The Ottawa Electronic Recording Dough Mixer. VII. Factors Affecting Performance and the Use of Digital Recording Techniques[1]

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ABSTRACT

Data from a pin-type dough mixer with an electronic recording system indicated that mixing-bowl temperature, mixing speed, flour weight, and added water must be controlled precisely to obtain accurate results. Control limits for these variables are suggested for 4-g. flour samples. It was concluded that accurate data could be obtained under practical conditions with the electronic recording dough mixer with 4-g. flour samples. Addition of a water jacket to the mixing bowl reduced the dimensions of the development curves. This occurred even though air temperature in the mixing cabinet was controlled. There was a high degree of correlation between dimensions of development curves and electronic integrator energy measurements. It is thus feasible to utilize computer techniques in the preliminary screening of plant breeders' samples.

The conversion of dough mixers from mechanical to electronic recording systems to increase precision and sensitivity was described previously. A mixograph (1,2,3), a farinograph (2,4), a Hobart mixer (3), and an amylograph (5) were converted. A 10-g. electronic recording pin-type mixer was developed (2,6) and evaluated (1). Different electronic recording techniques were investigated (7) and digital energy recording systems introduced (3,8). An electronic recording pin-type mixer for samples sizes up to 5 g. of flour (9) which could record development curves using 3.5 g. of flour was then developed[3]. It was shown with this apparatus that interchangeable mixing bowls could be manufactured for testing 5-g. samples (9). These new techniques have been demonstrated in the early-generation screening of durum wheat (10).

The purpose of the work here was to determine the effect of mixing speed, temperature, sample size, and added water on development curves recorded electronically when testing 4-g. flour samples. This information was required to determine the precision with which these factors must be controlled. The relation between measurements from electronically recorded curves and from electronic digital energy measurements was also examined to determine the usefulness of the latter in preliminary screening of plant breeders' samples and to compare the accuracy of the two recording methods.

MATERIALS AND METHODS

A 5-g. electronic recording pin-type mixer (9) was calibrated and operated by means of techniques (1–9) based on the standard mixograph method (AACC method 54–40). The mixing bowl was modified so that its temperature could be controlled by circulating water at 28°C. through a water jacket (Fig. 1).

The output of the electronic dynamometer was recorded as mixing torque vs. time on a strip-chart recorder to produce development curves similar to those of conventional mixograms. The 24-sec. full-scale response time of the recorder pen

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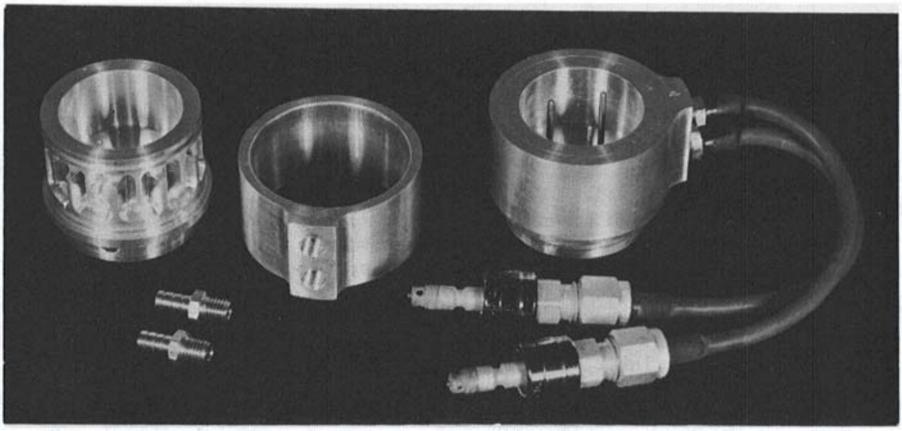

Fig. 1. Water-jacketed 5-g. bowl for controlling dough temperature. Components used for assembly at the right are shown at the left.

damped out the torque fluctuations, so that the average was plotted (2). An electronic integrator (9) was connected in parallel with the recorder to record the energy used during mixing at 10-sec. intervals in digital form. Data were taken from the records of torque and energy; the measurements used were similar to those suggested for mixograms by Swanson and Johnson (11) and Zalik and Ostafichuk (12) and other selected factors (Table I and Fig. 2).

