Factors Affecting Mechanical Dough Development. I. Effect of Mixing Intensity and Work Input[1,2]

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ABSTRACT

A laboratory-scale programmed dough-mixing unit and the GRL pin mixer were used to study some of the parameters of mechanical dough development related to the Chorleywood Bread Process. To achieve proper development of a dough, two basic requirements must be satisfied: Mixing intensity (impeller speed) must be above a minimum critical level that varies with both flour and mixer; and the work imparted to the dough must be greater than a minimum critical amount dependent on the flour used. Failure to comply with either of these two requirements resulted in suboptimum dough handling and bread properties and, in particular, loaf volume fell off sharply. Loaf volume and other bread characteristics showed little change when work levels and mixer speeds significantly in excess of the minimum requirements were used, although strong flours showed greater tolerance to overmixing than weak flours. Deterioration in this case mainly related to dough-handling properties and crumb texture.

The Chorleywood Bread Process (1) has become firmly established in the United Kingdom since its introduction and has subsequently attracted wide interest in many parts of the world. One essential feature of the process is a short period of intense mixing which brings about changes in the dough that permit elimination of the bulk-fermentation period required in conventional methods of breadmaking. The British Flour Milling and Baking Research Association claim that for optimum development of a dough a fixed level of work (0.4 h.p. min. per lb. or 5 w-hr. per lb.) must be imparted to the dough in a time of less than 5 min. (2).

Little experimental work has been published to indicate whether flours of different mixing characteristics require different levels of work input for optimum performance or whether the time restriction for imparting this work varies with different flours or dough mixers. Rheological evidence has been put forward (3) to suggest that for any one flour there exists a definite level of work input which gives maximum dough development, and that there may be an optimum rate of work input for producing the most stable dough and the best bread.

This paper presents results obtained with both a laboratory-scale programmed mixing unit (4) and the Grain Research Laboratory (GRL) pin mixer (5) in studying the effect of mixing speed (intensity) and work (energy)-input level on the performance in the Chorleywood Bread Process of Canadian hard red spring wheat flours both alone and in blends with soft wheat flour. Mixing speed was varied and the effects on mixing curves, dough-handling properties, and bread quality (loaf volume, loaf appearance, crumb grain, and texture) were noted.

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[2]Presented at the 55th Annual Meeting, Minneapolis, October 1970.

TABLE I. SOME CHARACTERISTICS OF THE FLOURS USED IN THIS STUDY

	Sample Number						
	1	2	3	4	5	6	7
Flour protein, %	12.8	11.0	9.6	13.8	12.8	11.4	12.9
Flour ash, %	0.43	0.46	0.47	0.46	0.46	0.48	0.43
Starch damage, Farrand units	19	13	6	23	25	29	18
Gassing power, mm.	310	325	295	380	380	390	305
Farinograph absorption, %	59.3	54.2	52.1	63.8	63.6	62.8	59.6
Farinograph peak, min.	5.75	3.5	1.5	5.75	5.25	4.5	6.75
Chorleywood baking absorption, %	65	60	58	66	65	64	65

MATERIALS AND METHODS

The main experimental work reported in this paper was carried out with seven flours (Table I). Sample No. 1 was laboratory-milled from hard red spring wheat. This sample had fairly long mixing characteristics in baking tests, although this was not indicated by the farinograph mixing curve, which showed a development time of 5.75 min. Sample No. 2 was a blend of 50% hard red spring wheat flour and 50% soft white winter wheat flour, both commercially milled. Sample No. 3 was prepared from the same two flours but blended in a ratio of 25% hard to 75% soft. Sample Nos. 4, 5, and 6 were obtained from large numbers of high-grade Canadian hard red spring wheat samples, segregated on the basis of protein content and laboratory-milled. Sample No. 7 was added to the series on the depletion of sample No. 1. However, although the source of the samples was similar and the analytical data were also similar, the mixing characteristics were somewhat different in the farinograph, GRL, and experimental mixers.

Flour protein of the seven flours ranged from 9.6 to 13.8%, starch damage from 6 to 29%, and Chorleywood-Process baking absorption from 58 to 66%.

The bread formula used is given in Table II.

The main part of the study was carried out on the experimental mixer with a Perspex block held in position over the mixing dough by an air motor. The amount of flour used for mixing was 220 g., and doughs were scaled on the basis of 100 g. of flour and processed as "pup" loaves.

All doughs were premixed at 50 r.p.m. for 1.5 min. with the Perspex block removed. There was an interval between the end of the premix and the beginning of the mix when the mixer was at rest for 1 min. This time was used to switch functions, insert the Perspex block, and apply a force of 36 lb. to the block by means of the air motor. This was equivalent to a pressure of about 7 p.s.i. on the dough. Doughs were then mixed at a predetermined r.p.m. and work level. The mixer temperature controller was preset for 95°F. Both the warm- and the cold-water baths supplying the water to the mixer jacket were preset according to the range in speed of the mixer to be studied, thus permitting close control of dough temperature.

