AN ELECTRONIC RECORDING DOUGH MIXER

II. An Experimental Evaluation[1]

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ABSTRACT

Data from a 30-g. mixograph and 5-, 10-, and 30-g. electronic recording mixers are compared to demonstrate the use of 5- or 10-g. samples and the data obtained with electronic apparatus. The electronic recording mixer can produce development curves whose width is a precise measurement related to shear strength of the dough which can be used as a sensitive index of flour quality. The mixograph underestimates the development curve and does not show the variation between samples of the same flour. The results of the mixing test are influenced by sample size, frequency response of the recording system, and interpretation of the curves. It is concluded that analog recording of the torque during development is not the most suitable method, because human interpretation of curves is required.

The electronic recording mixer previously described (1) records dough-development curves for 5- or 10-g. samples. Data presented here compare the results from the new mixer and a mixograph. Details are given for conversion of a 30-g. mixograph or mixer (National Mfg. Co., Lincoln, Nebr.) so as to record electronically. Results from a converted mixograph are compared with those from the new mixer and the mixograph, to evaluate the accuracy of the new machine, of the mixograph, and of a mixograph converted to electronic recording.

The accuracy with which curves recorded on different scales can be interpreted and the use of the maximum shear strength of dough during mixing as an indication of dough development are examined. The effect of recorder frequency response is also discussed. The interpretation of development curves in relation to flour quality has been discussed elsewhere (2–6).

Description of Apparatus

The following describes how an existing mixer or mixograph can be converted so as to record electronically for processing 30-g. samples. The electronic equipment and the calibrating and operating procedures used are the same as those described for the new recording mixer (1). The principles used can be applied to any type of mixer with a minimum of mechanical construction.

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Conversion of a National Micro-Mixer. A mixer is converted by removing the bowl mounting and replacing it with a torsion sensor (Fig. 1). Eight strain gages placed at 45° to the axis of a tube (Fig. 2) sense strains in these locations when the tube is subjected to torsion. The sample bowl is attached to one end of the tube, which is securely fixed to the mixer base. The strain gages are connected to the electronic recording equipment.

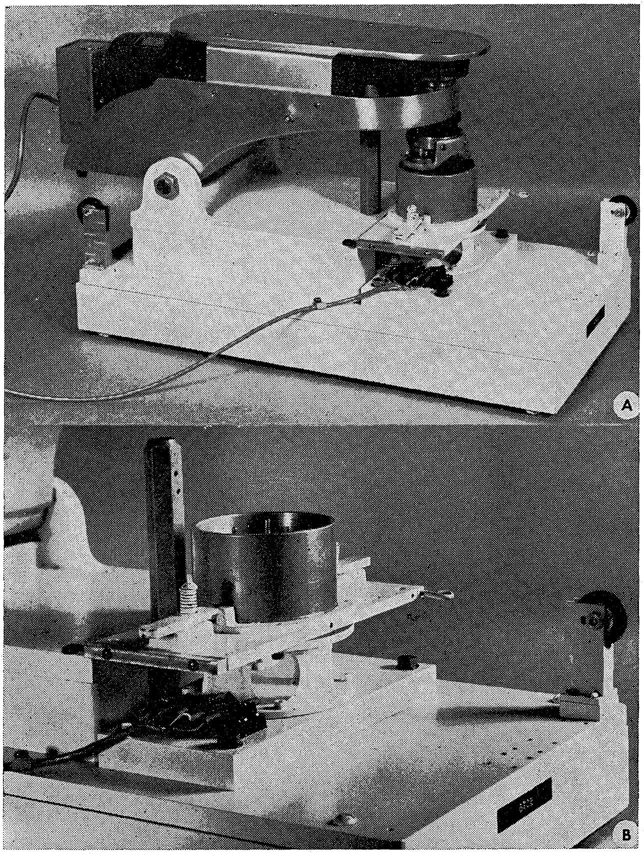

Fig. 1. A, modified National micro-mixer. B, torsion sensor. Note the pulleys used to apply torsion during calibration.

Conversion of National Micro-Mixograph. A mixograph is modified so that development curves can be recorded either mechanically or electronically by using a strain-gaged beam transducer (1) (Fig. 3). The beam is attached at one end to the recording arm and at the other to the mixograph base, with the arm in its mid-position (Fig. 3, B).

