THE EFFECT OF MIXER SPEED, TEMPERATURE AND WATER ABSORPTION ON FLOUR-WATER MIXOGRAM CHARACTERISTICS

by

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
Mixograph	1
Interpretation of a Mixogram	2
REVIEW OF LITERATURE	5
MATERIAL AND METHODS	8
Flour Data	8
Experimental Set Up	12
Baking Procedure	14
Response Surface Methodology	14
RESULTS AND DISCUSSION	16
Mixing Time Studies	16
Standard Flour 'C'	16
KSU Flour	24
Ross Flour	24
Centurk Flour	31
Study at Higher RPM	31
Mixogram Height Studies	36
Baking Test Results	47
SUMMARY	49
ACKNOWLEDGMENTS	51
LITERATURE CITED	52

INTRODUCTION

The laboratory determination of dough handling properties has attained increasing importance with the large use of flours in bakeries where the dough is handled almost wholly by machines. The behavior of the dough in mixing, moulding, and other mechanical manipulations is determined by its physical properties. An understanding of these physical properties is therefore desirable in the laboratory testing of flours (1).

These words are just as true today as when Dr. Swanson wrote them 30 years ago. The advent of the continuous bread making process has increased the desirability to measure and understand the physical characteristics of dough properties. The continuous bread process is characterized by a high speed mixer or developer. The energy input during dough development causes a dough temperature rise of 12-20 °F. (2).

The purpose of this study was to investigate the effect of rpm, temperature and water absorption on the properties of flour-water mixograms.

Mixograph. The mixograph (National Corp., Lincoln, Neb.) is a miniature high speed recording dough mixer. Its operation has been described by Finney and Yamazaki (3). The unit is enclosed in a thermostatically controlled cabinet to obviate the effect of temperature changes occurring while mixing the dough. The mixing effect is obtained by four vertical pins attached to a rotating mixing head which revolve through the dough in a planetary motion around three fixed pins in the bowl. As the gluten develops and dough consistency increases, a gradually increasing amount of force is required to push the revolving pins through the dough. This increasing dough resistance imparts a torque to the mixing bowl, which is placed in the center of a lever system. The degree of torque produced is measured and recorded by means of a stylus on a chart traveling at a uniform speed (4).

Interpretation of a Mixogram. A mixogram is shown in Figure 1, which also illustrates the method used in securing curve measurements. A line is drawn through the center of the curve to present the actual shape as closely as possible. Mixing time (M) is the time required (in min.) for the curve to reach a peak (P). The interval between two arcs on the paper corresponds to one minute. Curve height (H) was measured (in cms.), vertically from the center of the peak to the base line. It tends to be reduced with increased absorption and increased with increased protein content (within the same variety of wheat).

There are several other characteristics that could be included in the mixogram. Dough development is that part of the curve between the start and the peak during which dough formation and gluten development takes place. The dough development angle is the angle formed by the ascending and descending sections of the curve. The more tolerant a flour, the larger the angle. Dough weakening angle is the angle formed by a line drawn at the peak (P) and the line paralleling the general slope of the curve beyond the peak. The greater that angle, the more rapid is dough breakdown (4).

The width of the curve at the peak is an index of dough strength and tends to increase with increased protein content (5).

Fig. 1. Interpretation of a mixogram (P = peak, M = mixing time, H = height).

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

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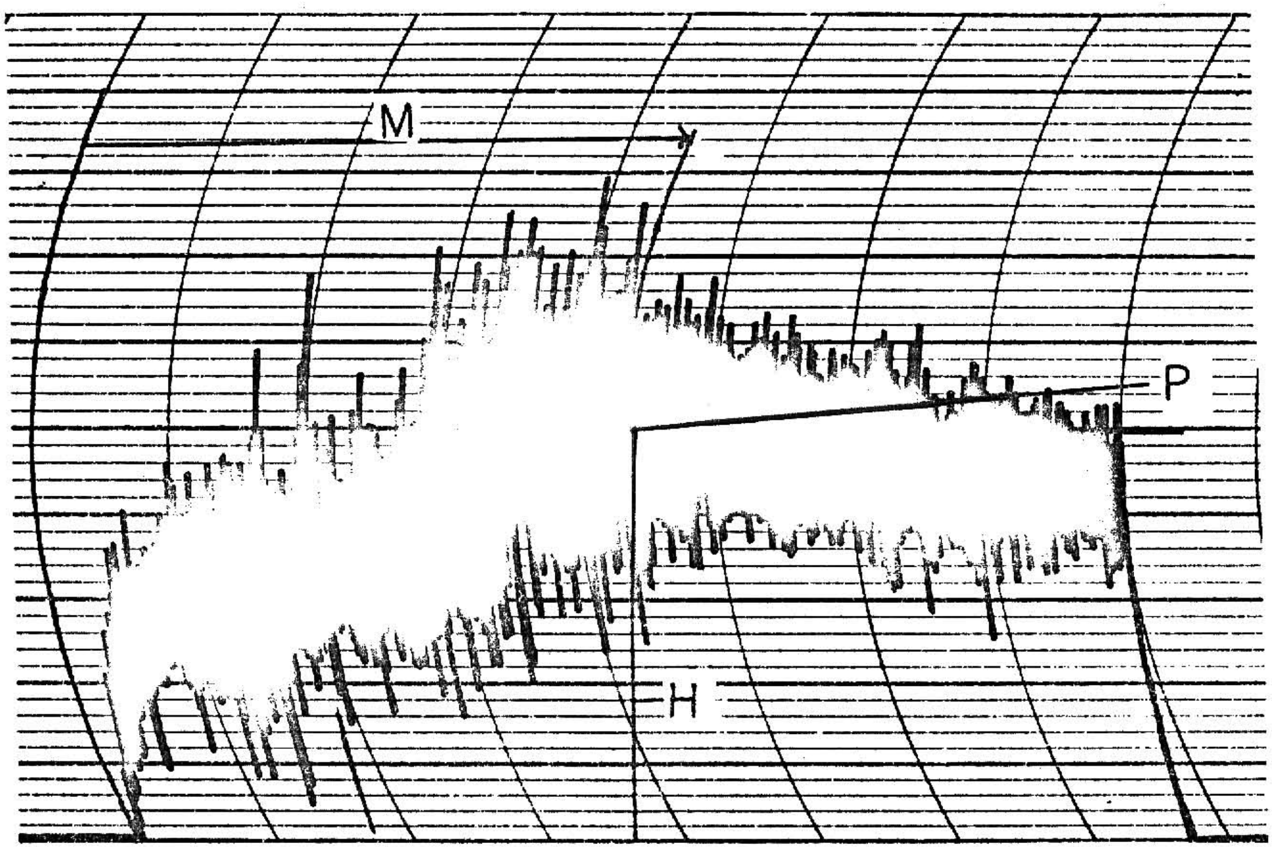

M
P
H

REVIEW OF LITERATURE

Mattern and Sandstedt (6) investigating the biochemical basis for variations in mixing time from flour to flour concluded that the water soluble constituents of flour are responsible for the variations in mixing time. Smith, et. al. (7) though obtaining similar data found that both the glutenin and gliadin fractions of gluten protein are required for normal mixing and that as the ratio of glutenin to gliadin increased, the mixing time increased. However, the ratio of gliadin to glutenin does not appear to vary from short-mixing to long-mixing flours (8). Fractionation and reconstitution studies have shown that the factor responsible for mixing time differences was in the glutenin protein fraction. Finney and Fryer (9) reported that high temperature and low humidity during fruiting period decreased mixing time. Varieties with short-mixing times were adversely affected more than were long mixing varieties. Artificial drying of wheat at excessively high temperatures was shown to lead to increased mixing times (10). Finney, et. al. (11) pointed out that within a variety mixing time decreased as protein content increased to about 12% and thereafter mixing time remains approximately constant with further increases in flour protein.

At the mixing stage, oxygen is incorporated into the dough. The studies conducted by Baker and Mize (12) have shown that doughs mixed in air offer more resistance to extension (height of curve) than those mixed in nitrogen, hydrogen or under vacuum. Smith, et. al. (13) concluded that the oxygen uptake during mixing varies directly with fatty acid content of the separated fat. In a related study (14) they found that the flour grade affects oxygen uptake. Patent flour absorbs much less than the first clear flour fraction, which, in turn absorbs much less than second clear fraction.

Mixogram studies conducted by Sanchez and Hoseney (15) demonstrated that salt increased dough consistency through out the mixing period. Chiu, et. al. (16) found that adding shortening (3%) decreased water absorption and increased mixing time. During mixing about half of the added shortening becomes bound to the protein fraction and can not be extracted.

Dempster, et. al. (17) demonstrated that normal levels of potassium bromate has no effect on mixing time. However, increased amounts of iodate increased a doughs resistance to extension, while decreasing the mixing time. Reducing agents such as cysteine reduces the mixing requirement (18, 19). The degree that mixing time is decreased appears to depend on the amount of cysteine added rather than flour type.

Several studies on the effect of temperature, water absorption and mixer rpm on dough properties have also been reported.