TABLE II. BREAD FORMULA

Ingredient	% (based on flour weight)
Flour	100
Yeast (compressed)	3.0
Sucrose	2.5
Salt	1.0
Barley malt syrup (250° L.)	0.3
Ammonium phosphate (monobasic)	0.1
Shortening	1.5
Water (adjusted for each flour)	58–66
Ascorbic acid	75 p.p.m.
Potassium bromate	45 p.p.m.

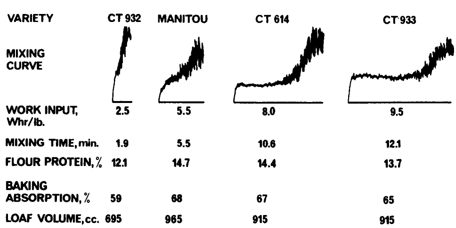
The pressure was released after mixing and the doughs were scaled, rounded, and placed in a fermentation cabinet at 95°F. Where two doughs were obtained from a single mix, one dough received an intermediate proof of 20 min., the second one received 25 min., and the results were averaged.

Panning was as for the Remix baking test with the GRL moulder (6). Proofing was at 95°F. for 55 min. Loaves were baked 25 min. at 430°F.

RESULTS AND DISCUSSION

Work Input Requirement—Variation with Different Flours

For a number of years this laboratory has carried out a Chorleywood-Process test-baking method on wheat varieties using the GRL pin mixer at 130 r.p.m. and mixing to peak dough development or a little beyond as indicated by the mixing curve. We have observed that for different varieties the work requirement may vary quite widely, as is illustrated by Fig. 1. Four samples have been selected out of 25 varieties tested in a 1969 Canadian plant breeders' series. Each sample represented a composite of material grown at 15 individual stations across Western Canada. Work-input requirement for the 25 varieties ranged from a low of 2.5 to a high of 9.5 w-hr. per lb., although 15 of the varieties had a work requirement between 5.5 and 7.0. There were two soft wheats in the test of the Pitic-62 type, and these had short mixing requirements of 2.5 and 3.0 w-hr. per lb.



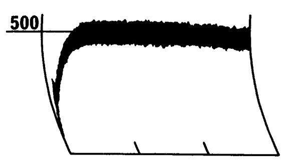


Fig. 1 (left). Mixing curves, with mixing and baking data for four wheat varieties in the Chorleywood baking test. GRL pin mixer at 130 r.p.m.

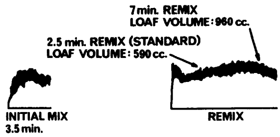
Fig. 2 (right). Farinogram of Red River 68 sample.

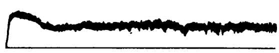
Experience has shown that if doughs are mixed significantly short of peak development, they are noticeably undermixed and give bread of greatly reduced and inconsistent volume. "Overmixing" past peak dough development has not been found to be as detrimental to bread quality as undermixing, although flours with short mixing requirements normally produce doughs that break down more rapidly, becoming sticky and difficult to handle.

Use of a fixed level of work input for the series of flours illustrated above would not be satisfactory. A level of 9.5 w-hr. per lb. would ensure that all samples were mixed past peak development, but would result in gross overmixing of a large proportion of the varieties. Use of a work level corresponding to the average requirement for all the varieties would not allow evaluation of the true potential of many of the samples in terms of loaf volume and dough-handling properties.

Experience with a Sample Having Extremely Long Mixing Requirements

An interesting sample of the variety "Red River 68" commercially grown in North Dakota was obtained in 1968. It was unusual in that it had an excessively long mixing requirement in Remix and Chorleywood baking tests. Several examples of this variety have since been tested, but while mixing requirements have been variable and generally long, none was as extreme as this sample. The farinograph curve (Fig. 2), with a peak-development time of 7.5 min., while indicating a strong wheat, did not suggest undue problems in baking. However, with the Remix baking method (7), a loaf volume of only 590 cc. was obtained with the standard 2.5 min. of remixing. The flour protein content of 13.8% would normally be expected to give a loaf volume in excess of 900 cc. That the flour had good baking potential was indicated by the fact that when blended 50/50 with soft wheat flour of 7.8% protein, a Remix loaf volume of 780 cc. was obtained. Repeating the Remix test with remixing time extended to give peak dough development required a remixing time of 7 min. and produced the mixing curves shown in Fig. 3. Loaf volume increased to 960 cc., and other loaf characteristics improved markedly, confirming that for the standard 2.5 min. of remixing, the dough was grossly undermixed and in the "hole" (8).





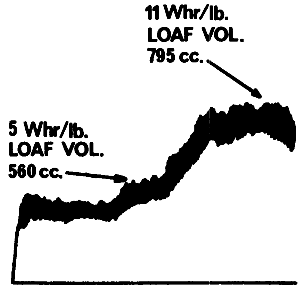


Fig. 3 (left). Red River 68 sample: Remix baking test mixing curves.