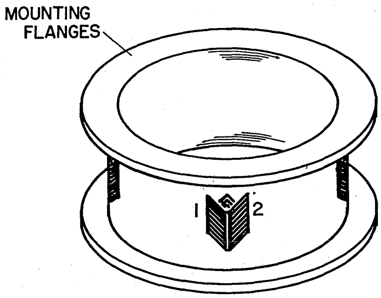

Fig. 2. Torsion sensor showing location of strain gages.

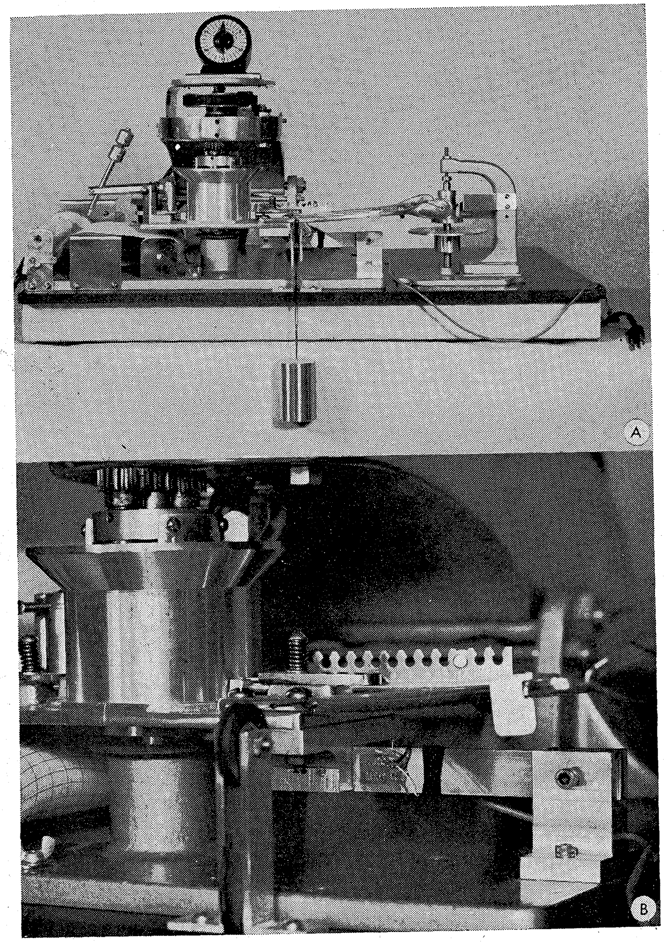

Fig. 3. The modified National micro-mixograph used in the experiment. A, method of calibration by gravity weight; B, strain-gage transducer installation.

The transducer is easily detached to convert the mixograph to its original method of recording.

Performance of Mixers. The performance characteristics of the three electronic recording mixers and the mixograph are summarized in Table I. Rotation of the mixing bowls of the electronic mixers was negligible compared with the 37-degree rotation in the mixograph,

