EFFECTS OF MIXER SPEED, DOUGH TEMPERATURE, AND WATER ABSORPTION ON FLOUR-WATER MIXOGRAMS[1]

M. M. BAIG and R. C. HOSENEY[2]

ABSTRACT

Cereal Chem. 54(3): 605-615

Effects of mixer rpm, dough temperature, and water absorption on mixing time and curve height of flour-water mixogram were studied by a response surface technique. Three flours with medium mixing requirements, but various protein contents, and a fourth with a longer mixing requirement were used. Mixer speed was varied from 70 to 170 rpm; dough temperatures, from 25° to 40°C, and absorption, ±3% from optimum. As expected, increased mixer speeds decreased mixing times. Increased dough temperatures and water absorption decreased curve height and increased mixing time. However, the effect on mixing time was less pronounced at high mixer speed than at low mixer speeds. Baking tests on dough mixed at different mixer rpm showed that doughs mixed at 104, 124, or 134 rpm had essentially equal characteristics, while dough mixed at 84 rpm produced bread with inferior grain.

The time required to mix a bread dough depends on several variables (1). Three of those variables are the mixer rpm, dough temperature, and water absorption. Effects of water absorption and temperature on flour-water farinograms have been reported (2–7). In general, the reports agree that dough consistency and dough development time decreased as temperature increased and, at a constant consistency, absorption decreased as temperature increased. Harris *et al.* (8), using a mixograph, concluded that curve height and width decreased as temperature increased. They also reported that dough development time decreased with increased temperature; however, the mixogram they presented showed no consistent effect of temperature on dough development. Heizer *et al.* (9) reported that mixogram area decreased as temperature increased.

TABLE I
Analyses of Flours Tested

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]N × 5.7, AACC Method 46-10 (10).
[b]Determined from mixogram.

[1]Contribution No. 913-J, Dept. of Grain Science and Industry, Kansas Agricultural Experiment Station, Manhattan, KS 66506.
[2]Graduate Research Assistant and Research Cereal Chemist, Dept. of Grain Science and Industry, Kansas State University.

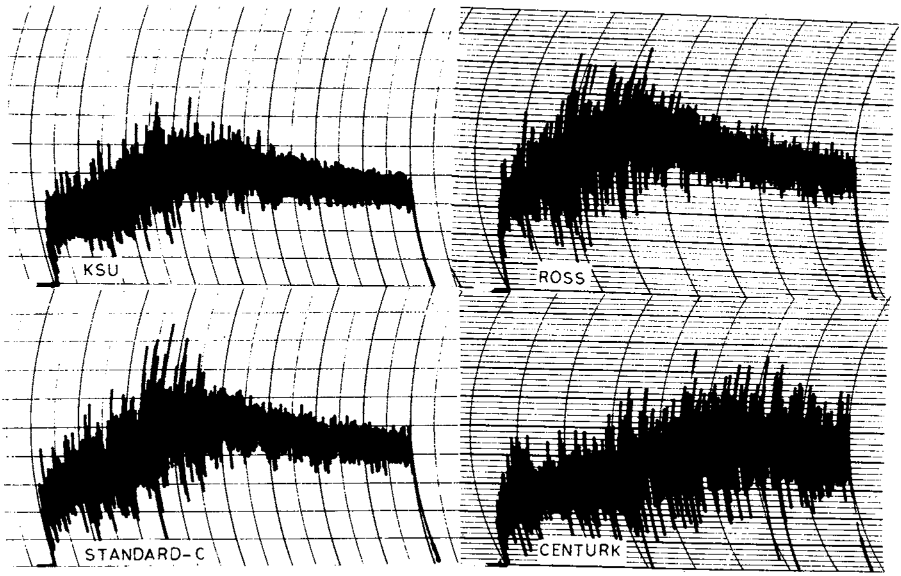

Fig. 1. Mixograms of the four hard winter wheat flours under standard conditions (rpm = 90, temperature = 25°C, and optimum absorption).

TABLE II
Response Surface Methodology Design for Three Variables

Run Number	Variables X_1[a]	X_2[b]	X_3[c]
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

[a]X_1 = rpm, −1 = 70, 0 = 90, 1 = 110.
[b]X_2 = temperature (°C), −1 = 25, 0 = 32.5, 1 = 40.
[c]X_3 = absorption, −1 = 3% less, 0 = optimum (at 25°C, 90 rpm), 1 = 3% more.