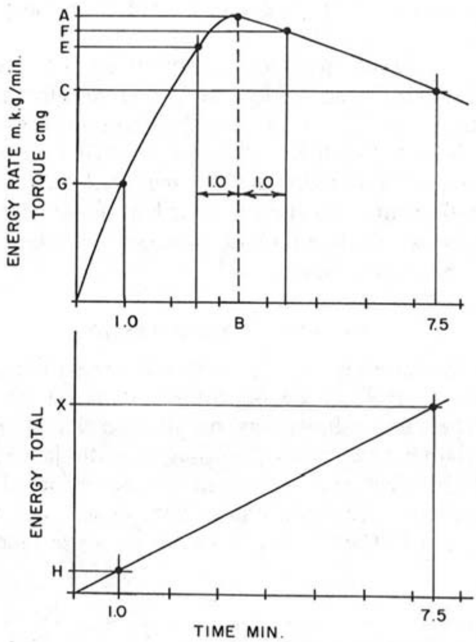

Fig. 2. Measurements taken from development curves and energy records.

TABLE I. MEASUREMENTS TAKEN FROM DEVELOPMENT CURVES AND ENERGY RECORDS[a]

Measurement	Recorder	Integrator
A	Maximum torque during mixing (cm.g.)	Maximum rate of use of energy (m.kg./min.)
B	Arrival time to A (min.)	Arrival time to A (min.)
C	Torque after 7.5 min. of mixing (cm.g.)	Rate of use of energy after 7.5 min. of mixing (m. kg./min.)
D	Total energy used to B[b] (m.kg.)	Total energy used to B (m.kg.)
E	Torque 1 min. before A (cm.g.)	Rate of use of energy 1 min. before A (m.kg./min.)
F	Torque 1 min. after A (cm.g.)	Rate of use of energy 1 min. after A (m.kg./min.)
G	Torque after 1 min. of mixing (cm.g.)	Rate of use of energy after 1 min. of mixing (m.kg./min.)
H	–	Total energy used in the first min. of mixing (m.kg.)
X	Total energy used in 7.5 min. of mixing[b] (m.kg.)	Total energy used in 7.5 min. of mixing (m.kg.)
A–E	Developing rate (cm.g./min.)	Developing rate (m.kg./min.)
A–F	Weakening rate (cm.g./min.)	Weakening rate (m.kg./min.)
(A–E)+(A–F)	Combined rate (cm.g./min.)	Combined rate (m.kg./min.)
G+F–E	Experimental index	Experimental index
X–D	Experimental index	Experimental index

[a]See Fig. 2.

[b]From area under development curve measured with a planimeter.

Unless otherwise specified, the following conditions were used in the experiment:

Temperature of water circulated through jacketed bowls, air in mixer cabinet, and added water 28, ± 0.3°C.;
Mixing speed, 100 ± 1 r.p.m.;
Flour sample nominal size, 4 g. ± 2 mg.;
Water added within ± 1% of amount required to give the correct absorption on 14% m.b.;
Mixing time, 7.5 min.;
For convenience, three flours were used, a commercial bread, a commercial cookie, and a 50–50 mixture of the two.

Tests and Observations

Development curves from the recorder (Fig. 3) were convenient to analyze. Mixing torque, the recorder pen deflection, and the energy recorded by the integrator were linearly related and accurate within ± 0.5%.

To examine the effect of adding the mixing bowl water jacket, a thermocouple was installed in the bottom of a bowl at the center, immersed in the dough but not in the path of the mixing pins. Dough temperature was then recorded on a strip-chart. Ten samples of the three flours were tested first without and then with water at 28°C. circulating through the jacket. In the latter case the bowl containing the sample was brought to operating temperature before testing by circulating 28°C. water through the jacket for 5 min.