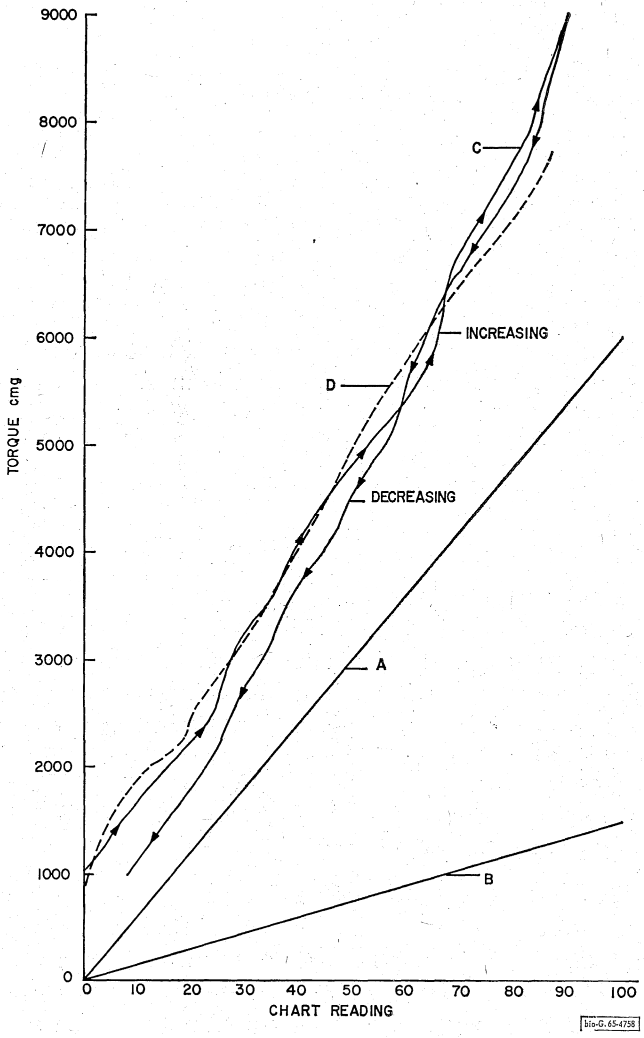

Fig. 4. Typical calibration curves: A, for 30-g., and B, for 10-g. electronic mixers. Linear within ± 0.6% (Table I). For comparison: C, National Mixograph calibrated by means of gravity weights showing nonlinearity and hysteresis, and D, the same calibration made with hand-held spring scale.

TABLE I

SUMMARY OF PERFORMANCE CHARACTERISTICS OF MIXERS

MIXER	SPEED	ANGULAR ROTATION OF BOWL[a]	LINEARITY OF CALIBRATION[b]
	r.p.m.	*degrees*	%
5- to 10-g. Electronic[c]	96	0.3	±0.6
30-g. Mixer conversion	90	0.0	±0.0
30-g. Mixograph conversion	90	1.3	±0.6
30-g. National mixograph[d]	90	37.0	±3.4

[a] Under 5,000 cmg. torque.

[b] Half deviation of curve from a line drawn between the minimum and maximum points on curve. Figures given are maximum noted for all sensitivities tested.

[c] See ref. 1.

[d] Spring position No. 10.

the converted mixograph having the maximum of the three electronic units (1.3°). With all the electronic recording systems used (5), the calibration curves were linear within ± 0.1 to ± 0.6%, depending on the sensitivity used (compare calibration curves, Fig. 4), and their repeatability-plus-accuracy was within ± 0.5%. The sensitivity of the 5-g. and 10-g. mixer ranged from 400 cmg. and that of the 30-g. electronic unit, from 3,000 cmg. up to any desired range.

Experimental Procedure

A check sample flour was tested to compare the mixograph used in the experiment with a mixograph used by the Ottawa Research Station, which in turn had been compared with mixographs in other laboratories. The mixograph used for the experiment was adjusted until it produced curves identical with those of the Ottawa Research Station. Calibration curves of torque *vs.* chart reading were then plotted for the new recording mixer, the mixograph, and the converted mixograph (Fig. 4). A single bowl was used in each mixer to eliminate variations due to differences between bowls. The experiment was conducted in an environmental chamber controlled at 25 ± 1°C. and 50 ± 1% r.h., so that the flour, added water, sample bowl, and mixing pins were at 25°C.

Three flours were used: a commercial bread flour, a commercial cookie flour, and a 50-50 mixture of the two. Absorptions were determined by standard farinograph procedures and all samples corrected to 14% m.b. Four samples were weighed to within ± 2.5 mg. and the added water was measured to within ± 0.013 ml. Ten samples of each flour were processed; 5- and 10-g. samples in the new electronic recording mixer, and 30-g. samples in the mixograph and the converted mixograph. Curves were recorded on four types of recorders (1) in turn with the electronic recording mixers. The mixograph procedure used by the Ottawa Research Station was followed.

Results

The mixograph calibration showed marked hysteresis when gravity weights were used, and calibrating by means of a hand-held spring scale gave a different result. This is indicated by the loop enclosed by curves taken in the increasing and decreasing torque directions (Fig. 4). This illustrates one of the major drawbacks of the mixograph: accurate, repeatable calibrations are difficult to achieve. If accurate data are required from mixograms, each point on the scale must be corrected by a different factor or an average line plotted through the points on the calibration curves, which introduces an error of ± 3.4% of full scale (f.s.).