Skovholt and Bailey (20) found that differences in temperature caused a decrease in dough plasticity to the extent of 12-40 farinograph units/1°C. Moore and Herman (21) studied the effect of temperature and absorption on a variety of farinograph indices and reported that as the temperature increased, the arrival time decreased and stability increased. The effect of water absorption and temperature on flour-water farinograms was studied by Bayfield and Stone (22). They found that at constant absorption, consistency decreased with increased temperature. With consistency held constant, the water absorption decreased as the temperature was increased.

Irvine, et. al. (23) reported that at a constant absorption as the temperature was increased dough development time decreased, maximum consistency decreased and the tolerance index increased. Hlynka (24) extensively studied the effect of temperature, mixer speed and absorption on the farinograph curve of an unbleached hard spring wheat-flour. He found increasing temperature, increasing mixer speed or reducing absorption shortened mixing time. Stanberg and Bailey (25) studied the relationship of mixing speed to dough development and concluded for each mixing speed there is an optimum mixing time. Harris (26) found that mixogram curve height and width decreased as temperature increased. Swanson and Bayfield (27) studied the relationship between mixing speeds, milk solids and bread quality. Mixing speeds ranged from 50 to 200 rpm. at intervals of 25 rpm. A Swanson mixer was used. They concluded that at all mixer speeds the optimum mixing time increased with increasing amounts of milk solids. Martha (28) found that at constant consistency, farinogram absorption, arrival time, peak, stability, departure time and time to break down were lower at 40 °C. than at 30 °C.

MATERIAL AND METHODS

Flour Data. Four hard winter wheat flours were used and their analyses are given in Table I. The mixograms of flours under standard conditions (rpm = 90, temperature = 25 °C, absorption = *optimum*) are shown in Figure 2.

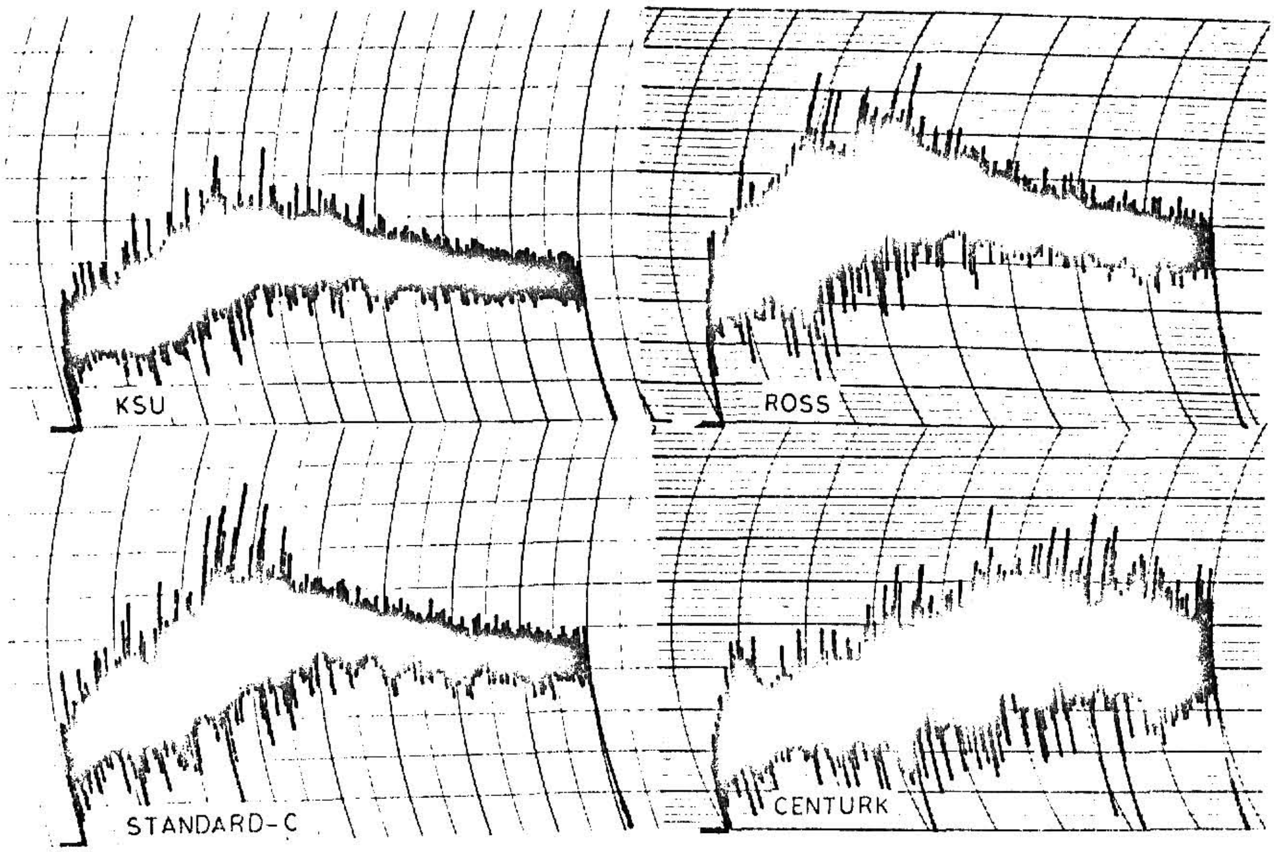
TABLE I. ANALYSIS OF FLOURS

Flour	Source	Protein[a] %	Moisture %	Water Absorption[b] %	Mixing Time[b] min.
K.S.U.	K.S.U. flour mill	11.3	12.6	62.0	3.25
Standard 'C'	Commercial	12.3	14.0	62.5	3.50
Ross	Commercial	13.3	13.0	64.5	3.25
Centurk	Experimental	13.4	14.7	62.5	6.00

[a] Protein factor: N x 5.7.

[b] Determined by mixogram.

Fig. 2. Mixograms of the four Hard winter wheat flours under Standard conditions (rpm = 90, Temp. = 25°C, Absorption = Optimum).


KSU
ROSS
STANDARD-C
CENTURK

Experimental Set-up. The flour-water mixograms were obtained by various combinations (Table II) of three levels of temperature, water absorption and mixer rpm. The temperature ranged from 25°C to 40°C with an interval of 7.5°C. The three levels of water absorption used were equivalent to optimum absorption for a flour (at 90 rpm, 25°C), 3% less and 3% more than optimum absorption. The doughs were mixed at three speeds, 70, 90, and 110 rpm. The rpm of the mixer was varied with different pulley combinations and variable speed motor, controlled by a rheostat.

The mixograph was equipped with a 0.125 H.P. variable speed motor, with a torque capacity of 32 in. lbs./min. With a pulley combination of 3.75": 3.75" (rear:front), and under a mixing load a constant rpm could not be maintained at speeds higher than 90 rpm. With a pulley combination of 2.25":3.75" (rear:front), constant rpm could be maintained through 110 rpm. At higher mixer speeds, the rpm dropped under load. To extend the study to higher speeds, we adjusted the mixer speed to give desired mixer rpm under a mixing load.

The flour sample (in a mixer bowl) and distilled water (in a beaker) were both brought to the desired temperature in a water bath. The water was added to the flour, just before mixing. The mixogram cabinet was maintained at the desired temperature by a thermostat. Temperature of the dough was measured at the end of mixing period and found to be equal to the cabinet temperature. Dough temperature would be expected to rise during mixing, because of the heat of hydration and mechanical energy expended during mixing. However, the quantity of dough was small and the heat generated, evidently dissipated into the environment of the mixer cabinet.

TABLE II. RSM DESIGN FOR THREE VARIABLES

Run Number	Variables		
	X_1	X_2	X_3
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	1	-1
11	0	-1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0

X_1 = RPM, -1 = 70, 0 = 90, 1 = 110.

X_2 = Temperature (°C), -1 = 25, 0 = 32.5, 1 = 40.

X_3 = Absorption, -1 = 3% less, 0 = Optimum (at 25°C, 90 rpm), 1 = 3% more.

Baking Procedure. The baking procedure described by Finney and Barmore (29-31) and Finney (32) was used. The baking formula included.

Ingredient	Gms.
Flour	100.00
Sugar	6.00
Salt	1.50
Malt	0.75
Shortening	3.00
NFDM	4.00
Yeast	2.00

A straight dough method was used with optimum mixing time and absorption. Doughs were fermented 3 hours and proofed 55 min. at 30°C and 86% humidity. Baking time was 24 min. at 218°C. Proof height were measured in centimeters and loaf volume by rape seed displacement, within 3 min. after removal from oven. Duplicate loaves were baked.

Response Surface Methodology. Response surface methodology (RSM), described by Cochran and Cox (33) and Henika (34), was used to investigate mixing time and curve height responses of flour-water mixograms. The design is given in Table II. The equation for response was:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3$$

The B values were estimated by a computer program for multiple regression and non-significant terms were eliminated by stepwise deletion until a minimum mean square term was obtained. The program provided a coefficient of determination (R^2) for each response. The equation was used to obtain contour plots of the response (Y) as a function of variables.

Reproducibility of the values obtained for mixing time and curve height at the data points was tested by running standard deviation on standard 'C' flour. The mixing times and curve heights were reproducible within a S.D. of $\pm$ 0.31 min. and 0.18 cm. respectively.