We investigated effects of mixer rpm, dough temperature, and water absorption and their interactions on certain properties of flour-water mixograms.

MATERIAL AND METHODS

Flour Data

Four hard winter wheat flours were used (Table I). Mixograms of flours under standard conditions (rpm, 90; temperature, 25° C; absorption, optimum) are shown in Fig. 1.

Experimental Procedure

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° 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

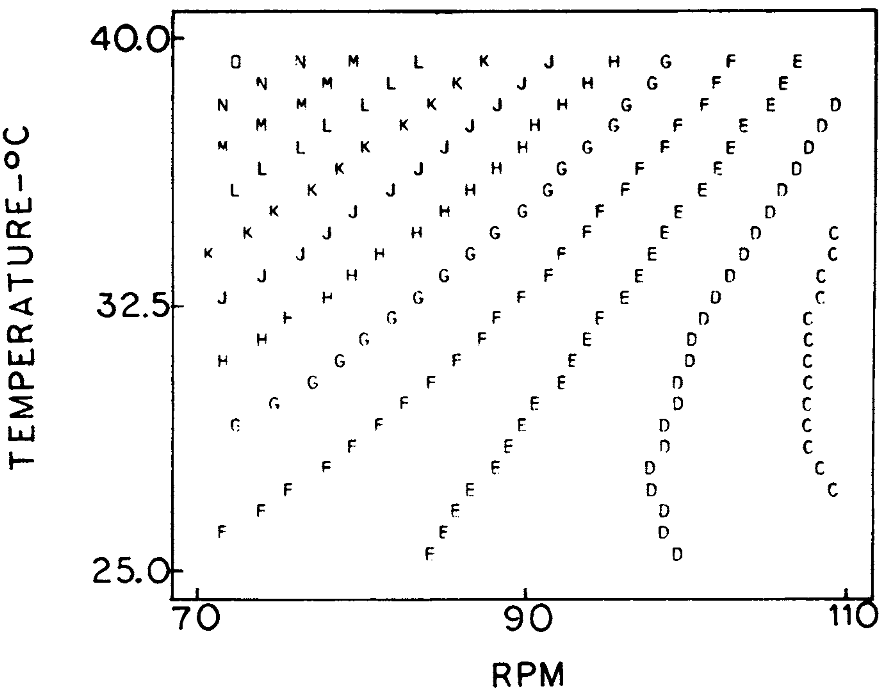

Fig. 2. C-standard flour. Contour plot of mixing time in min (C = 3, D = 3.5, E = 4, F = 4.5, G=5.0, H=5.5, J=6, K=6.5, L=7, M=7.5, N=8, and O=8.5) for rpm and temperature with absorption held constant at 62.5% (optimum at 90 rpm and 25° C). Equation for the response surface: $Y = 4.5 - 1.6563X_1 + 1.3438X_2 + 0.8125X_3 + 0.6562X_2^2 - 1.0625X_1X_2 - 0.375X_1X_3 + 0.625X_2X_3$, where X_1 = rpm, X_2 = temperature, and X_3 = water absorption. Coefficient of determination, $R^2 = 98.9$.

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.

The 35-g mixograph (National Mfg., Lincoln, Nebr.) was equipped with a 0.125 h.p. variable-speed motor, with a torque capacity of 32 in. lb/min. A constant spring setting of 10 was used throughout the study (11). Constant rpm could not be maintained at speeds higher than 90 rpm with a pulley combination of 3.75 in.:3.75 in. (rear:front), and under a mixing load. A pulley combination of 2.25 in.:3.75 in. (rear:front) maintained constant rpm through 110 rpm. At higher mixer speeds, the rpm dropped under load. To study 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. Water was added to the flour just before mixing. The mixogram cabinet was maintained at the desired temperature by an electric heater controlled by a thermostat. Temperature of the