Fig. 4 (center). Red River 68 sample: Chorleywood method mixing curve. GRL pin mixer, 130 r.p.m. Work-input level, 19.5 w-hr./lb. Mixing time, 35 min. Loaf volume, 580 cc.

Fig. 5 (right). Red River 68 sample blended 50/50 with soft flour. Chorleywood method mixing curve. GRL pin mixer, 130 r.p.m. Total mixing time, 13.5 min.

When baked by the Chorleywood method, the Red River 68 produced the mixing curve shown in Fig. 4. After an initial "peak", dough consistency decreased; and even with a work level of 19.5 w-hr. per lb., requiring 35 min. of mixing, the dough did not develop properly. Loaf volume was only 580 cc., and crumb texture and color scores were low. Blending Red River 68 with 50% soft wheat produced a satisfactorily developed dough with a work-input level of 11 w-hr. per lb. (Fig. 5) and a loaf volume of 795 cc. Imparting a work-input level of 5 w-hr. per lb. gave an undermixed dough and a loaf volume of 560 cc.

The inference was that this sample had an extremely long mixing requirement in baking both in terms of work-input level and rate of work input. The GRL mixer at 130 r.p.m., while fast enough to develop normal flours, was not capable of developing the Red River 68 sample unless it was diluted with soft flour. Fermentation reduced mixing requirements to the point where the dough could be developed at 130 r.p.m. in the Remix test, provided that mixing time was extended. The farinograph curve did not represent the true peak development and can be related to the "peak" shown in the "initial mix" curve for the Remix test (Fig. 3) and the first rise ("peak") in the Chorleywood mixing curve (Fig. 4). The dough would have to be mixed at a higher speed to achieve proper development and bring out the true peak with an unfermented dough.

Effect of Mixing Speed at Optimum Work-Input Level

Having observed that for each flour there appears to be an optimum level of work input necessary for satisfactory performance in the Chorleywood Process, we next studied the effect of mixing speed on bread properties with the experimental mixer. A speed of 140 r.p.m. was found to be sufficiently high to produce sharply defined peaks in mixing curves for a wide range of flours. This enabled optimum work level, in terms of peak dough consistency, to be easily determined for each flour. A wide range of speeds was then used for each flour according to the predetermined optimum work level.

Results obtained for three flours were as follows:

Flour No. 1. The first sample (Fig. 6) was mixed at speeds from 80 to 410 r.p.m. with a work level of 6.5 w-hr. per lb. for all speeds. The loaf volumes ranged from 810 to 1,080 cc.

The minimum mixing speed necessary to attain bread of high specific volume (from here on we will refer to this as the "critical" speed) was between 110 and 125 r.p.m. Subsequent tests showed that repeatable results were difficult to obtain at 115 and 120 r.p.m. Below 110 r.p.m. loaf volume was markedly reduced, as were values for other loaf properties. Doughs mixed at speeds below 110 r.p.m. were soft and sticky and lacked spring. At speeds of 125 r.p.m. and higher, bread of high specific volume was obtained and bread scores were consistent. Doughs were lively, extensible, and springy, and were not sticky at time of panning.

Figure 7 shows loaves obtained at 80, 110, 125, and 410 r.p.m. for sample No. 1. The sharp increase in loaf volume going from 80 to 110 r.p.m. is readily apparent. The 80-r.p.m. loaf had a slightly inferior texture score, whereas the other three loaves were almost identical in character.

Flour No. 2. Figure 8 shows results obtained for sample No. 2 with a work level of 3.5 w-hr. per lb. Speeds ranged from 50 to 410 r.p.m. The critical speed here was

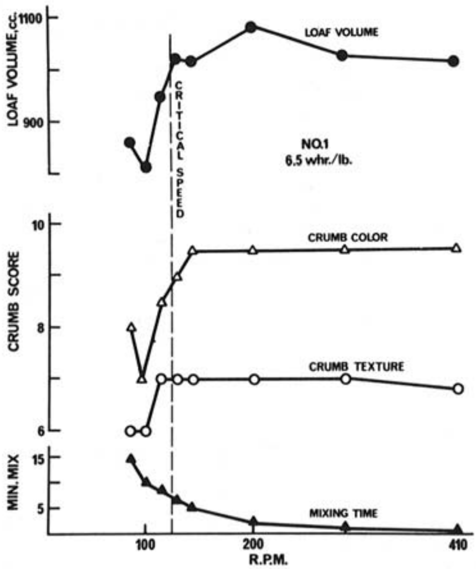


Fig. 6 (right). Effect of increasing mixing speed (experimental mixer) on loaf volume, crumb score, and mixing time for flour No. 1 at optimum work-input level (6.5 w-hr./lb.).