RESULTS AND DISCUSSION

Mixer rpm, temperature, and water absorption are considered as important factors that control both the mixing time and curve height (resistance of dough to extension) of a mixogram. Four flours were used. Three gave a range in protein content (Table I, page 9) at a constant mixing time and the fourth had a longer mixing time. A response surface technique was used to study the effect of three variables, rpm, temperature, and absorption on mixing time and curve height.

Mixing Time Studies.

Standard Flour 'C'. The mixing times for the partial factorial data points are given in Table III. The response surface equation (footnote Table III) has a coefficient of determination (R^2) = 98.9. Contour plots (Figs. 3 through 5) from that equation give mixing time as a function of the variables.

At 59.5% absorption with any temperature studied, the mixing time decreased as rpm was increased. At lower rpm (70-90) mixing time increased as temperature was increased from 25 to 40°C. At 110 rpm, however, the mixing time first decreased and then increased.

With 62.5% absorption (optimum at 90 rpm, 25°C) at all temperatures investigated mixing time decreased as rpm increased. At any rpm lower than 110 the mixing time increased as temperature increased. At 110 rpm as the temperature was increased the mixing time first decreased and then increased at temperatures higher than 34°C.

TABLE III. MIXING TIME DATA STANDARD 'C' FLOUR

Water Absorption %	RPM	Mixing Time, when temperature (°C) was 25.0 min.	32.5 min.	40.0 min.
59.5	70		5.00	
62.5	70	4.50		8.25
65.5	70		7.00	
59.5	90	3.50		5.00
62.5	90		4.5, 4.5, 4.5	
65.5	90	4.25		8.25
59.5	110		2.75	
62.5	110	3.00		3.50
65.5	110		3.25	

Equation for response surface $Y = 4.5 - 1.6563X_1 + 1.3438X_2 + 0.8125X_3 + 0.6562X_2^2 - 1.0625X_1X_2 - 0.375X_1X_3 + 0.625X_2X_3$.

Where: X_1 = RPM, X_2 = Temperature, X_3 = Water absorption.

Coefficient of determination (R^2) = 98.9.

Fig. 3. Standard 'C' Flour. Contour plot of mixing time (A = 2, B = 2.5, C = 3, D = 3.5, E = 4, F = 4.5, G = 5.0) for rpm and temperature with absorption held constant at 59.5%.

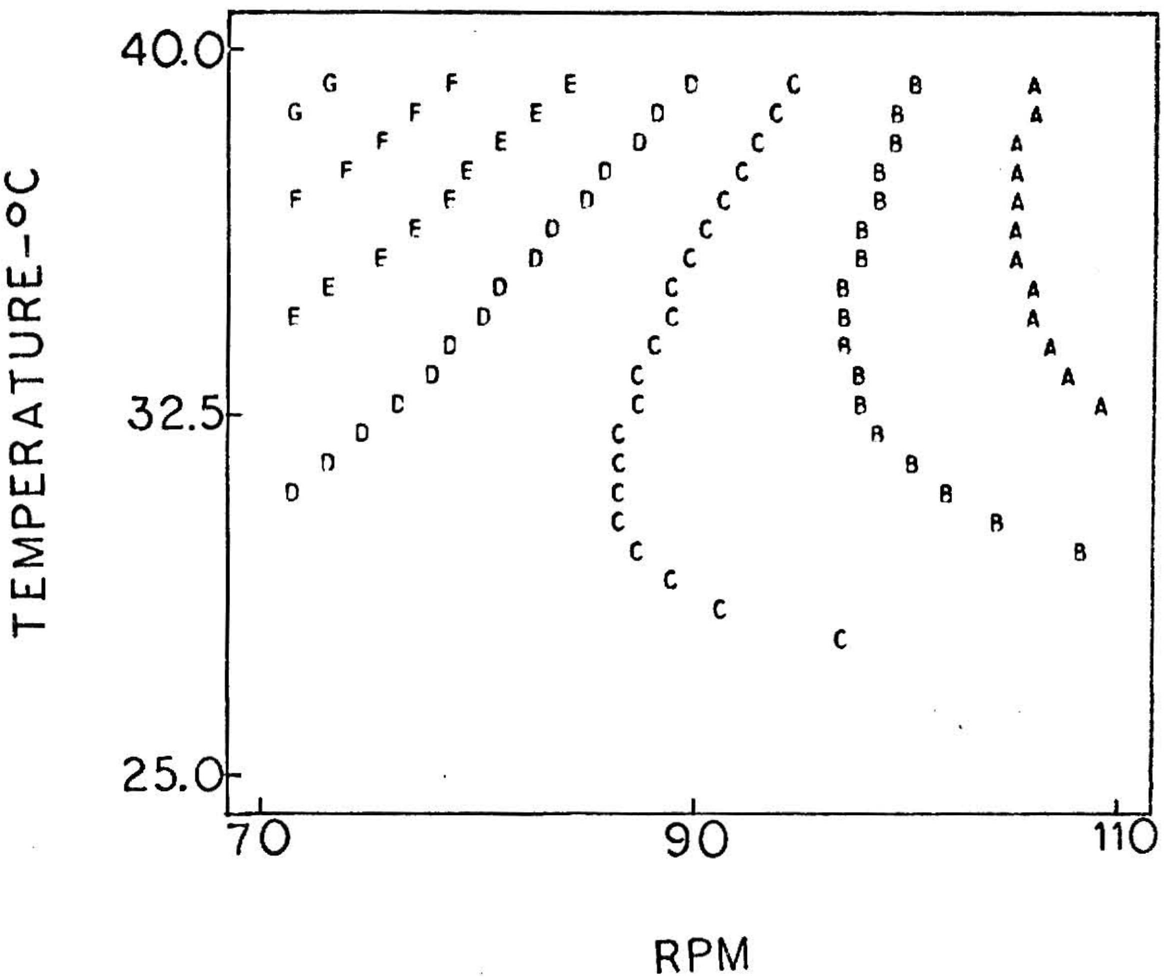

40.0
32.5
25.0
70
90
110
TEMPERATURE-°C
RPM

Fig. 4. Standard 'C' Flour. Contour plot of mixing time (C = 3, D = 3.5, E = 4, F = 4.5, G = 5, H = 5.5, J = 6, K = 6.5, L = 7, M = 7.5, N = 8, O = 8.5, P = 9.0) for rpm and temperature with absorption held constant at 62.5% (optimum at 90 rpm and 25°C).