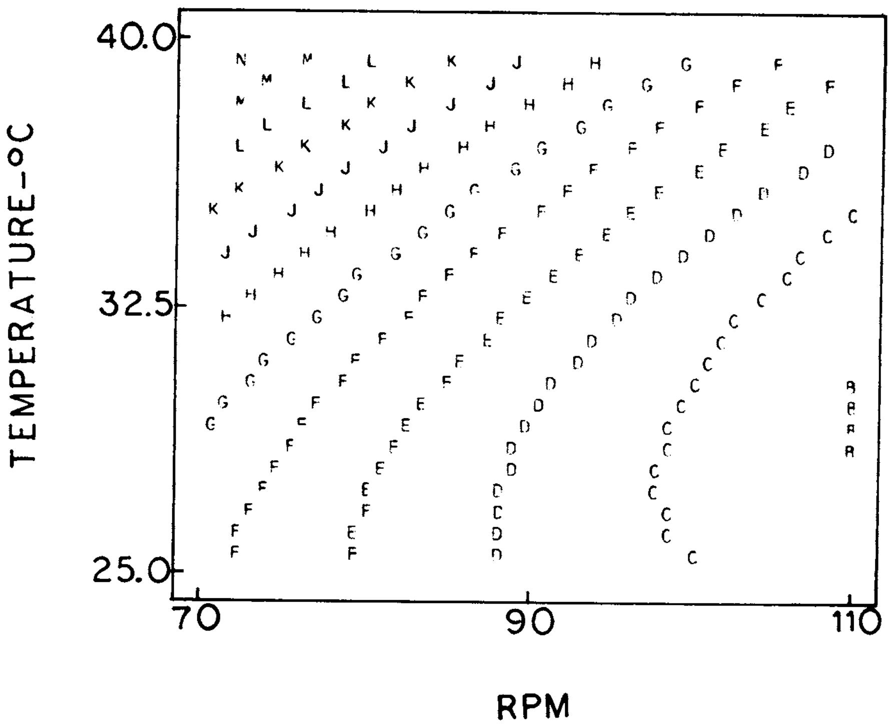

Fig. 3. KSU flour. Contour plot of mixing time in min (B = 2.5, C = 3.0, D = 3.5, E = 4.0, F = 4.5, G = 5.0, H = 5.5, J = 6.0, K = 6.5, L = 7.0, M = 7.5, and N = 8.0) for rpm and temperature with absorption held constant at 62.0% (optimum at 90 rpm, 25°C). Equation for the response surface: $Y = 4.0 - 1.5788X_1 + 1.4363X_2 + 0.795X_3 + 0.2563X_1^2 + 0.8762X_2^2 + 0.5337X_3^2 - 0.6325X_1X_2 + 0.7850X_2X_3$, where X_1 = rpm, X_2 = temperature, and X_3 = water absorption. Coefficient of determination, $R^2 = 97.4$.

dough at the end of mixing period was equal to the cabinet temperature. Dough temperature would be expected to rise during mixing because of heat of hydration and mechanical energy expended during mixing. However, the quantity of dough was small and the heat generated apparently dissipated into the mixer cabinet.

Baking Procedure

The baking formula included: flour, 100.0 g; sugar, 6.0 g; salt, 1.5 g; 60 L malt syrup, 0.75 g; shortening, 3.0 g; nonfat dry milk, 4.0 g; and yeast, 2.0 g. A straight-dough method was used with optimum mixing time and absorption. Doughs were fermented 3 hr and proofed 55 min at 30° C and 86% humidity. Baking time was 24 min at 218° C. Proof heights were measured in centimeters, and loaf volume by rapeseed displacement, within 3 min after loaves were removed from oven. Duplicate loaves were baked.