Typical development curves obtained with four types of electronic recording apparatus and the new 10-g. mixer, the converted mixer, and the mixograph were shown previously (1). Curves were drawn on the records over the maximum torque, under the minimum torque, and through the mean torque recorded during mixing, and the following were noted from the curves: A, maximum value of the mean; B, time to reach A; C, mean value at 7.5 min.; D, area under the mean curve (total energy absorbed during mixing); E, width of curve at maximum mean; F, width of curve at 7.5 min.; G, area under maximum (max. shear energy); H, area under minimum (min. shear energy); I, area enclosed by maximum and minimum (shear energy) (Fig. 5). Measure-

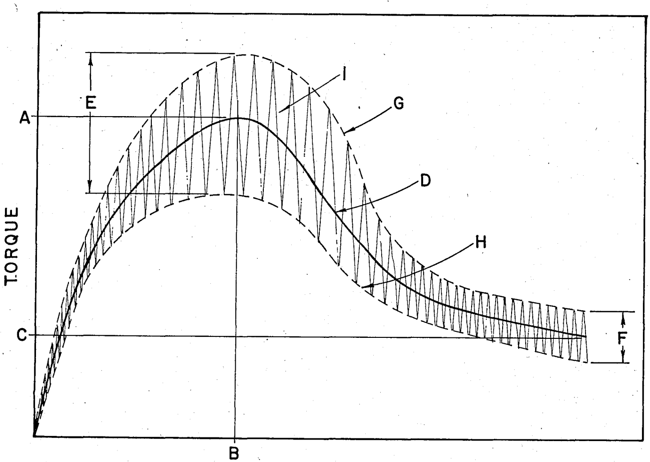

Fig. 5. Method of analysis of curves (see text).

TABLE II

MEAN OF MEASUREMENTS (10 SAMPLES) FROM DEVELOPMENT CURVES FOR THREE SAMPLE WEIGHTS RECORDED ELECTRONICALLY WITH FOUR TYPES OF RECORDERS AND A MIXOGRAPH