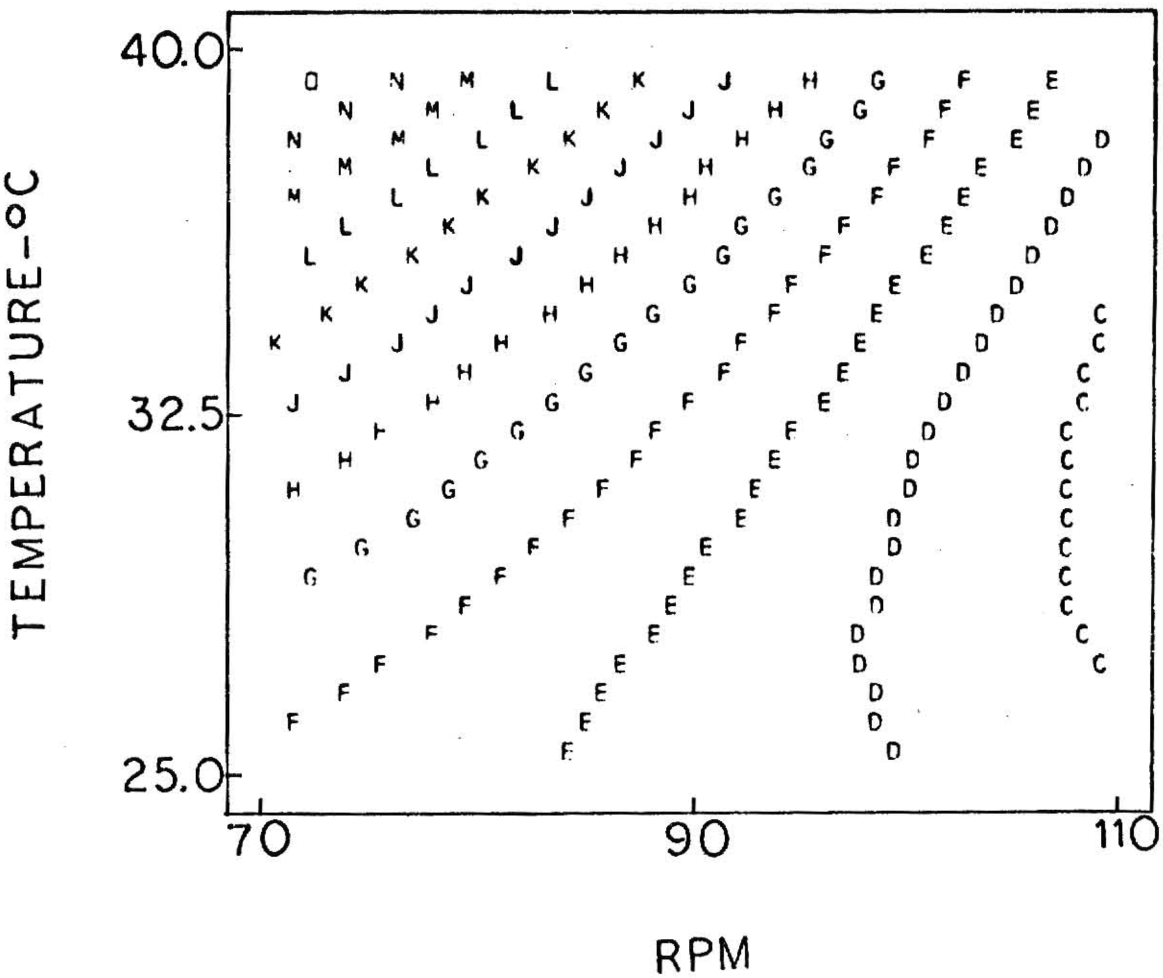
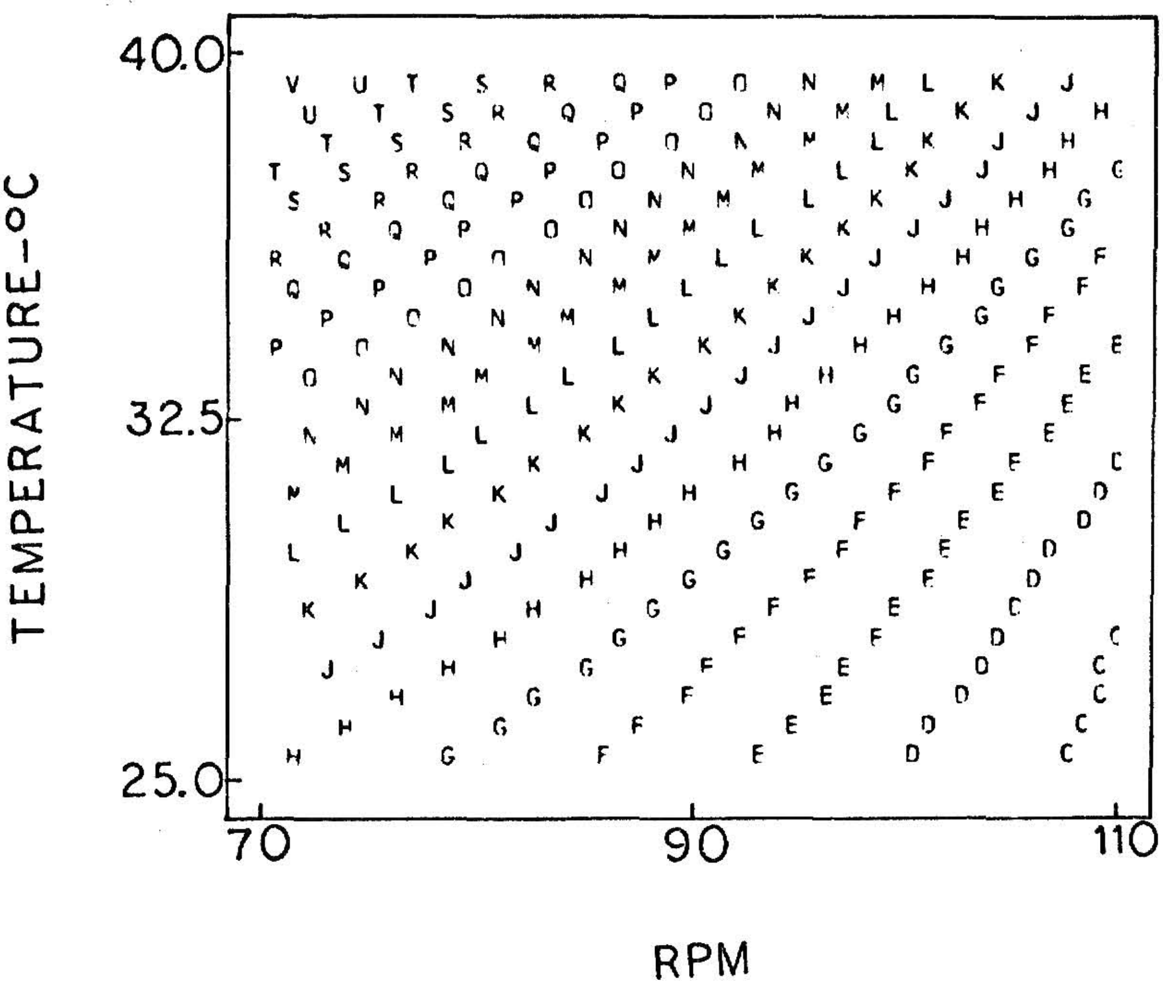

40.0
32.5
25.0
TEMPERATURE-°C
70
90
110
RPM

Fig. 5. Standard 'C' Flour. Contour plot of mixing time (C = 3, D = 3.5, E = 4, F = 4.5, G = 5, H = 5.5, J = 6, K = 6.5, L = 7, M = 7.5, N = 8, O = 8.5, P = 9, Q = 9.5, R = 10, S = 10.5, T = 11, U = 11.5, V = 12) for rpm and temperature with absorption held constant at 65.5%.



40.0
32.5
25.0
TEMPERATURE-°C
70
90
110
RPM

At 65% absorption and any temperature studied, mixing time decreased as rpm was increased. At lower rpm (70-100) mixing time increased with increased temperature. At 110 rpm there was a slight change in mixing time at temperature below 29°C, above 29°C mixing time increased. The minimum mixing time within the limits of the study was obtained at 110 rpm, 59.5% absorption and 34°C.

K. S. U. Flour. The mixing times for the partial factorial data points are given in Table IV. The response surface equation (footnote Table IV) has a coefficient of determination (R^2) = 97.4. Contour plot (Fig. 6) from the equation gives mixing time as a function of the variables.

At 62% absorption (optimum at 90 rpm, 25°C) and all temperatures investigated, mixing time decreased as rpm was increased. At low rpm (70-100) mixing time increased as temperature was increased. At 110 rpm increasing the temperature from 25 to 32.5°C gave only a small change in mixing time, while higher temperatures increased mixing time.

At 59 and 65% absorption, in general, the effect of rpm and temperature on mixing time was similar to that discussed in the preceding paragraph. The mixing time decreased with increased rpms and increased with increased temperature. The minimum mixing time within the limits of the study was obtained at 110 rpm, 59 to 62% absorption, and 29°C.

Ross Flour. The mixing times for the partial factorial data points are given in Table V. The response surface equation (footnote Table V) has a coefficient of determination (R^2) = 97.6. Contour plot (Fig. 7) from the equation gives mixing time as a function of the variables.

TABLE IV. MIXING TIME DATA - KSU FLOUR

Water Absorption %	RPM	Mixing Time, when temperature (°C) was 25.0 min.	32.5 min.	40.0 min.
59.0	70		6.10	
62.0	70	4.50		8.50
65.0	70		7.00	
59.0	90	3.50		5.00
62.0	90		4.0, 4.0, 4.0	
65.0	90	4.25		8.80
59.0	110		2.50	
62.0	110	3.00		4.50
65.0	110		3.50	

Equation for response surface $Y = 4.0 - 1.5788X_1 + 1.4363X_2 + 0.795X_3 + 0.2563X_1^2 + 0.8762X_2^2 + 0.5337X_3^2 - 0.6325X_1X_2 + 0.7850X_2X_3$.

Where: X_1 = RPM, X_2 = Temperature, X_3 = Water absorption.

Coefficient of determination (R^2) = 97.4.

Fig. 6. KSU Flour. Contour plot of mixing time (C = 3, D = 3.5, E = 4, F = 4.5, G = 5, H = 5.5, J = 6, K = 6.5, L = 7, M = 7.5, N = 8) for rpm and temperature with absorption held constant at 62% (optimum at 90 rpm, 25°C).

