.m.)	Salt concentration (g/413 g batter)				
	0.0	0.5	1.0	1.5	2.0
			(poise)		
0.5	400	300	320	300	284
1	600	490	448	428	400
2.5	1000	800	728	704	660
5	1460	1200	1092	1056	980
10	2250	1860	1696	1640	1544
20	3550	2960	2712	2632	2480
50	6530	5700	5450	5120	5070
100	11160	9340	8920	8510	8450

stress value is important to the shape and stability of batter applied to the baking plates, and batters with low yield stress values may be expected to creep and, thus, cause increased problems with adhesion and weak spots in the cones.

Effect of pregelatinized starch addition on batter viscosity. Since flours with low viscosity present adhesion problems, attempts were made to increase batter viscosity by adding pregelatinized corn starch (A.E.Staley Mfg. Co.). Addition of 1% by wt to flour was found to increase the flour viscosity by a factor of 1.6, while 2 and 3% caused an increase by factors of 2.7 and 5.3 respectively. Within a practical application range, fortification with 1% pregelatinized starch would appear reasonable. Boettger (7) observed that the addition of 3–3.5% pregelatinized starch in cake baking brought about an effective increase in moisture absorption of the dry ingredients, yielding batters of higher viscosity. Addition of cellulose gum, or CMC, has been shown to increase viscosity substantially (8).

Discussion

Baking performance of rolled ice cream cones is of concern because it affects the economy of baking as well as the quality of the product. Satisfactory baking performance mandates that the operation proceeds automatically and continuously without adhesion of baked waffles to the baking plates and without build-up of residues on the plates.

It was shown that baking performance depends principally upon batter viscosity because the spread of the batter and the amount of application is controlled by the rheological behavior of the batter. When the batter is too thin, the recovery yield stress is also low, and the batter spreads too fast on the plates and penetrates too deeply into the grid seams. Again, it should be noted that the measured 'recovery yield stress' is not true yield stress but, for the purpose of this study, represents a reproducible quantity which is related to the stress relaxation of a viscoelastic batter.

Within the thinner batter it may be expected that cohesion within the mixture is decreased and that the adhesive force between the baked wafer and baking plates will increase, and thus will enhance the stickiness problem. Batter viscosity was shown to be influenced principally by flour characteristics and to a lesser extent by other ingredients. The results showed that baking performance improved proportionally with the viscosity of flours. Both the flour composition and the maturing treatment affected the viscosity. Although a high viscosity value can be achieved by using flour with high protein content, such as from hard wheats, this approach is not desirable because the texture of the cones might become hard and tough. However, the control of flour viscosity through the selection of flours with low amylase activity and starch damage, low mineral content (ash value) and with proper level of chlorination may be helpful.

Flour minerals, as well as added salt in the batter, exert a modifying influence on the batter viscosity. Reports have been published on the effect of salt decreasing the consistency of dough, but none so far relating to batter viscosity (9,10). The effect of salt is thought to be primarily due to changes in gluten conformation (11). In the absence of salt or other electrolytes the hydrodynamic volume of the protein molecules will expand, with the more open configuration permitting stronger solute–solute interactions and increased opportunity for occlusion of water. Both effects would result in enhanced viscosity. In the presence of salts, the proteins are folded and associate more closely with each other due to charge suppression. This in turn will decrease the viscosity of the batter. Thus, control of the salt concentration in the formulation is important for maintaining a consistent batter viscosity; however, the proper level would depend upon pH, protein and ash content of the flour.

Other methods to enhance the viscosity of the batter include addition of food grade thickening agents in the formulation, such as pregelatinized starch or hydrocolloids. Control of the agitation speed and time/temperature of batters in the holding tank might also be helpful.

Acknowledgements

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