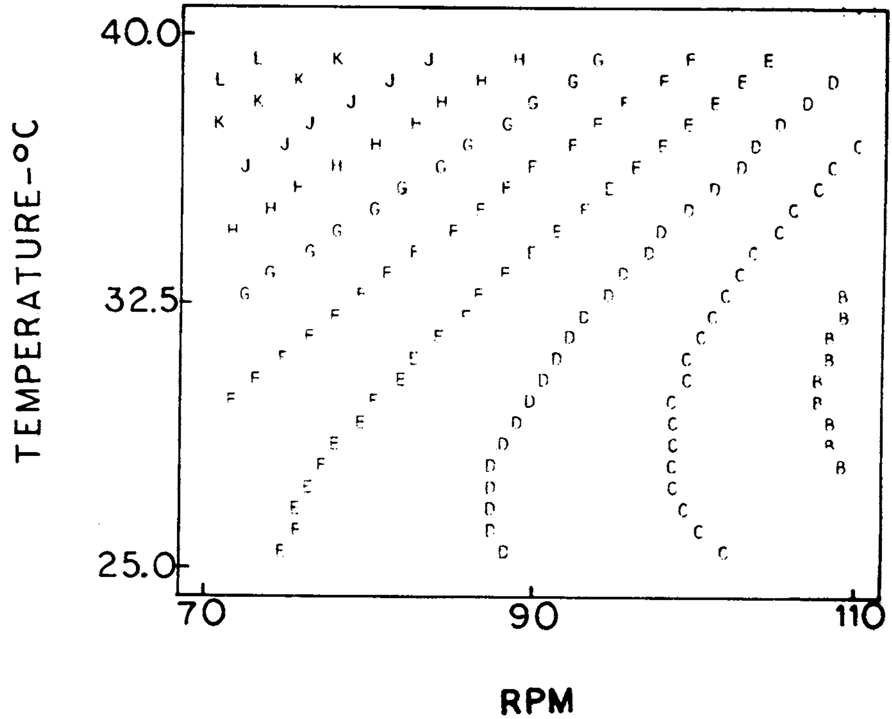

Fig. 4. Ross flour. Contour plot of mixing time in min (B = 2.5, C = 3.0, D = 3.5, E = 4.0, F = 4.5, G = 5.0, H = 5.5, J = 6.0, K = 6.5, and L = 7.0) for rpm and temperature with absorption held constant at 64.5% (optimum at 90 rpm, 25° C). Equation for response surface: $Y = 3.8077 - 1.3438X_1 + 1.125X_2 + 0.4063X_3 + 0.774X_2^2 + 0.3365X_3^2 - 0.625X_1X_2 - 0.3125X_1X_3$, where X_1 = rpm, X_2 = temperature, and X_3 = water absorption. Coefficient of determination, $R^2 = 97.6$.

Response Surface Methodology

Response surface methodology (RSM), described by Cochran and Cox (12) and Henika (13), 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 nonsignificant terms were eliminated by stepwise deletion until a minimum residual 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 the variables.

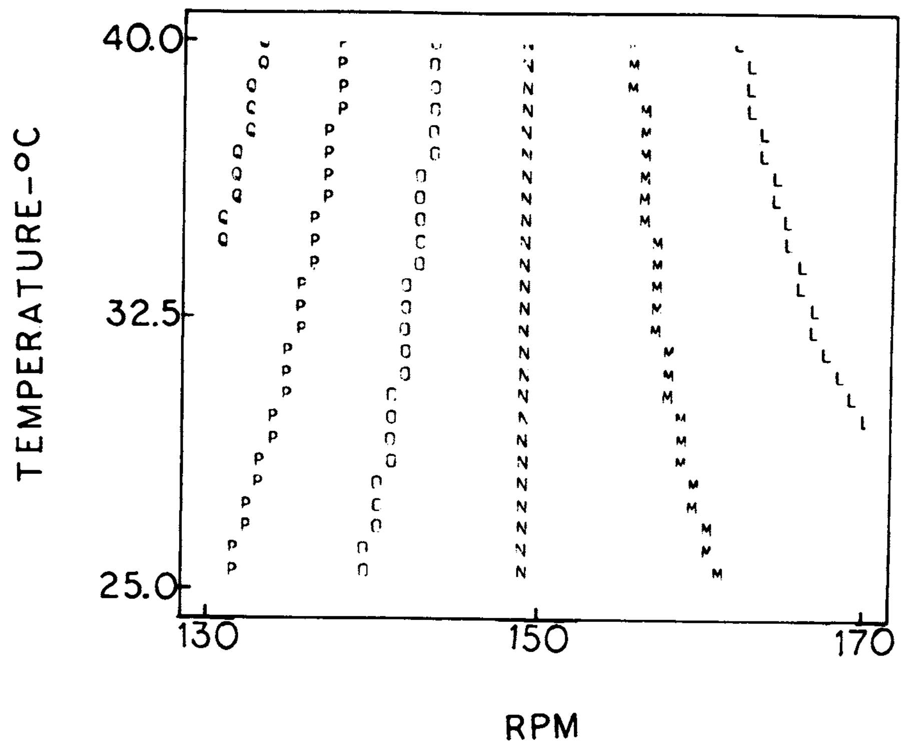

Fig. 5. C-standard flour. Contour plot of mixing time in min (L=1.75, M= 1.875, N=2.0, O=2.125, P=2.25, and Q=2.475) for rpm and temperature with absorption held constant at 62.5% (optimum at 90 rpm, 25°C). Equation for the response surface: $Y = 1.99 - 0.3288X_1 + 0.1563X_3 + 0.0475X_1^2 - 0.1075X_3^2 - 0.095X_1X_2 + 0.0625X_1X_3$, where X_1 = rpm, X_2 = temperature, and X_3 = water absorption. Coefficient of determination, $R^2 = 98.7$.