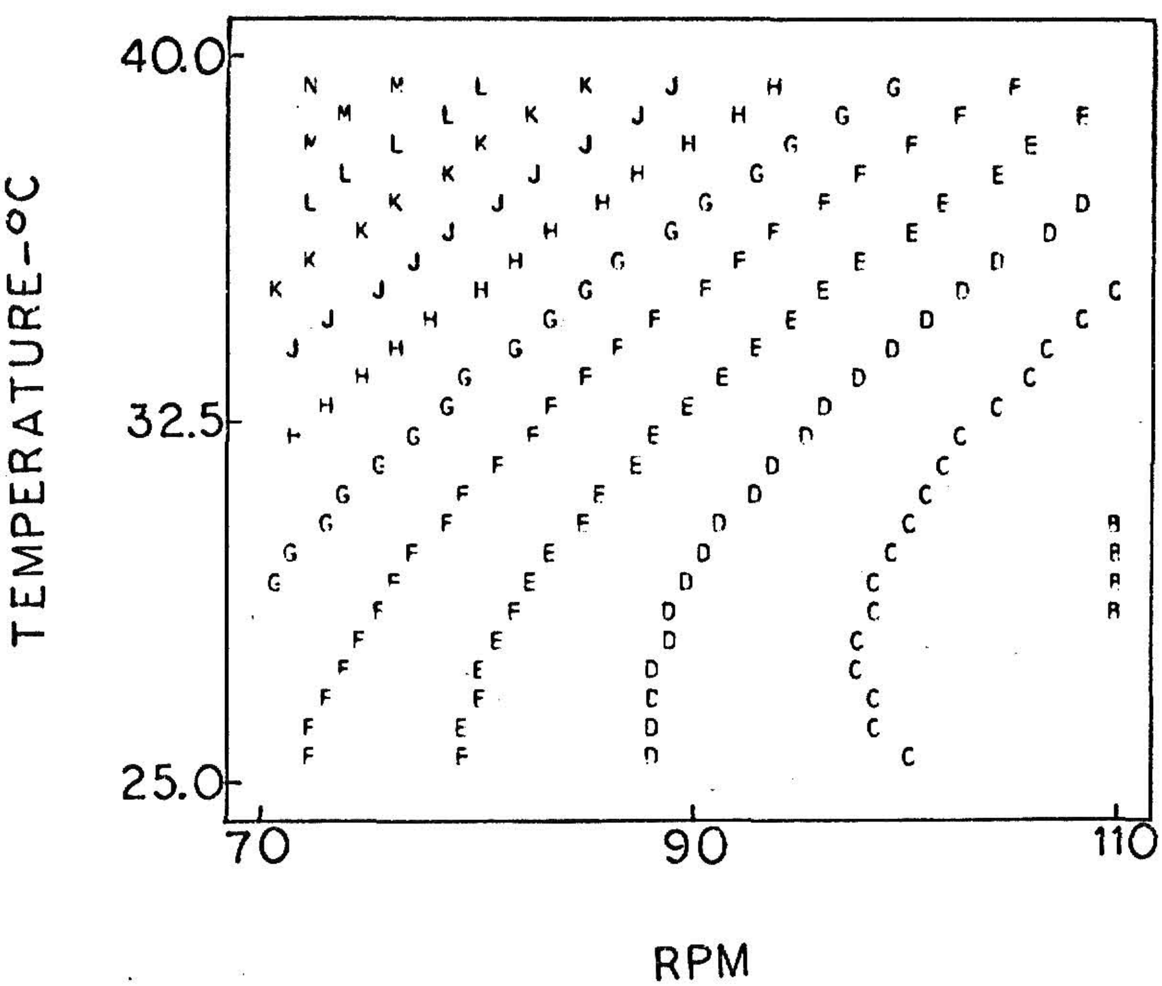

TEMPERATURE-°C
40.0
32.5
25.0
70
90
110
RPM

TABLE V. MIXING TIME DATA - ROSS FLOUR

Water Absorption %	RPM	Mixing Time, when temperature (°C) was 25.0 min.	32.5 min.	40.0 min.
61.5	70		4.50	
64.5	70	4.50		8.00
67.5	70		6.00	
61.5	90	3.50		5.50
64.5	90		3.75, 3.75, 3.75	
67.5	90	4.00		6.50
61.5	110		3.00	
64.5	110	2.50		3.50
67.5	110		3.25	

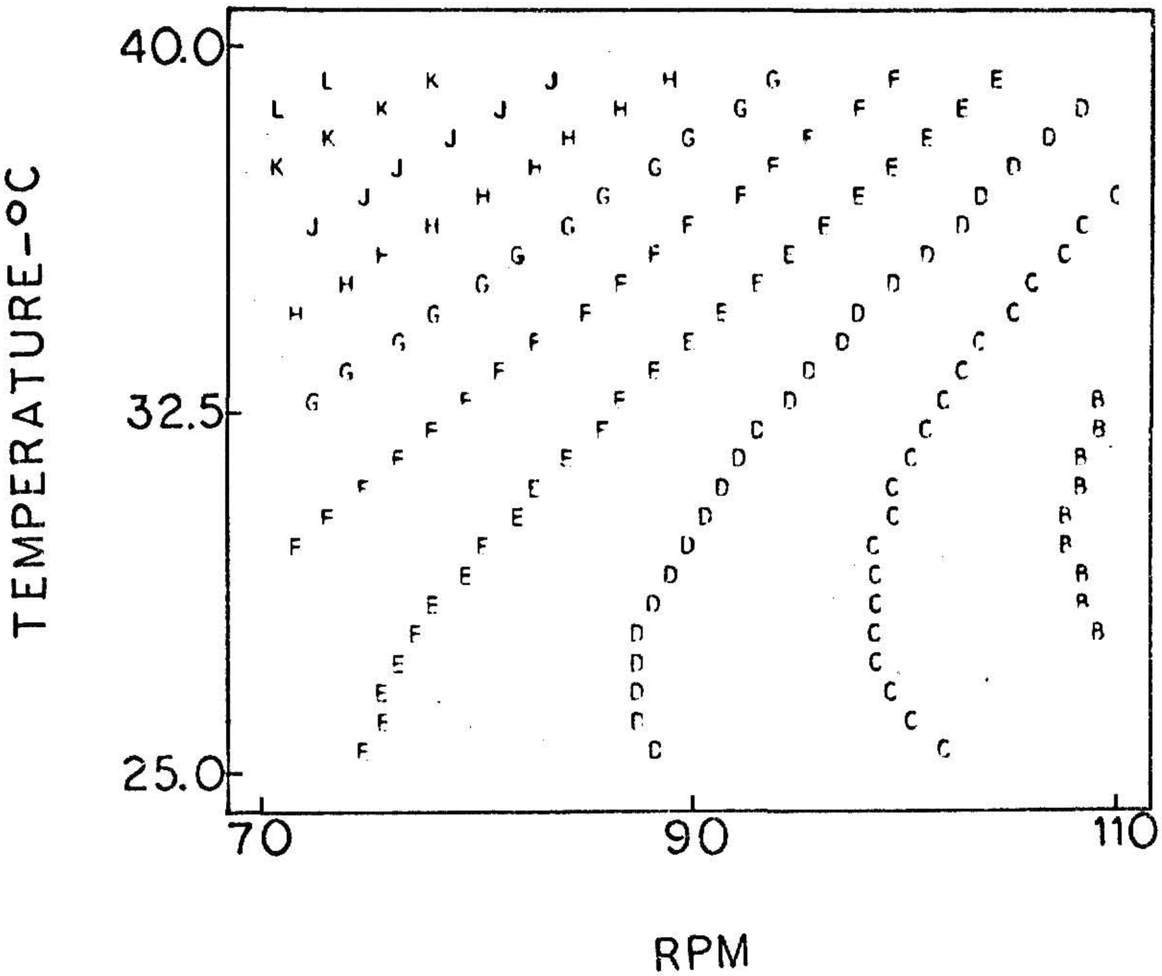
Equation for response surface $Y = 3.80769 - 1.3438X_1 + 1.125X_2 + 0.4063X_3$

$+ 0.774X_2X_2 + 0.3365X_3X_3 - 0.625X_1X_2 - 0.3125X_1X_3$.

Where: X_1 = RPM, X_2 = Temperature, X_3 = Water absorption.

Coefficient of determination (R^2) = 97.6.

Fig. 7. Ross Flour. Contour plot of mixing time (B = 2.5, C = 3, D = 3.5, E = 4, F = 4.5, G = 5, H = 5.5, J = 6, K = 6.5, L = 7) for rpm and temperature with absorption held constant at 64.5% (optimum at 90 rpm, 25°C).


TEMPERATURE-°C
40.0
32.5
25.0
70
90
110
RPM

At 64.5% absorption (optimum at 90 rpm, 25°C) with any temperature studied, the mixing time decreased as rpm was increased. At lower rpm (70-100) mixing time increased as temperature was increased. But at 110 rpm there was little change in mixing time up to a temperature of 34°C. At higher temperatures mixing times again increased. At 61.5% and 67.5% absorption, in general, rpm and temperature influenced as detailed above. The shortest mixing time within the limits of the study was obtained at 30°C., 110 rpm, and 64.5% absorption.

Centurk Flour. In an effort to extend the study to flour having inherently longer mixing times, a sample of Centurk flour which gave a 6 min. mixing time at 25°C, 90 rpm, and optimum absorption was included. However, mixing times at certain data points (Table VI) could not be determined because the mixograms were flat and showed no visible peak. Those points appear to result from a combination of high temperatures and low rpms.

The values obtained at points where mixing time could be determined showed the same general trends as found with the other (shorter mixing) flours. Kilborn and Tipples (35) found that for every flour there is a minimum critical mixing speed, below which bread of inferior quality is produced. This could be true only at 25°C. However, this study has shown, the temperature at which dough is mixed is also an important factor.