Circulating water through the jacket prior to testing did not bring the sample to

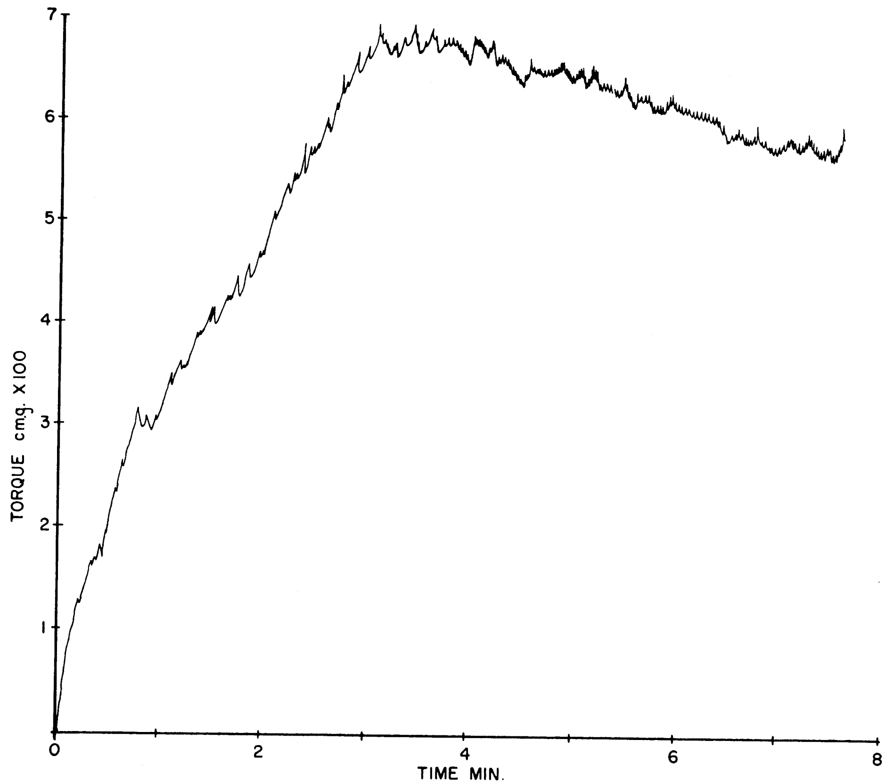

Fig. 3. Typical development curve from the 24-sec. response-time strip-chart recorder, 4-g. bread flour sample.

28°C. (Table II), but it did increase the temperature before mixing by about 1°C. The major effect was that the temperature of the dough was 28.3 ± 0.2°C. by the end of the mixing cycle. This was about 1°C. higher than the samples tested without circulating water. The temperature records indicated that the water jacket maintained the dough at 28° ± 0.5°C. throughout the mixing cycle. When water was not circulated through the jacket the temperature fluctuated and tended to increase 1° to 2°C. during mixing.

The water jacket had a consistent effect on the development curves and energy measurements (Table II). The improved temperature control tended to reduce the dimensions of the development curves and energy measurements. The variation between samples was also affected, but this trend was not consistent within each measurement or between flours. Variation in about half the measurements increased whereas it decreased in the others. Thus, while addition of the water jacket improves the precision of temperature control by only a limited amount, it does affect the behavior of the dough.

To further investigate the effect of the water-jacket temperature, a sample of each flour was tested with water at 20°C. circulating through the jacket. This was then repeated at water temperatures rising in 2° increments up to 36°C.