RESULTS AND DISCUSSION

Effects of three variables (mixer rpm, dough temperature, and water absorption) on the mixing time of three flours (KSU, C-standard, and Ross) were studied by a response surface technique. The three flours had essentially the same mixing time but varied in protein contents from 11.3 to 13.3%.

The response surface equation for each flour and the coefficient of determination (R^2) for each equation are given in the legend of the respective figure for that flour. Contour plots (Figs. 2–4) derived from the response surface equations give the mixing times of the three flours as a function of mixer rpm and dough temperature. In each case, water absorption was held constant at the optimum for each flour at standard conditions (90 rpm and 25° C). The plots for the three flours are similar, indicating that effects of different protein contents were minor. For all flours studied, as expected, increasing the mixer rpm decreased mixing time. The effect was much more pronounced at high temperature (40° C). In general, as dough temperature was increased, mixing time increased. The effect was pronounced at lower mixer rpms (70 and 90);

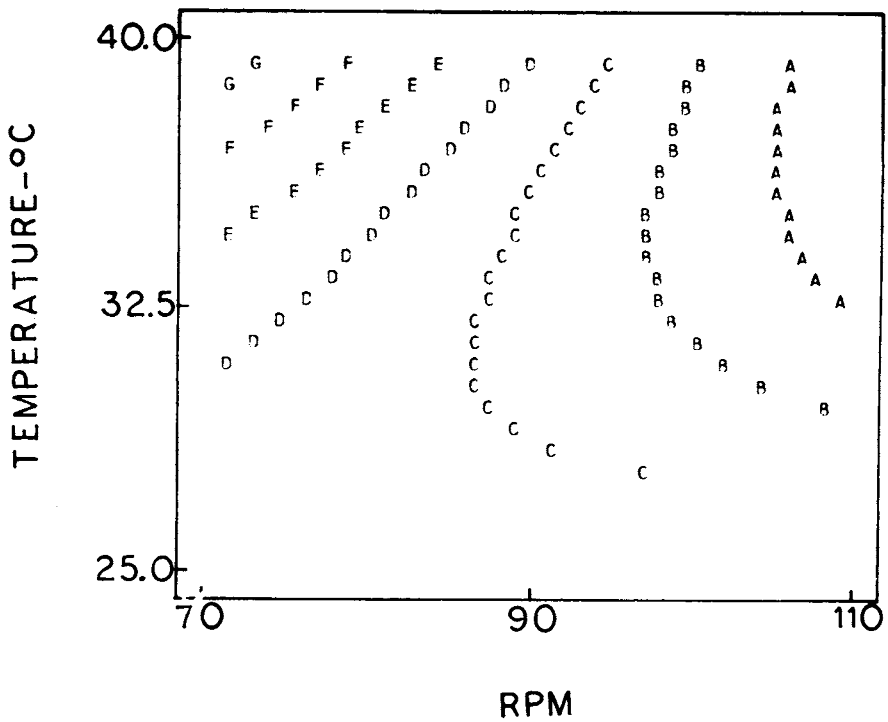

Fig. 6. C-standard flour. Contour plot of mixing time in min (A = 2.0, B = 2.5, C = 3.0, D = 3.5, E = 4.0, F = 4.5, and G = 5.0) for rpm and temperature with absorption held constant at 59.5% (minus 3% from optimum). The equation for response surface is the same as in Fig. 2.

however, at 110 rpm the effect of temperature on mixing time was minor. At even higher mixer rpms (Fig. 5), the effect of dough temperature remained minor. The increase in mixing time with increased temperature is contrary to the effect of temperature on farinograms (2–7). Perhaps the different mixing actions of the two instruments are responsible for the apparent disagreement.

Effects of water absorption on mixing time are shown in Figs. 6 and 7. In general, as water in the dough was increased, mixing time increased. The effect was large at combinations of low mixer rpm and high temperature. At high mixer rpm (110) and low temperature (25° C), amount of water did not significantly affect mixing time.