Study at Higher RPM. To extend the study to higher rpms the standard 'C' flour was used. The mixing times for the partial factorial data points are given in Table VII. The response surface equation (footnote Table VII) has a coefficient of determination (R^2) = 98.7. Contour plots (Fig. 8)

TABLE VI. MIXING TIME DATA - CENTURK FLOUR

Water Absorption %	RPM	Mixing Time, when temperature (°C) was 25.0 min.	32.5 min.	40.0 min.
59.5	70		a	
62.5	70	9.50		a
65.5	70		a	
59.5	90	6.00		a
62.5	90		6.25, 6.25, 6.25	
65.5	90	8.50		a
59.5	110		5.00	
62.5	110	5.50		6.00
65.5	110		8.75	

a : Mixogram peak not discernable.

TABLE VII. MIXING TIME DATA - STANDARD FLOUR 'C'

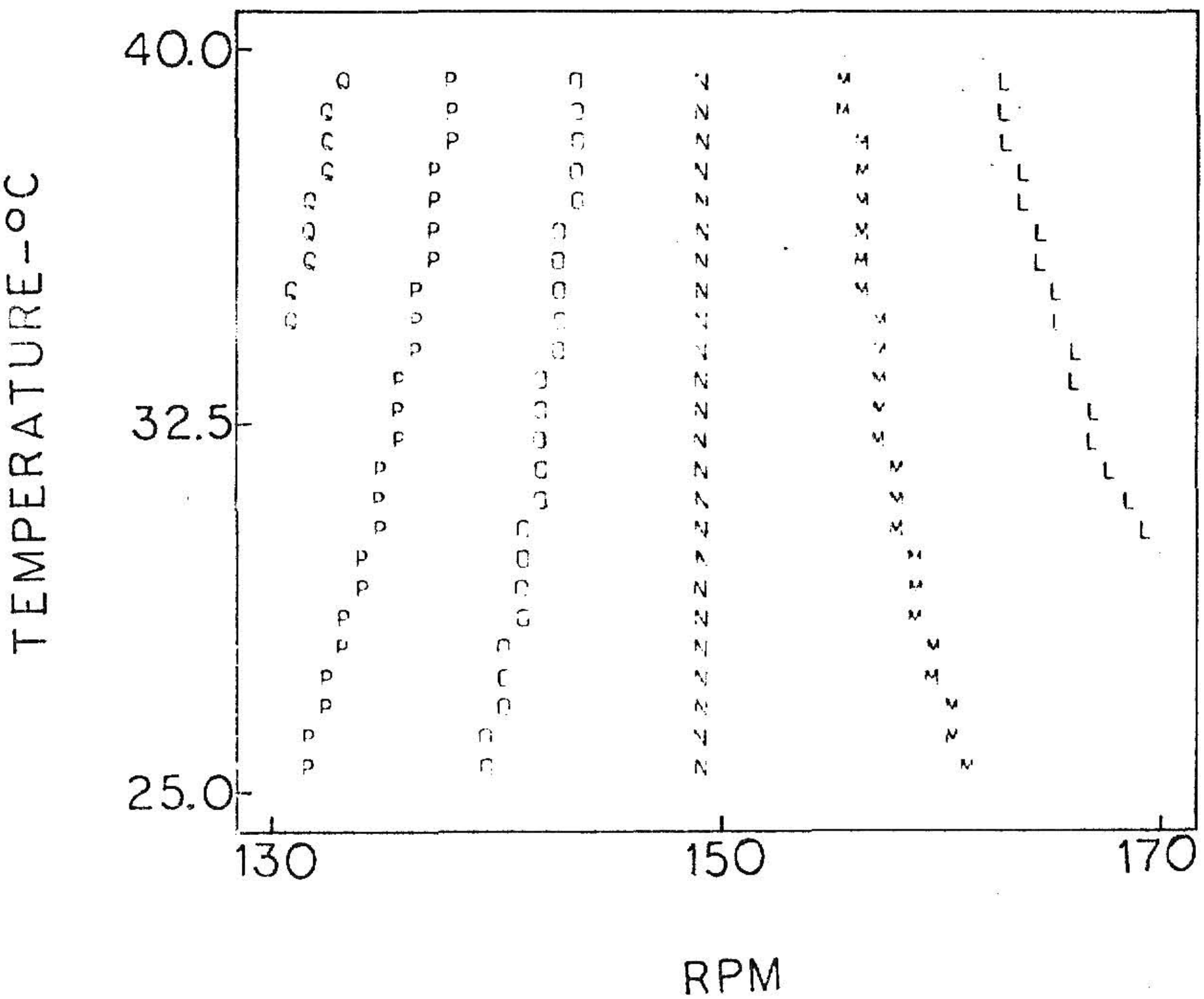
Water Absorption %	RPM	Mixing time, when temperature (°C) was 25.0 min.	32.5 min.	40.0 min.
59.5	130		2.00	
62.5	130	2.25		2.25
65.5	130		2.50	
59.5	150	1.75		1.75
62.5	150		2.0, 2.0, 2.0	
65.5	150	2.00		2.00
59.5	170		1.50	
62.5	170	1.75		1.60
65.5	170		1.75	

Equation for response surface $Y = 1.99 - 0.3288X_1 + 0.1563X_3 + 0.0475X_1^2 - 0.1075X_3^2 - 0.095X_1X_2 + 0.0625X_1X_3$.

Where: X_1 = RPM, X_2 = Temperature, X_3 = Water absorption.

Coefficient of determination (R^2) = 98.7.

Fig. 8. Standard 'C' Flour. Contour plot of mixing time (L = 1.75, M = 1.875, N = 2, O = 2.125, P = 2.25, Q = 2.375) for rpm and temperature with absorption held constant at 62.5% (optimum at 90 rpm, 25°C).



40.0
32.5
25.0
TEMPERATURE-°C
130
150
170
RPM

from the equations give mixogram heights as a function of the variables.

With 62.5% absorption (optimum at 90 rpm, 25°C) and any temperature used, the mixing time decreased slightly with increased rpm. The effect of temperature on mixing time was even less. It is of interest that around 150 rpm increased temperatures did not influence mixing time. At 59.5% and 65.5% absorptions, similar trends were observed. The shortest mixing time was obtained at about 40°C and 170 rpm.

Mixogram Height Studies

The mixogram heights (measure of resistance to extension) for the flours studied at the partial factorial data points, are given in Tables VIII through XI. The corresponding response surface equation for a flour together with coefficient of determination are given as footnotes in the respective tables. Contour plots (Figures 9 through 11) from the equations give mixogram heights as a function of the variables.

The heights of the mixograms increased as rpm was increased. However, it was felt that this effect was due to torque imparted to the dough, by the mixing pins striking the dough more often, rather than a change in the dough's resistance to extension. At a constant rpm, both higher absorptions and temperatures decreased the curve height. In the case of standard flour 'C', an increase of 1°C was equivalent to 1% increase in absorption in decreasing curve height by 0.16 cm. For Ross and KSU flours, an increase of 1°C was equivalent to 1.4% increase in absorption in reducing curve height by 0.16 cms.

TABLE VIII. CURVE HEIGHT DATA - STANDARD 'C' FLOUR

Water Absorption %	RPM	Curve height, when temperature (°C) was 25.0 cms.	32.5 cms.	40.0 cms.
59.5	70		4.00	
62.5	70	4.80		2.00
65.5	70		3.00	
59.5	90	5.70		3.00
62.5	90		4.0, 3.8, 4.0	
65.5	90	4.40		2.00
59.5	110		5.00	
62.5	110	6.00		3.60
65.5	110		3.80	

Equation for response surface $Y = 3.93333 + 0.575X_1 - 1.2875X_2 - 0.5625X_3$.

Where: X_1 = RPM, X_2 = Temperature, X_3 = Water absorption.

Coefficient of determination (R^2) = 97.4.

TABLE IX. CURVE HEIGHT DATA - KSU FLOUR

Water Absorption %	RPM	Curve height, when temperature (°C) was 25.0 cms.	32.5 cms.	40.0 cms.
59.0	70		3.80	
62.0	70	5.20		2.40
65.0	70		3.50	
59.0	90	5.40		3.20
62.0	90		4.0, 3.8, 3.8	
65.0	90	4.40		1.80
59.0	110		5.00	
62.0	110	5.80		2.80
65.0	110		3.90	

Equation for response surface $Y = 3.78 + 0.3325X_1 - 1.325X_2 - 0.4675X_3 + 0.2775X_1X_1 - 0.185X_1X_3$.

Where: X_1 = RPM, X_2 = Temperature, X_3 = Water absorption.

Coefficient of determination (R^2) = 97.5.

TABLE X. CURVE HEIGHT DATA - ROSS FLOUR

Water Absorption %	RPM	Curve height, when temperature (°C) was 25.0 cms.	32.5 cms.	40.0 cms.
61.5	70		4.50	
64.5	70	5.00		2.10
67.5	70		3.30	
61.5	90	5.70		
64.5	90		4.9, 4.7, 4.8	3.40
67.5	90	5.10		3.00
61.5	110		5.50	
64.5	110	6.20		3.80
67.5	110		4.80	

Equation for response surface $Y = 4.8 + 0.675X_1 - 1.2125X_2 - 0.3625X_3 - 0.15X_1X_1 - 0.375X_2X_2 - 0.125X_3X_3 + 0.125X_1X_2 + 0.125X_1X_3$.