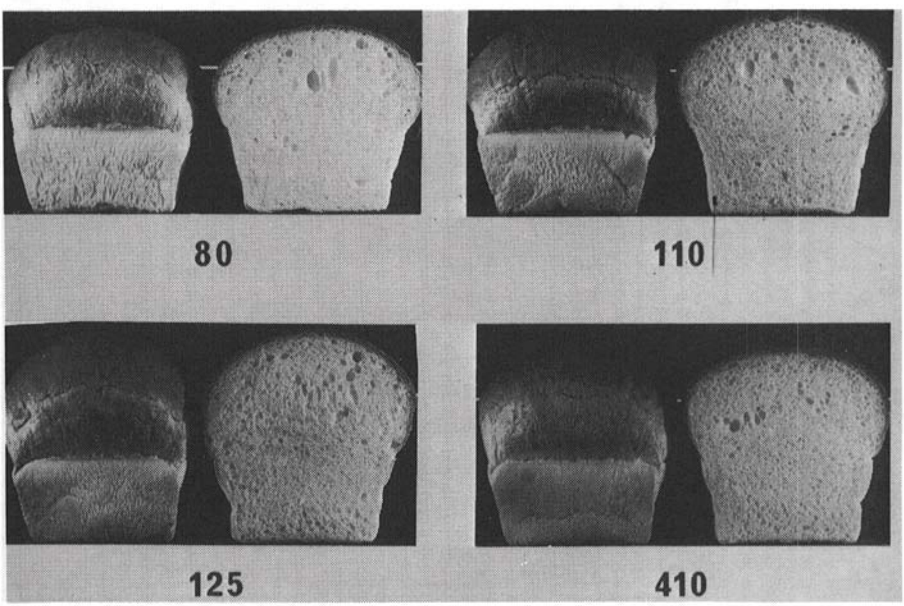


Fig. 7. External and internal appearance of loaves baked from flour No. 1. Doughs mixed on experimental mixer (6.5 w-hr./lb.) at 80, 110, 125, and 410 r.p.m.

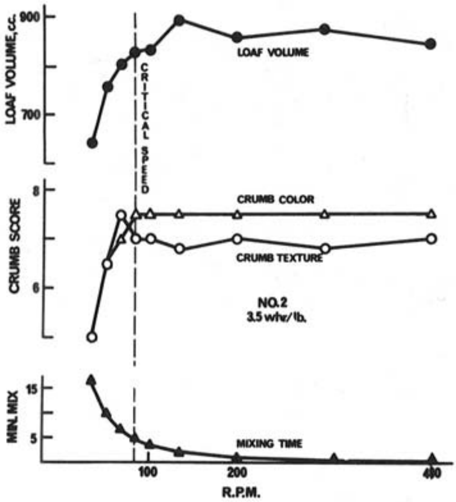


Fig. 8. Effect of increasing mixer speed (experimental mixer) on loaf volume, crumb score, and mixing time for flour No. 2 at optimum work-input level (3.5 w-hr./lb.).

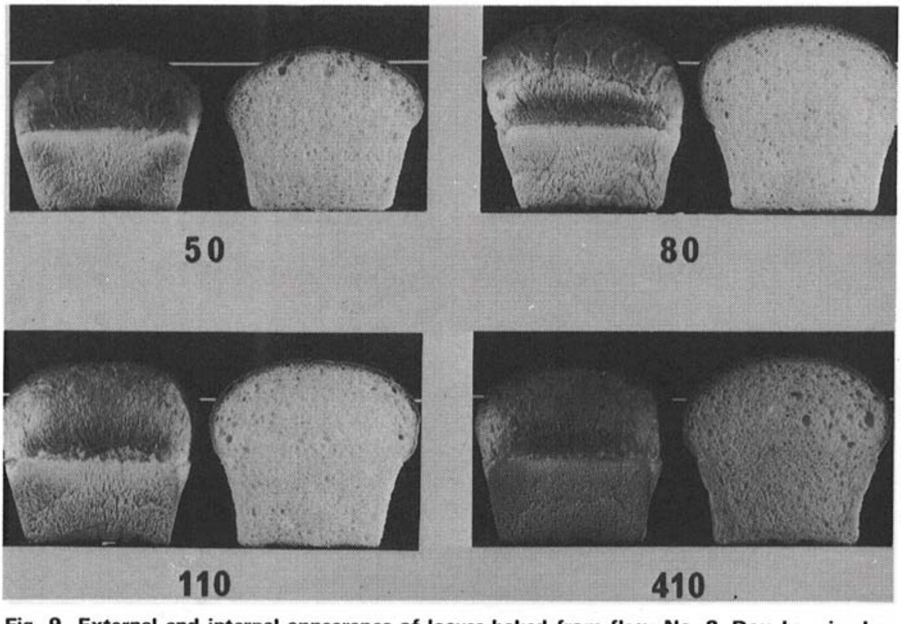


Fig. 9. External and internal appearance of loaves baked from flour No. 2. Doughs mixed on experimental mixer (3.5 w-hr./lb.) at 50, 80, 110, and 410 r.p.m.