TABLE II. EFFECT OF WATER JACKET ON DEVELOPMENT CURVES AND ENERGY MEASUREMENTS

	Bread Flour				50–50 Flour				Cookie Flour			
	Mean[a]		C.V.%		Mean[a]		C.V.%		Mean[a]		C.V.%	
Measurement[b]	No[c]	Yes[c]	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Recorder												
A	1,026	1,004	2.1	3.0	754	725	1.7	2.4	511	490	3.5	2.2
B	2.4	2.3	7.3	5.6	2.1	2.1	9.6	11.0	1.9	2.1	12.0	16.5
C	638	685	7.2	11.4	559	527	2.5	5.5	379	372	3.0	2.6
D	11.2	10.4	11.7	9.5	7.6	7.4	12.8	12.5	4.8	5.4	12.1	18.3
E	862	839	7.2	6.9	625	614	6.7	5.8	440	430	6.9	8.5
F	951	940	1.6	3.4	685	668	6.8	2.1	485	461	3.1	2.3
G	792	764	5.8	4.1	612	604	4.1	4.5	456	427	3.5	5.3
X	37.9	37.5	2.4	3.7	28.8	27.9	1.6	2.3	20.2	19.7	2.6	2.6
A–E	164	166	35.2	23.8	121	111	28.9	31.6	72	60	47.0	56.1
A–F	76	65	29.5	28.1	69	57	57.2	17.2	27	29	47.9	31.6
Dough temp.												
at start, °C.	25.7	26.8	0.9	1.8	25.6	26.2	1.0	2.2	25.9	27.4	2.1	1.3
at 7.5 min., °C.	27.1	28.1	0.4	1.9	26.7	28.3	1.3	0.3	26.9	28.5	1.2	0.0
Integrator												
A	6.5	6.3	2.4	2.9	4.7	4.6	2.3	2.0	3.2	3.1	1.8	2.8
B	2.5	2.4	12.0	7.0	2.2	2.1	11.2	9.4	1.9	2.1	12.3	16.3
C	4.1	4.3	7.1	11.8	3.4	3.3	2.4	6.1	2.4	2.4	1.5	2.5
D	12.1	11.6	12.6	8.9	8.4	8.1	13.5	10.4	5.5	6.1	16.6	13.1
E	5.8	5.6	5.6	6.2	4.2	4.1	5.4	4.3	2.9	2.9	4.9	4.1
F	6.1	5.9	2.8	3.2	4.4	4.3	3.1	2.8	3.0	2.9	2.6	2.4
G	5.2	5.0	5.8	4.5	4.0	4.0	3.3	4.4	2.9	2.8	1.8	4.2
H	3.7	3.5	11.5	5.3	3.0	3.1	8.0	8.2	2.5	2.4	4.0	6.5
X	38.8	38.0	2.7	3.5	29.2	28.5	1.7	2.6	20.4	20.1	1.5	2.5
A–E	0.73	0.64	42.7	45.6	0.60	0.53	29.9	33.0	0.30	0.18	45.9	62.8
A–F	0.43	0.42	23.0	24.6	0.35	0.31	31.1	29.7	0.14	1.51	53.9	38.0

[a]Ten samples.

[b]See Table I.

[c]Water circulating.

To a first approximation, measurements from the development curves and energy measurements varied linearly with temperature. For simplicity the change in each measurement was calculated as a percentage of the value at 28°C. (Table III). The change was generally less than 4% per degree C. for individual measurements from the curves or energy values, unless two factors were combined. For example, the developing rate A–E and the weakening rate A–F changed up to 14.5% per degree C. The arrival time fluctuated at random with temperature. The energy used in the mixing cycle up to the maximum torque from the area under the development curve A and from the integrator D varied widely and at random with changing temperature. Changes for individual samples ranged from 0.1 to 12.1% per degree C. and averaged from 2.1 to 6.6% per degree C., depending on the flour and recording method. Temperature changes affected energy measurements slightly more than the development curves. It is therefore concluded that, for precise measurements, the bowl temperature should be controlled within at least 0.25°C. to reduce errors from this source to acceptable limits.

TABLE III. EFFECT OF WATER-JACKET TEMPERATURE ON DEVELOPMENT CURVES AND ENERGY MEASUREMENT

Measurement[a]	Change in Measurement, % per °C.[b]					
	Recorder			Integrator		
	Bread %	50–50 %	Cookie %	Bread %	50–50 %	Cookie %
A	2.3	2.7	2.8	2.4	2.9	3.3
C	2.6	2.1	2.5	2.9	2.7	3.4
E	1.5	2.0	2.2	1.6	2.3	2.7
F	2.7	3.5	3.7	2.7	2.1	3.8
G	1.7	2.1	3.0	1.6	2.7	1.8
X	2.6	2.8	2.8	2.4	2.7	3.3
A–E	6.6	4.0	7.5	14.5	7.0	8.1
A–F	−4.0	7.7	2.5	0.0	3.3	3.1

[a]See Table I.