Where: X_1 = RPM, X_2 = Temperature, X_3 = Water absorption.

Coefficient of determination (R^2) = 98.5.

TABLE XI. CURVE HEIGHT DATA - CENTURK FLOUR

Water Absorption %	RPM	Curve height, when temperature (°C) was 25.0 cms.	32.5 cms.	40.0 cms.
59.5	70		a	
62.5	70	4.10		a
65.5	70		a	
59.5	90	4.90		a
62.5	90		4.0, 3.9, 3.9	
65.5	90	4.30		a
59.5	110		4.30	
62.5	110	5.90		3.20
65.5	110		3.10	

a : Mixogram peak not discernable.

Fig. 9. Standard 'C' Flour. Contour plot of mixogram height (C = 2.5, D = 3.5, F = 4, G = 4.5, H = 5, J = 5.5) for absorption and temperature with rpm held constant at 90 rpm.

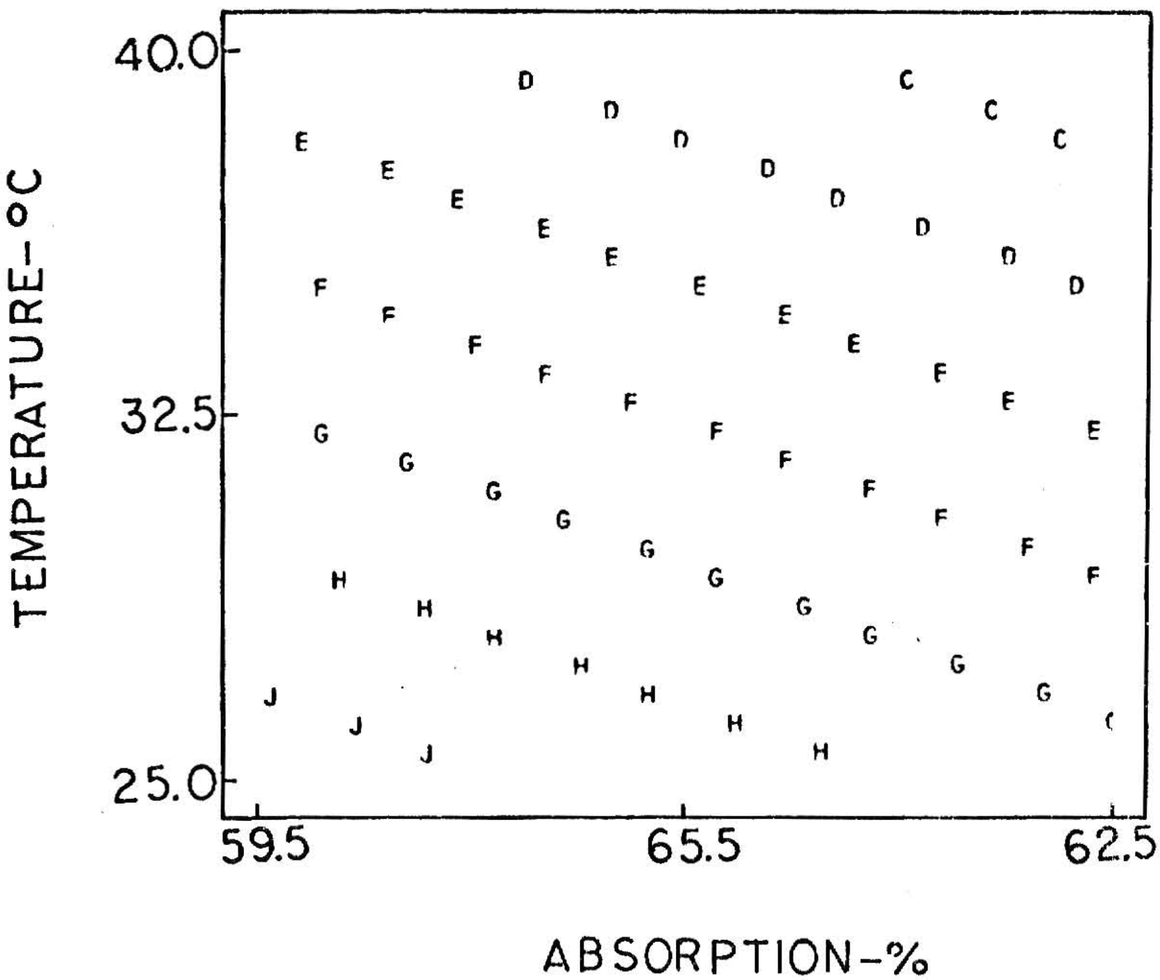
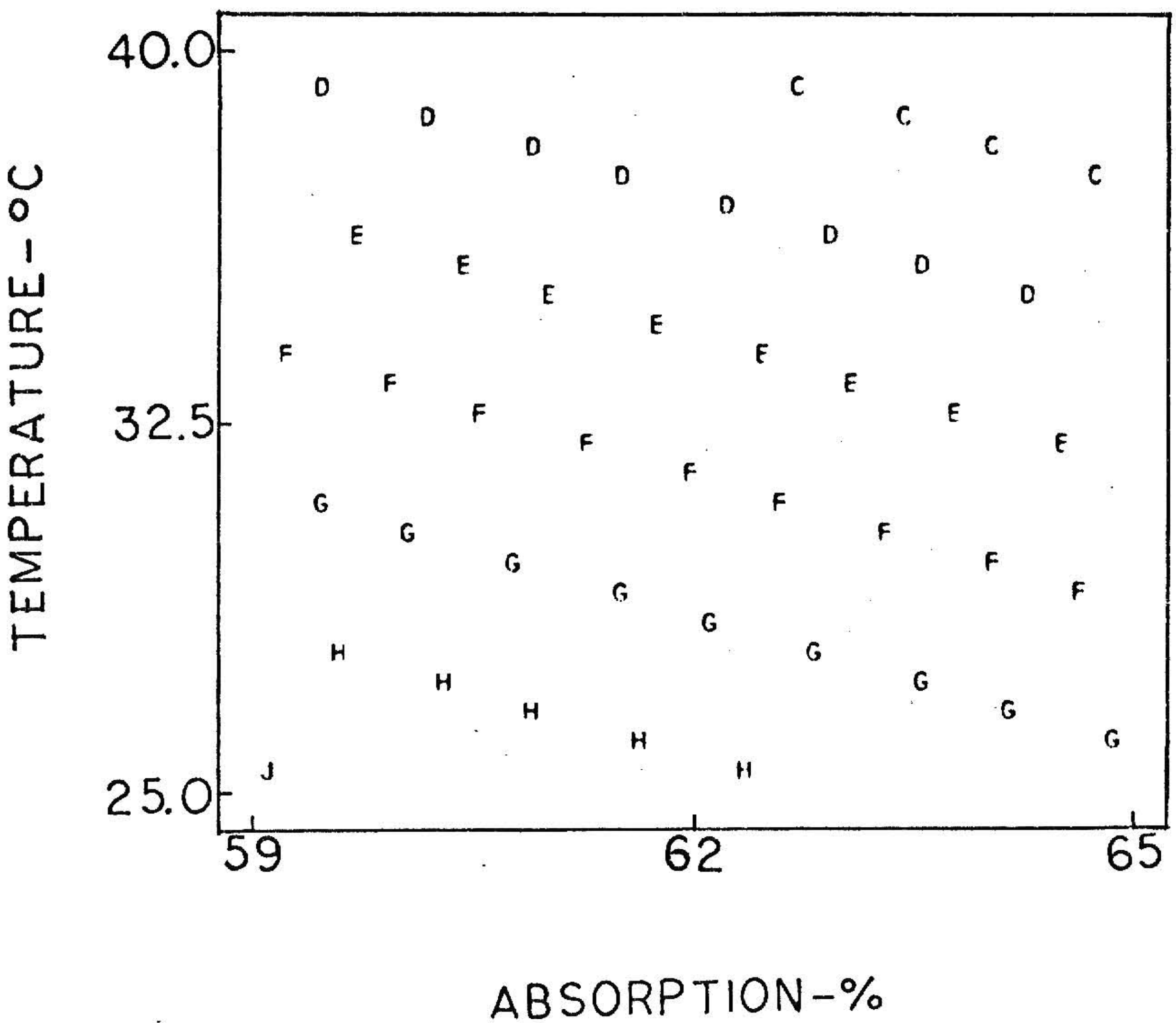
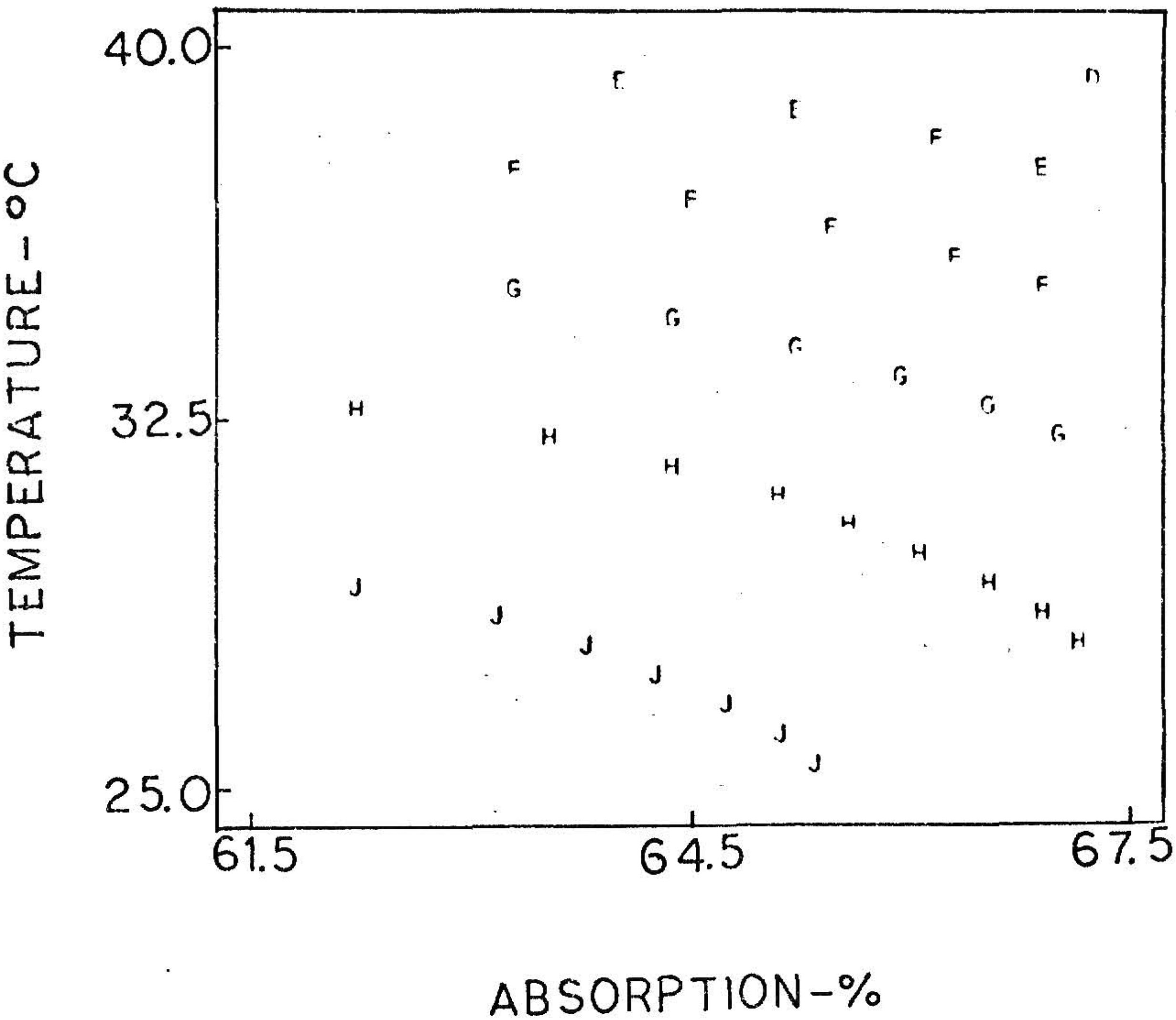