MEASUREMENT [a]	RECORDER [b]	BREAD FLOUR			BLENDED FLOUR			COOKIE FLOUR		
		5 g.	10 g.	30 g.	5 g.	10 g.	30 g.	5 g.	10 g.	30 g.
A. Torque	Mixograph	. . .	. . .	43.54	. . .	. . .	25.90	. . .	. . .	18.06
	Microammeter	6.25	11.35	43.99	4.77	8.21	32.56	3.17	5.91	22.16
	Rustrak	. . .	11.31	. . .	. . .	8.34	. . .	. . .	6.40	. . .
	T-Y	6.26	11.56	45.97	4.93	8.50	34.14	3.27	6.51	24.03
	600 c.p.s.	6.07	11.11	42.25	4.57	8.58	31.13	3.47	6.21	25.13
B. Time	Mixograph	. . .	. . .	3.10	. . .	. . .	3.50	. . .	. . .	3.40
	Microammeter	5.20	3.80	3.40	4.80	3.80	3.20	4.60	3.20	2.80
	Rustrak	. . .	4.00	. . .	. . .	3.80	. . .	. . .	2.70	. . .
	T-Y	5.60	4.50	3.70	5.20	4.10	3.50	4.80	3.10	3.10
	600 c.p.s.	5.50	3.40	3.20	5.10	3.40	3.00	4.60	2.20	2.30
C. Torque	Mixograph	. . .	. . .	31.75	. . .	. . .	22.70	. . .	. . .	16.72
	Microammeter	5.57	9.01	34.01	4.12	6.55	26.15	2.82	4.90	18.21
	Rustrak	. . .	9.03	. . .	. . .	6.92	. . .	. . .	5.17	. . .
	T-Y	5.61	9.78	36.13	4.28	6.68	27.10	2.87	5.28	20.17
	600 c.p.s.	5.23	9.11	33.15	4.01	6.96	24.23	3.04	5.04	19.30
D. Energy	Mixograph	. . .	. . .	141,000.00	. . .	. . .	89,240.00	. . .	. . .	49,280.00
	Microammeter	20,050.00	42,810.00	153,230.00	15,850.00	30,550.00	114,190.00	11,290.00	22,830.00	80,740.00
	Rustrak	. . .	42,480.00	. . .	. . .	31,180.00	. . .	. . .	24,530.00	. . .
	T-Y	19,920.00	43,230.00	158,470.00	16,300.00	31,980.00	119,430.00	11,520.00	25,200.00	87,680.00
	600 c.p.s.	18,900.00	42,210.00	147,350.00	15,020.00	32,330.00	110,260.00	12,320.00	23,380.00	88,270.00
E. Torque	Mixograph	. . .	. . .	13.52	. . .	. . .	8.71	. . .	. . .	5.65
	T-Y	4.31	3.94	22.39	3.41	3.24	20.39	2.32	2.89	18.50
	600 c.p.s	10.59	17.76	64.63	7.61	14.81	50.20	5.83	13.83	45.20
F. Torque	Mixograph	. . .	. . .	5.01	. . .	. . .	4.03	. . .	. . .	3.06
	T-Y	3.65	3.29	17.80	2.64	2.61	14.80	1.78	2.22	12.37
	600 c.p.s.	8.03	10.54	37.23	5.60	8.66	25.95	4.32	7.38	23.05
G. Energy	Mixograph	. . .	. . .	156,310.00	. . .	. . .	100,850.00	. . .	. . .	57,130.00
	T-Y	28,830.00	50,970.00	202,210.00	24,090.00	37,990.00	158,160.00	16,920.00	31,080.00	122,700.00
	600 c.p.s.	46,950.00	83,970.00	277,610.00	35,970.00	68,400.00	214,180.00	28,710.00	54,950.00	169,840.00
H. Energy	Mixograph	. . .	. . .	125,889.00	. . .	. . .	78,936.00	. . .	. . .	41,693.00
	T-Y	12,175.00	34,992.00	115,433.00	10,156.00	24,853.00	82,465.00	7,086.00	19,046.00	56,453.00
	600 c.p.s.	3,597.00	17,018.00	62,317.00	3,099.00	12,639.00	44,804.00	2,782.00	7,385.00	31,543.00
I. Energy	Mixograph	. . .	. . .	30,418.00	. . .	. . .	21,907.00	. . .	. . .	15,427.00
	T-Y	16,665.00	15,975.00	87,113.00	13,934.00	13,136.00	76,375.00	9,834.00	12,028.00	66,258.00
	600 c.p.s.	43,056.00	66,473.00	215,298.00	32,872.00	55,774.00	163,725.00	26,273.00	47,546.00	137,883.00

[a] See text. Data are presented in units of torque in meter g., energy in meter g.

[b] [illegible] Arranged in order of increasing frequency response.

ments E, F, G, H, and I were not noted where they were not recorded accurately (1), as on the Rustrak and microammeter recordings; they were noted for the mixograph for comparative purposes only. The term *shear energy* is used for descriptive purposes only.

The new mixer and the mixograph operate at different speeds (Table I), and the area measurements represent work done. The faster (10-g.) mixer generates more energy than the slower (30-g.) mixers in the same time. The area measurements of the 5- and 10-g. curves were therefore corrected to allow comparison of the 5-, 10-, and 30-g. data:

$$\text{Work done} = 2\,\pi\,\text{NT}$$

where N = r.p.m., T = torque. Therefore, the areas for the 5- and 10-g. samples were multiplied by (96/90).

The results (Tables II and III) show the mean values and coefficients of variation for 10 samples in each configuration for the measurements taken from the curves of 5-, 10-, and 30-g. samples.

Assuming that measurements from curves recorded with a high frequency response recorder (600 c.p.s.) are precise, the following general trends were observed:

(a) Measurements A, C, and D are overestimated by low frequency response recorders and underestimated by the mixograph;

(b) Measurements E, F, G, and I are underestimated by both low frequency response recorders and the mixograph;

(c) Measurement H is overestimated by both the low frequency response recorders and the mixograph.