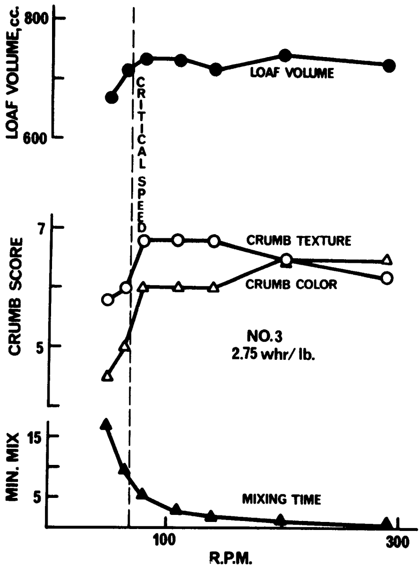


Fig. 10. Effect of increasing mixer speed (experimental mixer) on loaf volume, crumb score, and mixing time for flour No. 3 at optimum work-input level (2.75 w-hr./lb.).

around 95 r.p.m. Again loaf properties deteriorated below this level and were consistently high at all speeds above this level. Mixing times ranged from 16.5 to 0.4 min., with the best bread occurring for mixing times of 4.8 min. or less. Figure 9 shows loaves for 50, 80, 110, and 410 r.p.m. Again there was a significant difference in loaf volume, this time between the loaves mixed at 50 and 80 r.p.m. Optimum crumb texture was obtained at 80 r.p.m. and higher.

Flour No. 3. Sample No. 3 (low-protein blend) required only 2.75 w-hr. per lb., and speeds of from 50 to 290 r.p.m. were examined (Fig. 10). Here the critical mixing intensity occurred between 65 and 80 r.p.m. The same pattern occurred as with the previous two samples with speeds below and above the critical intensity range, except that at the top speeds of 200 and 290 r.p.m. there was some deterioration in texture scores and a marked change in the side-wall characteristics, as can be seen in Fig. 11. The loaf baked from dough mixed at 290 r.p.m. showed sharp corners and other characteristics normally associated with "green" or underoxidized dough.

Mixing Time vs. Mixing Speed

The minimum intensity at which doughs may be considered to be mechanically developed for the system used in these experiments varied with flour. Table III shows a summary of mixing data for the seven flours studied with the experimental mixer (bear in mind that this intensity was not sharply defined in terms of r.p.m.). Critical speeds varied from 70 to 125 r.p.m., and mixing times for these critical speeds ranged from 3.5 to 8 min. The minimum mixing intensity that would be satisfactory for all flours, therefore, would be a speed higher than the highest critical mixing speed (125 r.p.m.) of any of the flours. Mixing times ranged from 2.0 to 5.3 min. At 140 r.p.m., a satisfactory mixing intensity for all seven flours.

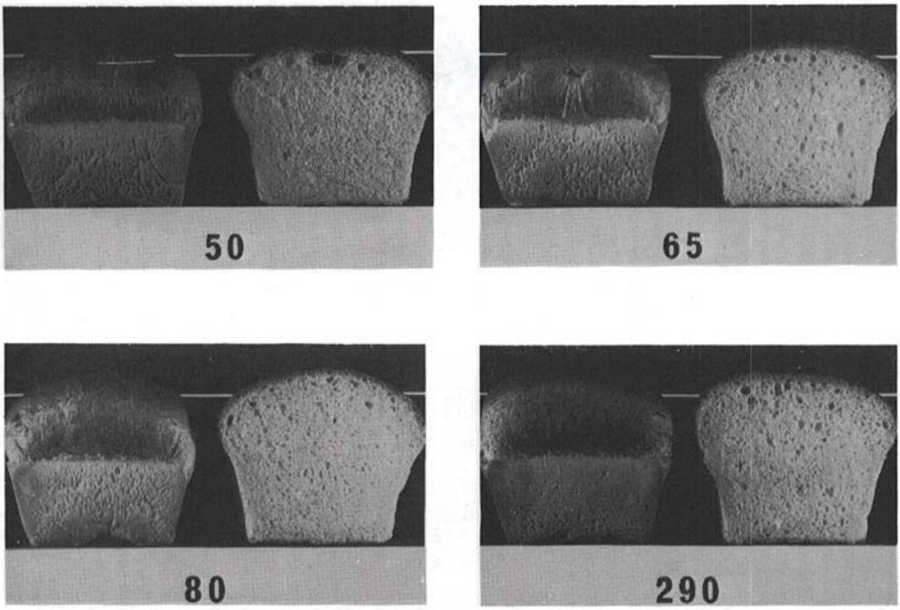


Fig. 11. External and internal appearance of loaves baked from flour No. 3. Doughs mixed on experimental mixer (2.75 w-hr./lb.) at 50, 65, 80, and 290 r.p.m.