The study was extended to include a flour (Centurk) with inherently longer mixing time. Mixing times at certain combinations of dough temperature and mixer rpm could not be determined because the mixograms were flat and showed no visible peak. The flat curves appeared to result from a combination of high dough temperature and low mixer rpm. The value obtained from curves where mixing time could be determined showed the same general trends as the other

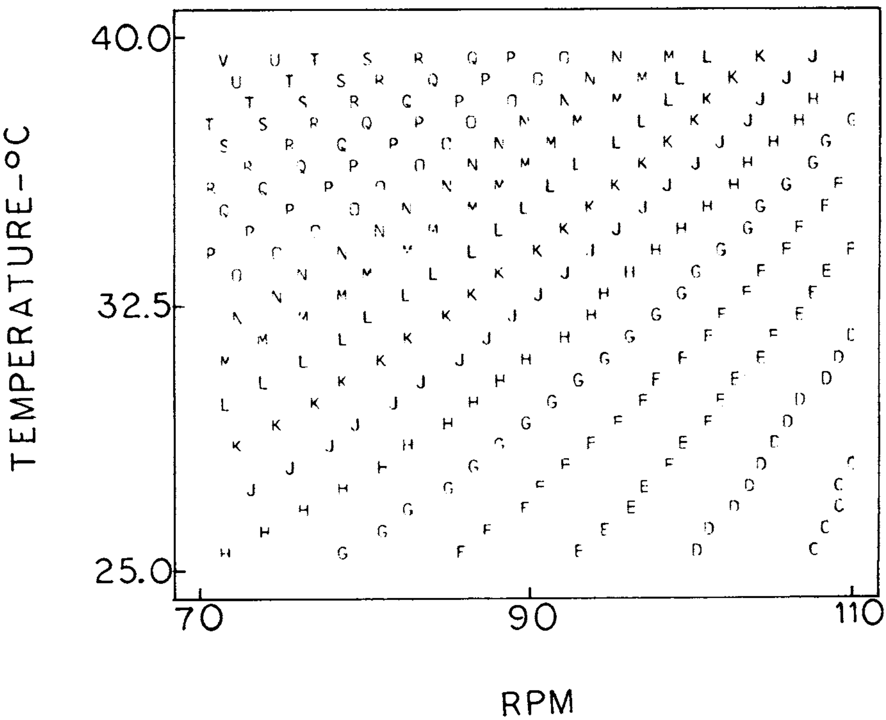

Fig. 7. C-standard flour. Contour plot of mixing time in min (C = 3.0, D = 3.5, E = 4.0, F = 4.5, G = 5.0, H = 5.5, J = 6.0, K = 6.5, L = 7.0, M = 7.5, N = 8.0, O = 8.5, P = 9.0, Q = 9.5, R = 10.0, S = 10.5, T = 11.0, U = 11.5, V = 12.0) for rpm and temperature with absorption held constant at 65.5% (plus 3% from optimum). The equation for the response surface is the same as given in Fig. 2.

(shorter-mixing) flours did. Kilborn and Tipples (14) reported that each flour has a minimum critical mixing speed, below which bread of inferior quality is produced. Our results indicate that dough temperature would affect the critical mixing speed.

At higher mixer speeds (Fig. 8), the Centurk (longer-mixing) flour gave essentially the same responses to the variables as did the other flours. However, the effect of temperature at higher mixer rpm appears to be more pronounced.

Mixogram Height

The height of the mixogram peak is also affected by water absorption and dough temperature. Higher mixer speed also increases the curve height, but that appears to result from the mixer pins striking the dough oftener, rather than from a change in the dough's resistance to extension. At constant mixer rpm, both