These differences appear systematic for each mixer; therefore, once a standard method is established it should be possible to extrapolate the data to compare results with those of other mixers and methods of recording.

The coefficients of variation of all measurements tended to be higher for the electronic records than the mixograms, possibly indicating that the natural variation between samples was sensed by the electronic mixers. For example, the area measurements (D, G, H, and I, Fig. 5) showed higher variations when recorded electronically, particularly where the recorder (600 c.p.s.) registered the torque accurately. However, variation between samples was obviously influenced by interpretation of the records. For example, the time of the maximum mean torque (B) is difficult to determine accurately and the variation is therefore high in all recording methods. The irregular data suggest that this measurement may be an unreliable indication of flour quality. The curve width (E and F) and the area enveloped by

TABLE III

Coefficient of Variation (10 Samples) of Measurements from Development Curves Recorded Electronically with Four Types of Recorders and a Mixograph for Three Sample Weights

Measurement[a]	Recorder[b]	Bread Flour			Blended Flour			Cookie Flour		
		5 g.	10 g.	30 g.	5 g.	10 g.	30 g.	5 g.	10 g.	30 g.
A	Mixograph	..	..	2.8	..	..	1.3	..	..	2.9
	Microammeter	4.3	3.2	1.1	3.7	4.8	3.2	6.5	5.7	3.3
	Rustrak	..	5.6	..	..	4.8	..	...	4.7	..
	T-Y	4.8	1.2	1.3	3.5	1.0	2.3	6.2	0.6	0.2
	600 c.p.s.	1.3	4.2	2.8	1.7	3.9	2.8	2.4	1.1	0.5
B	Mixograph	..	..	6.2	..	..	10.3	..	..	16.6
	Microammeter	5.2	12.5	5.8	8.2	9.1	8.5	7.9	8.5	11.8
	Rustrak	..	7.9	..	..	8.9	..	..	28.7	..
	T-Y	5.2	9.7	7.0	4.2	5.3	4.3	8.1	6.4	8.3
	600 c.p.s.	5.3	15.2	9.4	9.6	16.0	11.5	16.8	11.5	10.9
C	Micrograph	..	..	2.8	..	..	1.9	..	..	2.6
	Microammeter	6.2	4.0	2.1	6.2	6.2	2.3	6.1	6.3	3.0
	Rustrak	..	5.9	..	..	4.3	..	..	6.5	..
	T-Y	3.0	2.2	3.3	8.3	1.5	1.7	8.5	2.1	2.0
	600 c.p.s.	1.1	4.5	2.9	2.6	4.3	2.8	4.0	1.9	2.3
D	Mixograph	..	..	1.3	..	..	1.4	..	..	3.6
	Microammeter	4.8	2.8	1.3	5.0	4.4	2.2	6.0	5.4	2.6
	Rustrak	..	5.4	..	..	4.7	..	..	5.9	..
	T-Y	6.0	4.0	1.6	4.1	4.0	2.3	6.3	5.1	1.6
	600 c.p.s.	6.1	4.4	0.7	6.0	4.1	2.2	6.4	3.4	0.9
E	Mixograph	..	..	10.3	..	..	8.8	..	..	5.0
	T-Y	6.4	1.1	5.1	6.2	2.7	5.0	6.3	2.4	5.1
	600 c.p.s.	3.6	6.7	6.7	2.8	12.7	6.5	3.0	10.2	3.5
F	Mixograph	..	..	8.7	..	..	16.7	..	..	13.5
	T-Y	6.8	2.5	3.1	7.4	2.5	3.4	7.8	3.3	3.0
	600 c.p.s	5.2	10.3	3.3	4.7	20.5	4.9	4.7	21.3	3.4
G	Mixograph	..	..	1.3	..	..	2.1	..	..	3.2
	T-Y	4.8	3.9	1.4	4.9	4.1	2.2	4.6	4.3	2.0
	600 c.p.s.	6.3	5.2	4.0	8.1	8.7	4.0	11.5	8.1	2.4
H	Mixograph	..	..	2.2	..	..	1.4	..	..	4.5
	T-Y	6.5	4.6	2.7	5.8	5.1	3.9	8.6	6.3	2.7
	600 c.p.s.	24.8	6.6	6.2	22.8	15.0	7.8	25.5	19.4	8.9
I	Mixograph	..	..	7.2	..	..	9.4	..	..	9.2
	T-Y	6.2	3.9	2.0	6.1	7.1	5.4	5.5	6.4	3.6
	600 c.p.s.	11.1	7.1	4.1	10.2	12.5	4.5	13.9	11.2	2.7