TEMPERATURE-°C
40.0
32.5
25.0
59.5
65.5
62.5
ABSORPTION-%
C
D
E
F
G
H
J

Fig. 10. KSU Flour. Contour plot of mixogram height (D = 3, E = 3.5, F = 4, G = 4.5, H = 5, J = 5.5) for absorption and temperature with rpm held constant at 90 rpm.



TEMPERATURE - °C
40.0
32.5
25.0
59
62
65
ABSORPTION-%

Fig. 11. Ross Flour. Contour plot of mixogram height (C = 2.5, D = 3, E = 3.5, F = 4, G = 4.5, H = 5, J = 5.5, K = 6) for absorption and temperature with rpm held constant at 90.


40.0
32.5
25.0
61.5
64.5
67.5
TEMPERATURE - °C
ABSORPTION-%

Baking Test Results

As seen from mixograms, peaks (points of minimum mobility) were obtained over a range of mixer speeds. To determine if doughs mixed to the point of minimum mobility at different mixer speeds were mixed to optimum dough development, baking test was conducted. 'C' standard flour was used in this test. Doughs were mixed at 84, 104 (standard), 124 and 134 rpm. The speeds were obtained by using different pulley combinations.

Baking results (Table XII) showed no difference in the bread baked by mixing dough at 104, 124 and 134 rpm. All the loaves were of acceptable characteristics. However, bread baked from a dough mixed at 84 rpm was of green structure. This shows that for the flour used in this test there is a minimum critical mixing speed, below which bread of poor quality is produced. This finding is in agreement with the results of Kilborn and Tipples (35).

TABLE XII. BAKING DATA

RPM	Mixing Time min.	Absorption %	Loaf Volume c.c.	Oxidation
84	6.12	62.5	993	-1 *
104	4.25	62.5	985	OK
124	3.75	62.5	982	OK
134	3.50	62.5	975	OK

* Inferior grain--corresponding to minus 10 ppm $KBrO_3$.

SUMMARY

The effect of three variables (mixer speed, temperature and water absorption) on mixing time and curve height of flour-water mixograms was studied. Three flours (standard 'C', KSU and Ross) had essentially the same mixing time (3.25 to 3.50 min.), but ranged in protein content from 11.3 to 13.4%. A fourth flour (Centurk) had a protein content of 13.4% and a long mixing time (6 min.). However, mixogram data at certain experimental conditions for the Centurk flour could not be obtained, because the mixograms were flat and peaks were not discernable.

RSM analysis of the effect of three variables on mixing time and curve height of flour-water mixograms led to following conclusions.

A) The rpm at which flour-water mixograms were mixed affected mixing time and curve height. Mixing time decreased and curve height increased when rpm was increased. B) Temperature had a constant effect on mixing time and curve height for all the flours studied. Mixing time increased and curve height decreased as the temperature was increased. C) In general, mixing time increased and curve height decreased with increased absorptions. However, at 25°C and high rpm for standard 'C' flour and any rpm for KSU flour, mixing time did not change with increased absorption.

D) The minimum mixing time for all the flours studied was obtained at 110 rpm. When absorption was increased, the shortest mixing time was obtained at a lower temperature. The shortest mixing time for Ross flour was obtained at 30°C, regardless of absorption.

E) In a separate higher rpm (130-170) study, using standard 'C' flour, the minimum mixing time was obtained at 170 rpm and 39 to 40°C, at any absorption studied.

The mixogram height is a measure of dough's resistance to extension. For all the flours studied, heights of mixogram curves increased as rpm were increased. It was felt that this effect was due to torque imparted to the dough by the mixing pins striking the dough more often, rather than a change in dough's resistance to extension. At a constant rpm, both higher absorption and temperature decreased the curve height. In the case of standard 'C' flour, an increase of 1°C or 1% absorption, each decreased the curve height by 0.16 cm. For Ross and KSU flours, an increase of 1°C was equivalent to 1.4% increase in absorption, in reducing the curve height by 0.16 cm.

It can be concluded from this study that at any absorption studied, the shortest mixing time was obtained at 170 rpm and 39 to 40°C. However, the decrease in mixing time between 130 and 170 rpm was slight. A similar study, based on response surface methodology (involving developer speed, absorption and dough temperature) in the continuous bread making process, could possibly lead to optimization and increased production rates.

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THE EFFECT OF MIXER SPEED, TEMPERATURE AND WATER ABSORPTION ON FLOUR-WATER MIXOGRAM CHARACTERISTICS

by

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The effect of mixer rpm, dough temperature, and water absorption on mixing time and curve height of flour-water mixograms was investigated. Three flours with medium mixing times (3.25 to 3.50 min.) and one with a long mixing time (6 min.) were used. Flour-water mixograms were obtained at various combinations of rpm, temperature and absorption according to a partial factorial design. Temperature ranged from 25°C to 40°C with an interval of 7.5°C. Absorptions used were optimum absorption for a flour (at 90 rpm, 25°C), 3% less and 3% more than optimum. Doughs were mixed at 70, 90 and 110 rpm. Speed of the mixer was varied with different pulley combinations and a variable speed motor. Flour sample and distilled water were brought to the desired temperature in a water bath, before mixing. The mixogram cabinet was maintained at the desired temperature by a thermostat.

RSM analysis of the effects of the three variables on mixing time and curve height indicated that mixing time decreased and curve height increased as the mixer rpm was increased. Increased temperatures and absorptions, each decreased curve height and increased mixing time. Shortest mixing time within the limits of the experiment for all flours studied was obtained at 110 rpm and 29-34°C. In a separate, higher rpm (130-170) study (using one flour) minimum mixing time was obtained at 170 rpm, 39-40°C. Absorption at which shortest mixing time was obtained varied.

Baking test was conducted by mixing the dough at different rpm (84, 104, 124, 134). Bread baked by mixing dough at 104, 124, and 134 rpm had acceptable characteristics. However, dough mixed at 84 rpm, produced loaves of inferior grain.

A similar study involving (developer speed, dough temperature and absorption) in continuous bread making processes was suggested.