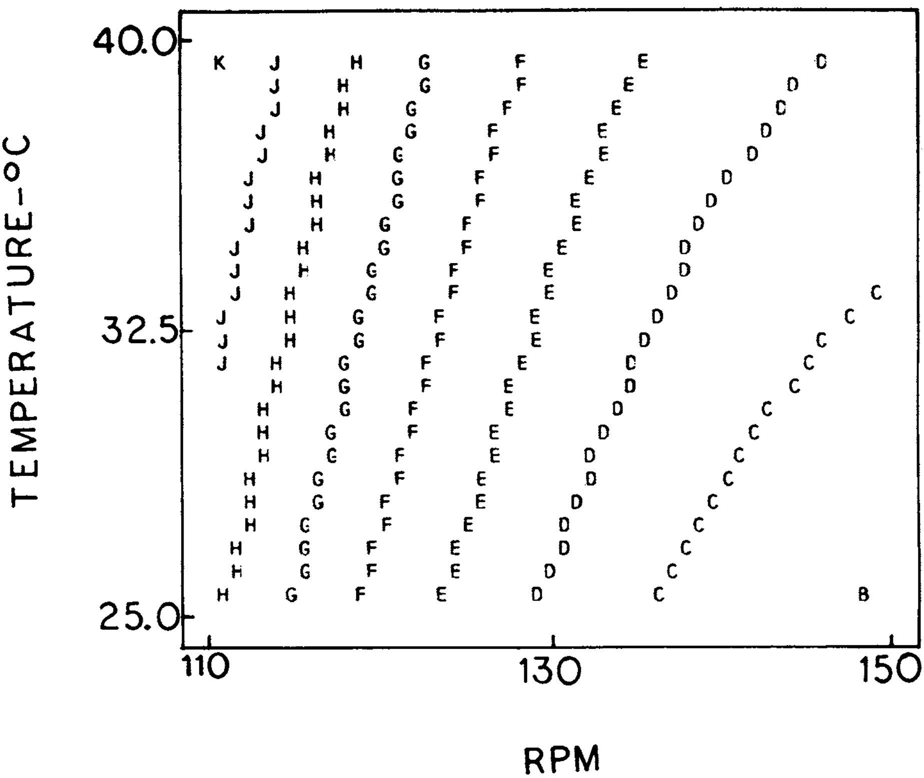

Fig. 8. Centurk flour. Contour plot of mixing time in min (B = 2.5, C = 3.0, D = 3.5, E = 4.0, F = 4.5, G = 5.0, H = 5.5, J = 6.0, and K = 6.5) for rpm and temperature with absorption held constant at 62.5% (optimum at 90 rpm, 25° C). Equation for the response surface: $Y = 3.9423 - 1.5938X_1 + 0.5X_2 + 0.9063X_3 + 0.6010X_1^2 + 0.3510X_3^2 - 0.8125X_1X_3 + 0.25X_2X_3$, where X_1 = rpm, X_2 = temperature, and X_3 = water absorption. Coefficient of determination, $R^2 = 95.2$.

higher dough temperature and higher water absorption decreased the curve height (Fig. 9). With the C-standard flour, an increase of 1°C or 1% absorption each decreased the curve height by 0.16 cm. The other flours studied gave similar responses.