[a] See text.
[b] Described in ref. 1. Arranged in order of increasing frequency response.

the maximum and minimum curves (I) showed large variations in the mixograph because it is not a precise measurement (1) and accurate interpretation was difficult. The data from the 5- and 10-g. samples tended to show greater variation than those from the 30-g. samples. This may show that the small mixers are less precise for determining flour quality. From the data it appears possible to convert between

5-, 10-, and 30-g. data with reasonable accuracy, using a factor. The factor is not the same for each flour or measurement, but its range for each measurement is small, and factors could be established to convert data from one sample size to another to within 5%.

The data in Table II were converted to torque and energy values per g. of flour using a base of unity for the 5-g. samples (Table IV). The torque/g. values (measurements A, C, E, and F) were different for each sample size, as would be expected. These values depend on the spacing of the mixing pins and the volume of dough on the pins, as well as on the rheological properties of the dough. There were small differences between measurements A and C per g. of flour as determined by different recording methods. There were large differences in measurements E and F per g., caused by the difference in frequency response of the recorders.

The area, or energy, measurements (D, G, H, and I) per g. of flour were not the same for different sample sizes. Two measurements, D (total energy) and H (minimum shear energy), increased with increasing sample size. The remainder, G (maximum shear energy) and I (shear

TABLE IV

Ratio of Mean Torque or Energy (10 Samples) per Gram Flour for Three Sample Weights in Relation to 5-g. Samples Reduced to a Value of Unity

Measurement[a]	Recorder[b]	Bread Flour		Blended Flour		Cookie Flour	
		10 g.	30 g.	10 g.	30 g.	10 g.	30 g.
A (Torque)	Microammeter	0.91	1.18	0.86	1.15	0.93	1.14
	T-Y	0.93	1.22	0.86	1.15	1.00	1.23
	600 c.p.s.	0.92	1.17	0.95	1.52	0.90	1.22
C (Torque)	Microammeter	0.81	1.02	0.80	1.06	0.88	1.09
	T-Y	0.88	1.07	0.78	1.05	0.93	1.18
	600 c.p.s.	0.87	1.06	0.85	0.99	0.82	1.05
E (Torque)	T-Y	0.45	0.87	0.47	1.00	0.63	1.35
	600 c.p.s.	0.83	1.01	0.97	1.10	1.18	1.29
F (Torque)	T-Y	0.45	0.81	0.49	0.92	0.61	1.14
	600 c.p.s.	0.65	0.77	0.78	0.77	0.86	1.04
D (Energy)	Microammeter	1.07	1.27	0.96	1.24	1.01	1.19
	T-Y	1.06	1.33	0.98	1.22	1.09	1.27
	600 c.p.s.	1.12	1.30	1.08	1.22	0.95	1.19
G (Energy)	T-Y	0.88	1.17	0.79	1.09	0.92	1.21
	600 c.p.s.	0.89	0.99	0.95	0.99	0.96	0.99
H (Energy)	T-Y	1.44	1.58	1.22	1.35	1.34	1.32
	600 c.p.s.	2.37	2.89	2.04	2.41	1.33	1.89
I (Energy)	T-Y	0.48	0.87	0.47	0.91	0.61	1.12
	600 c.p.s	0.77	0.83	0.85	0.83	0.91	0.87

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[a] See text.
[b] Described in ref. 1.

energy), were at a minimum for 10-g. samples and about equal for the 5- and 30-g. samples, the 30-g. samples tending to have lower energy absorptions. Thus, it would appear that dough absorbs a greater amount of energy per g. in larger mixers; this may explain why larger mixers tend to be more efficient. Differences in energy absorption for different samples cannot be explained fully here, but the main cause is possibly heat-dissipation within the sample. These findings are at variance with those of Axford and Elton (7), who found that the energy per g. of dough was independent of the type of mixer. These authors were studying the energy absorption to give optimum development, however, and did not discuss different sample sizes.