TABLE III. SUMMARY OF MIXING DATA FOR SEVEN FLOURS WITH THE EXPERIMENTAL MIXER[a]

	Sample Number						
	1	2	3	4	5	6	7
Critical r.p.m.	120	95	70	100	100	115	125
Mix (min. at critical r.p.m.)	7.5	5	8	5	4	3.5	5.5
Mix (min. at fixed 140 r.p.m.)	5.3	2.3	2.0	3.0	2.3	2.4	4.8
r.p.m. for fixed 3-min. mix	190	120	100	140	120	130	185

[a]All mixing to peak consistency.

Alternatively, if instead of minimum speed, maximum mixing time was selected as a criterion for determining sufficient mixing intensity, then the mixing time of 3.5 min. would be considered maximum and something short of 3.5 min. would be selected (e.g., approximately 3.0 min.). At this fixed mixing time the r.p.m. requirement varied from 100 to 190 r.p.m.

From these results it is obvious that generalizations of either mixing time or mixing intensity (speed) are not adequate to cover variations in flour performance when doughs are mixed to peak consistency. At a fixed mixing speed, mixing times will vary widely between flours; and conversely, at a fixed mixing time, mixer speed requirements will vary widely.

Critical Mixing Speed—Effect of Mixer

Having established that different flours have different critical mixing speeds using the experimental mixer, our next logical step was to determine whether the same relative mixing requirements applied to a different type of mixer.

Comparisons were made between the experimental mixer and the GRL pin mixer for samples No. 4, 5, 6, and 7. Table IV shows a summary of mixing data for the four flours with these two mixers. For the GRL pin mixer, critical mixing speeds varied from 85 to 100 r.p.m., compared with 100 to 125 r.p.m. with the experimental mixer. Mixing times ranged from 8 to 21 min. with the GRL mixer compared with 3.5 to 5.5 min. for the experimental mixer. At a fixed speed sufficiently high to be beyond the critical mixing speed for all samples (nominally 130 r.p.m.), mixing times ranged from 5.5 to 10.7 min. for the GRL mixer. With a fixed time that would assure development for all samples (7.0 min.), speeds would have to be varied from 105 to 155 r.p.m.

Figure 12 summarizes data showing loaf volumes plotted against mixing speed for the two mixers and four flours. Optimum work-input levels for each flour with each mixer are indicated. Work levels necessary to achieve peak dough consistency were about 50% higher for the pin mixer. The reason for the differences in (gross) work levels between the two mixers will be discussed in a subsequent publication. Work requirement for a point slightly past peak consistency ranged from 4.5 to 7.5 w-hr. per lb. on the pin mixer and 3.5 to 5 on the experimental mixer. Bread of high volume was achieved at lower "critical" speeds with the pin mixer.

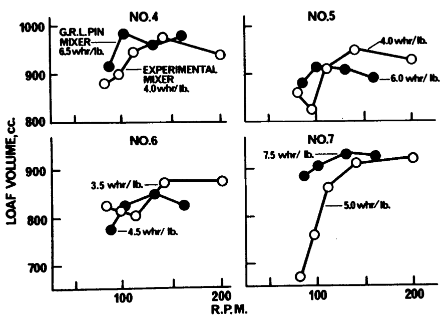
Figure 13 shows the same loaf-volume data plotted against the mixing times corresponding to the mixing speeds shown in Fig. 12. The longer mixing times, of course, correspond to the lower mixing speeds. It is obvious that optimum work must be imparted in a shorter time with the experimental mixer in order to achieve high-volume bread. This is particularly evident for flour No. 7. While differences in critical mixing speeds between the two mixers might have been expected owing to their vastly different mixing actions (3 pins vs. 1 blade), the large difference in mixing time emphasized the complicated nature of dough development and demonstrated the unreliability of using mixing time as an index of optimum mixing conditions.

Two General Requirements

It has been demonstrated that generalizations of time restriction or mixer speed to achieve dough development are not applicable to mixers of different design or to flours of different mixing characteristics.

TABLE IV. RANGE OF MIXING DATA FOR FOUR FLOURS AND TWO MIXERS

	Range, Flours 4 to 7, Inclusive	
	GRL pin mixer	Experimental mixer
Critical r.p.m.	85–100	100–125
Mix (min. at critical r.p.m.)	8–21	3.5–5.5
Mix (min. at fixed speed)	5.5–10.7 (130 r.p.m.)	2.3–4.8 (140 r.p.m.)
r.p.m. for fixed mixing time	105–155 (7 min.)	120–185 (3 min.)



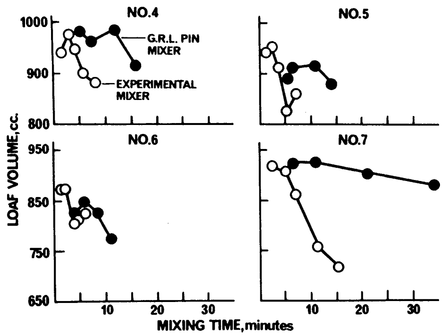


Fig. 12 (left). Effect of increasing mixing speed on loaf volume for four flours mixed at optimum work-input level in the GRL pin mixer (closed circles) and the experimental mixer (open circles).