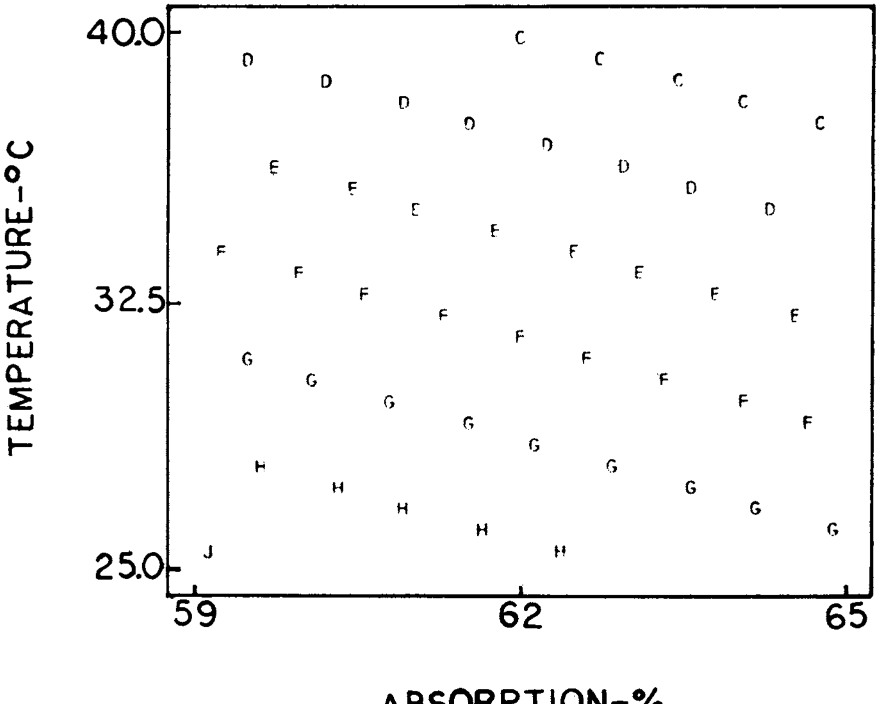

Fig 9. KSU flour. Contour plot of mixogram height in cm (C = 2.5, D = 3.0, E = 3.5, F = 4.0, G = 4.5, H = 5.0, J = 5.5) for absorption and temperature with rpm held constant at 90 rpm. Equation for the response surface: $Y = 3.78 + 0.3325X_1 - 1.325X_2 - 0.4675X_3 + 0.2775X_1^2 - 0.185X_1X_3$, where X_1 = rpm, X_2 = temperature, and X_3 = water absorption. Coefficient of determination, $R^2 = 97.5$.

TABLE III
Baking Data for the Standard "C" Flour at Indicated Mixer rpms

Mixer rpm	Mixing Time min	Absorption %	Loaf Volume cc	Oxidation
84	6.12	62.5	993	−1[a]
104	4.25	62.5	985	OK
124	3.75	62.5	982	OK
134	3.50	62.5	975	OK

[a]Inferior grain—corresponding to −10 ppm $KBrO_3$.

Baking Results

As shown by the mixogram peaks, points of minimum mobility were obtained over a range of mixer speeds. Baking tests were conducted to determine if doughs mixed to the point of minimum mobility at different mixer speeds had reached optimum development. The C-standard flour and mixer (100-g Swanson-type mixer) speeds of 84, 104, 124, and 134 rpm were used.

Baking results (Table III) showed no difference in the breads baked by mixing dough at 104, 124, or 134 rpm. However, bread produced from the dough mixed at 84 rpm was green.

Literature Cited

1. HOSENEY, R. C., and FINNEY, P. L. Mixing: A contrary view. Baker's Dig. 48(1): 22 (1974).
2. SKOVHOLT, O., and BAILEY, C. H. The effect of temperature and of the inclusion of dry skimmilk upon the properties of doughs as measured with the farinograph. Cereal Chem. 9: 523 (1932).
3. MOORE, C. L., and HERMAN, R. S. The effect of certain ingredients and variations in manipulations on the farinograph curve. Cereal Chem. 19: 568 (1942).
4. BAYFIELD, E. G., and STONE, C. D. Effects of absorption and temperature upon flour-water farinograms. Cereal Chem. 37: 233 (1960).
5. IRVINE, G. N., BRADLEY, J. W., and MARTIN, G. C. A farinograph technique for macaroni doughs. Cereal Chem. 38: 153 (1961).
6. HLYNKA, I. Influence of temperature, speed of mixing and salt on some rheological properties of dough in the farinograph. Cereal Chem. 39: 286 (1962).
7. MARTHA, M. Y. W. The relationship of dough characteristics at conventional and elevated temperatures to the quality of bread made by conventional and continuous processes. M.S. Thesis, Kansas State University (1969).
8. HARRIS, R. H., SIBBITT, L. D., and SCOTT, G. M. The effect of temperature differences on some mixogram properties of hard red spring wheat flours. Cereal Chem. 21: 374 (1944).
9. HEIZER, H. K., MOSER, L., BODE, C. E., YAMAZAKI, W. T., and KISSELL, L. T. Studies concerning mixograph standardization. Trans. Amer. Ass. Cereal Chem. 9: 16 (1951).
10. AMERICAN ASSOCIATION OF CEREAL CHEMISTS. Approved methods of the AACC. Method 46-10, approved April 1961. The Association: St. Paul, Minn.
11. SHUEY, W. C., and GILLES, K. A. Effect of spring setting and absorption on mixograms for measuring dough characteristics. Cereal Chem. 43: 94 (1966).
12. COCHRAN, W. G., and COX, G. M. Experimental designs. John Wiley and Sons: New York (1957).
13. HENIKA, R. G. Simple and effective system for use with response surface methodology. Cereal Sci. Today 17: 309 (1972).
14. KILBORN, R. H., and TIPPLES, K. H. Factors affecting mechanical dough development. I. Effect of mixing intensity and work input. Cereal Chem. 49: 34 (1972).

[Received June 17, 1976. Accepted November 10, 1976]