The data indicate that there is some scale effect, and, if energy absorption is to be predicted from small samples, a correction factor may be required to use the data for processing production-sized batches of dough.

The nine measurements, taken from the curves recorded by all methods, graded the three flours in descending order: bread, blended, and cookie – with the exception of the time to reach the maximum mean (B), which showed several reversals. All measurements increased with increasing sample size except B, which decreased, indicating that larger mixers complete the mixing process in a shorter time. The maximum mean torque (A), the mean torque at 7.5 min. (C), and the area under the mean (D) tended to increase with increasing recorder frequency response up to a frequency response of 0.6 sec. f.s. The measurements then decreased. The width of the curve (E and F), the area under the maximum (G), and the area enveloped by the maximum and minimum curves (I), which are related to the shear strength of the dough, increased rapidly with frequency response. The area under the minimum (H) decreased rapidly with increasing frequency response. The effect of frequency response was most pronounced in the 30-g. samples.

The measurements related to shear stress in the dough (E, F, G, H, and I) had a wide range for the three flour qualities, which indicates that they could be used as indices of quality. The sensitivity of these measurements to changes in quality was of the same order as the measurements normally taken from mixograms (A, C, and D).

Discussion

In the design chosen by the authors for a 5- to 10-g. mixer, the same mixing action was used as in the mixograph, because it produces development curves which are comparable to those of the mixograph. The mixograph is an established apparatus, and there is an advantage to the cereal chemist if the data from smaller samples on a different machine can be compared with full-scale mixograph data for a breeding experiment. Five-gram samples appear to be the limiting size for the new machine because of the bowl size selected. A smaller bowl could be made, because the electronic method is sensitive enough and smaller mechanical components are readily available. Maintaining sufficient strength in the mixing pins is then the chief problem. The need for interlaboratory standardization of recording mixers is partly eliminated by the use of electronic recording, since an accurate independent calibration method can be used for the recording system. One problem still remains — interchangeability of mixing bowls and the mixing head in a single machine or between different machines.

The effect of recorder frequency response on the data shows that a high frequency response is required. To record a torque cycling at 4 c.p.s., a frequency response of at least 20 c.p.s. is required. However, the use of high frenquency response recorders to record the curves increases errors in interpreting the curves. Drawing the mean value of widely dispersed curves is difficult, but the maximum shear strength of the dough during mixing can be estimated from such records.

The data show that the variation in measurements taken from dough-development curves for the same flour covers a wide range. This variation arises from four sources: the flour, the measuring apparatus, changes in test conditions, and human errors in interpreting the curves. Flour is viable, and some variation must occur in any real measurement. The electronic mixers are accurate, and variations due to temperature, the sample bowl, sample size, and added moisture were eliminated by careful experimental technique. Thus, it is logical that a major source of error arises during interpretation of the curves. The data obtained do not allow separation of natural variation and human errors.

It is desirable to eliminate the interpretation. This is not feasible with the mixograph. Electronic mixers, however, allow the use of methods other than analog recording — for example, digital or automatic integration. Since the area under the curve, or total energy during mixing, is sensitive to flour quality, the integration method is the best choice. Details of this method will be published later.

The electronic analog recording method is suitable for both research and routine quality control, but the apparatus required will be different in each case. For research, the high frequency recording system appears the most suitable; for routine quality control or initial selection of the best flours from a wide quality range, a low frequency response recorder, plotting mean torque, will be most efficient.

Conclusions

Electronic recording mixers are more suitable than other types for recording dough-development curves, because they are more accurate and sensitive. For research applications an electronic recording mixer should be capable of accurately recording the torque during mixing. Two additional indices of flour quality are then available — that is, width of curve and maximum torque during mixing — which are related to the physical properties of the dough. For purposes of routine quality control a recorder with low frequency response can be used, so that interpretation is reduced.

Since interpretation of the development curves is a major source of error, this should be eliminated. Instead of an analog record of torque during mixing, some other means must be developed. Further work is required to determine the relation between the physical properties of the dough and torque on the bowl.

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