Fig. 13 (right). Effect of increasing mixing time on loaf volume for four flours mixed at optimum work-input level in the GRL pin mixer (closed circles) and the experimental mixer (open circles). Mixing times correspond to mixing speeds shown in Fig. 10, with longest times corresponding to lowest mixing speeds.

Two requirements that may be generalized, however, are: 1) A mixing intensity sufficiently high to be above the critical mixing speed for all flours likely to be encountered, and 2) a reliable means of determining dough development, such as an energy- or torque-indicating device, to ensure that optimum development (peak consistency) has been achieved.

Effect of Mixing Speed on Work-Input Requirement

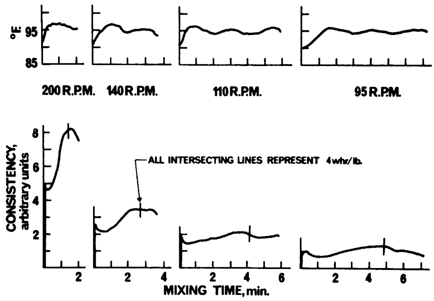
Part of this study involved determining whether optimum work-input level for peak dough development changed with changes in mixing speed.

Figure 14 shows mixing curves obtained for sample No. 4 at four different speeds on the experimental mixer. The lower set of curves shows dough consistency in arbitrary units plotted against time. The upper set of curves is a continuous plot of dough temperature during the corresponding mix. In each case the whole mixing curve shown represents a total work-input level of 6 w-hr. per lb. of dough. The peak occurred at around 4 w-hr. per lb. for all speeds from 95 to 200 r.p.m. The temperature curves indicate that the peaks in the mixing curves corresponded to peak dough development and were not artifacts resulting from changes in consistency with temperature fluctuation. Apart from a short initial surge at the beginning of the mix, dough temperatures were controlled to within ±1°F. throughout mixing.

Doughs mixed at 95 r.p.m., despite the apparent peak in consistency, were not developed for any of the work levels examined, being nonelastic and tearing easily when removed from the mixer. Dough properties improved with increased mixer speed, and at 110 r.p.m. doughs appeared developed for 4, 5, and 6 w-hr. per lb. work levels.

Effect of Various Work-Input Levels and Different Mixing Speeds

The experiments discussed above have shown that in order to achieve peak dough development mixing speed must be above the critical speed for a given mixer



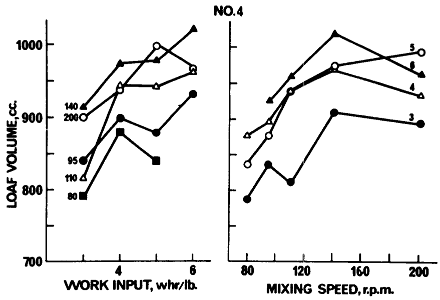


Fig. 14 (left). Mixing curves (below) and corresponding dough temperature curves (above) for flour No. 4 mixed at four different speeds (200, 140, 110, and 95 r.p.m.) in the experimental mixer. Each mixing curve, showing dough consistency in arbitrary units plotted against time, represents a total work-input level of 6.0 w-hr./lb.

Fig. 15 (right). Loaf-volume data for flour No. 4 mixed in the experimental mixer. Left-hand figure shows effect on loaf volume of increasing work-input level at five different mixing speeds (80 to 200 r.p.m.). Right-hand figure shows effect of increasing mixing speed at four levels of work input (3, 4, 5, and 6 w-hr./lb.).

and a given flour. Furthermore, at a level of work corresponding to peak dough development, satisfactory results were obtained at speeds considerably in excess of the critical minimum. The effect of using work levels different from those corresponding to curve peak was the next factor examined.

Flour No. 4. Flour No. 4 was mixed at four levels of work at five different speeds in the experimental mixer. Loaf-volume data are shown in Fig. 15. Critical mixing speed was considered to be around 100 r.p.m.; and work-input level corresponding to peak dough consistency was 4.0 w-hr. per lb. As shown in the left-hand figure, high-volume bread was obtained only at 4 w-hr. per lb. and higher and at 110 r.p.m. and higher – 80 and 95 r.p.m. did not produce bread of high volume at any work level.

Similarly (right-hand figure), high-volume bread was not achieved at 3 w-hr. per lb. at any speed. There was no deterioration in loaf volume when doughs were mixed beyond peak consistency to 6 w-hr. per lb. at speeds up to 200 r.p.m.

Flour No. 7. A wide range of work levels was studied with sample No. 7. Figure 16 shows bread volumes obtained at speeds ranging from 95 to 350 r.p.m., and work levels of from 2 to 8 w-hr. per lb. The right-hand figure, with mixing speed plotted against loaf volume, shows most clearly that mixing speeds below the critical speed of around 125 r.p.m. gave bread of low volume. Provided that speeds above the critical speed were used at work levels of 4, 5, or 6 w-hr. per lb., bread of high volume was produced. Work levels of 3 and 2 w-hr. per lb. produced poor bread regardless of the speed used. There was a definite indication that, at mixing speeds below the critical speed, increased work levels did produce a further increase in loaf volume. This is evident in the left-hand figure in the curve for 95 r.p.m. However, imparting as much as 8 w-hr. per lb. of dough at low speeds did not raise the loaf volume to the level obtained at higher speeds, and mixing times required to put in high work levels at low speed were extremely long.

It is interesting to note that for both flours No. 4 and 7 (Figs. 15 and 16) there was an indication that a further increase in loaf volume may be obtained by using mixing speeds well in excess of the critical speed with extended levels of work. However, the use of such extreme conditions would probably not be a practical proposition, and the effect was not found for all flours.

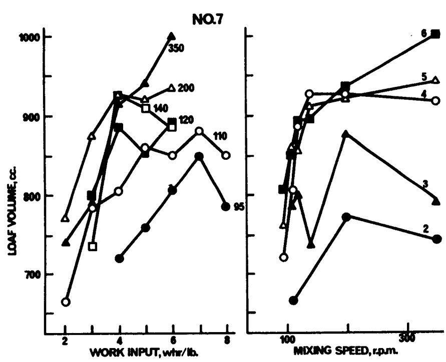
Mixing Efficiency

One further item of interest is related to the actual number of turns of the mixer blade required to impart the optimum work-input level at different impeller speeds. Figure 17 shows r.p.m. plotted against number of turns of the mixer blade for flours 1, 2, and 3. Critical mixing speeds are indicated. The number of turns of the mixer blade increased markedly as mixing speed decreased, suggesting that the mixing action was more efficient at higher speeds and approached maximum efficiency at speeds of 250 r.p.m. and above. That is, at higher speeds more work was imparted per turn of the mixer blade. At very low speeds a point is reached where the speed may be so low that extremely long mixing times are required to impart a given work-input level to the dough.

CONCLUSIONS

In this paper some of the variables involved in mechanical dough development have been explored with two laboratory dough mixers of different design. Investigation centered around the effect of mixing speed and work-input level on the performance in the Chorleywood Bread Process of a series of flours with different mixing requirements. The main conclusions of this study may be summarized as follows:

1. To achieve peak dough development (as indicated by mixing curve peak), different flours require different levels of work. Use of a fixed level of work input is not adequate for flours exhibiting a wide range of mixing requirements.



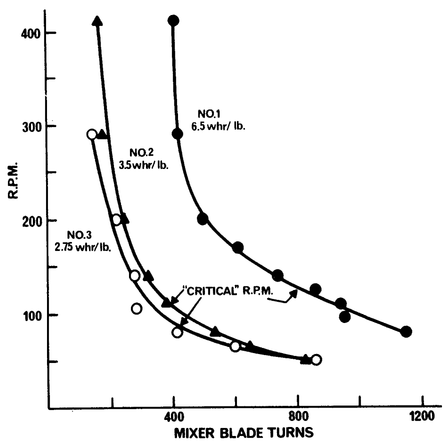


Fig. 16 (left). Loaf-volume data for flour No. 7 mixed in the experimental mixer. Left-hand figure shows effect on loaf volume of increasing work-input level at six different mixing speeds (95 to 350 r.p.m.). Right-hand figure shows effect of increasing mixing speed at five levels of work input (2 to 6 w-hr./lb.).

Fig. 17 (right). Effect of mixing speed (experimental mixer) on number of turns of the mixer blade required to impart a given (optimum) level of work input for three flours.

Short-mixing flours would be overmixed and doughs would become very sticky. Long-mixing flours would be undermixed, producing loaves of greatly reduced volume.

2. For a given flour there is a critical minimum mixing speed below which bread of lower and inconsistent loaf volume is produced. Speeds considerably in excess of the critical level may be used without deterioration in bread properties, although very high speeds may produce deterioration in crumb texture, particularly with weaker flours.

3. For a given flour dough, mixers of different mixing action and design show differences in critical mixing speed, gross energy requirement, and in mixing times corresponding to critical speed when imparting the correct level of work to the dough. For example, with the experimental mixer, optimum work must be imparted in a considerably shorter time than with the GRL pin mixer.

4. Work requirement for peak dough consistency does not appear to change with changes in mixing speed.

5. At mixing speeds above the critical minimum, satisfactory bread can be produced at work levels in excess of that indicated by peak dough consistency. With some flours a further increase in loaf volume may be achieved by the use of high mixing speeds and extended levels of work. At mixing speeds below the critical mixing speed where low-quality bread is produced, increased work levels can produce an improvement in loaf volume, but cannot raise volume to the level obtained at higher speeds.

6. At a fixed work level, the number of turns of the mixer blade increased markedly as mixing speed decreased, suggesting a more efficient mixing action at higher speeds.

7. A fixed work-input level would not provide the same degree of tolerance to flour variations as mixing to peak consistency, and a fixed work input would have to be qualified by the particular mixer used.

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