[b]Expressed as a percentage of the value at 28°C.

To determine the optimum flour sample size for the mixing bowl, samples of the three flours were tested with 1.0 g. of flour. This test was then repeated, with the sample size increased by 0.5-g. increments up to 5.0 g., the maximum capacity of the bowl.

The development curve-peak became more pronounced as sample size increased (Fig. 4). A sample size of 4 g. appeared to produce a curve similar to that of conventional mixograms, and it was concluded that this was the optimum size. It may, however, be useful to use larger samples to accentuate the peak for some purposes. These effects were similar for the three flours tested. The results were therefore averaged and the changes expressed as a percentage of the value for a 4-g. sample.

Digital energy measurements and measurements from the curves changed with sample size (Fig. 5 and Table IV). All the measurements increased with sample size except the arrival time, which decreased. Differences ranged up to 30% per g. Thus it would appear that by using a sample weighed within 10 mg., errors could be reduced to acceptable limits.

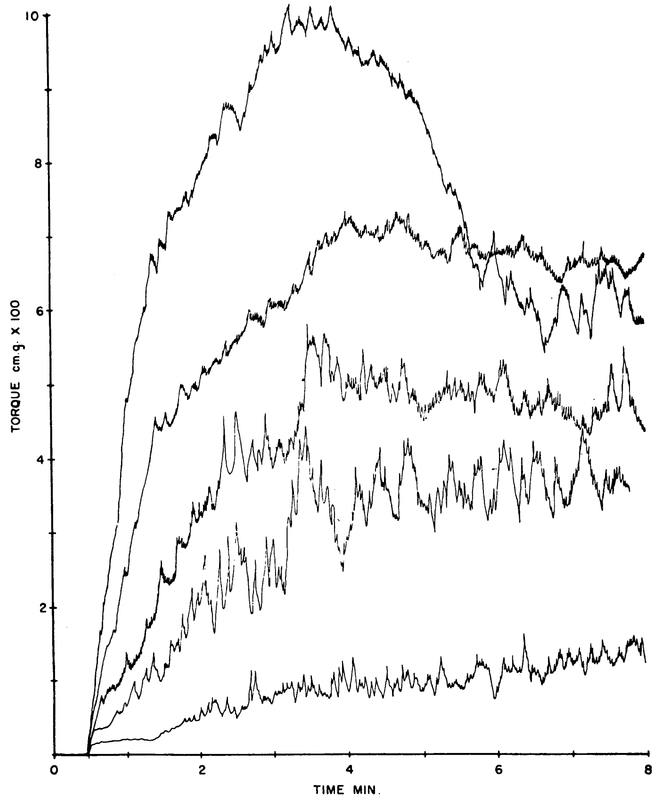

Fig. 4. Effect of sample size on development curves. Bread flour, 1-, 2-, 3-, 4-, and 5-g. samples (bottom to top).

TABLE IV. EFFECT OF FLOUR SAMPLE SIZE

Measurement[a]	Change in Measurement, %/g.[b] Recorder	Change in Measurement, %/g.[b] Integrator	Measurement[a]	Change in Measurement, %/g.[b] Recorder	Change in Measurement, %/g.[b] Integrator
A	30.5	28.4	H	...	26.8
B	−17.8	−20.0	X	25.8	22.8
C	21.8	24.9	A−E	18.8	27.6
D	21.6	19.3	A−F	26.8	22.2
E	24.0	16.4	A−E+A−F	21.4	26.6
F	25.9	25.0	G+F−E	26.6	26.6
G	32.0	24.5	X−D	26.6	27.7

[a]See Table I.

[b]Expressed as a percentage of the value for 4 g. of flour and averaged for three flours.

The effect of variations in the amount of water added to the flour was checked by testing samples of each flour at 80 to 120% in increments of 5%, of the required added water.

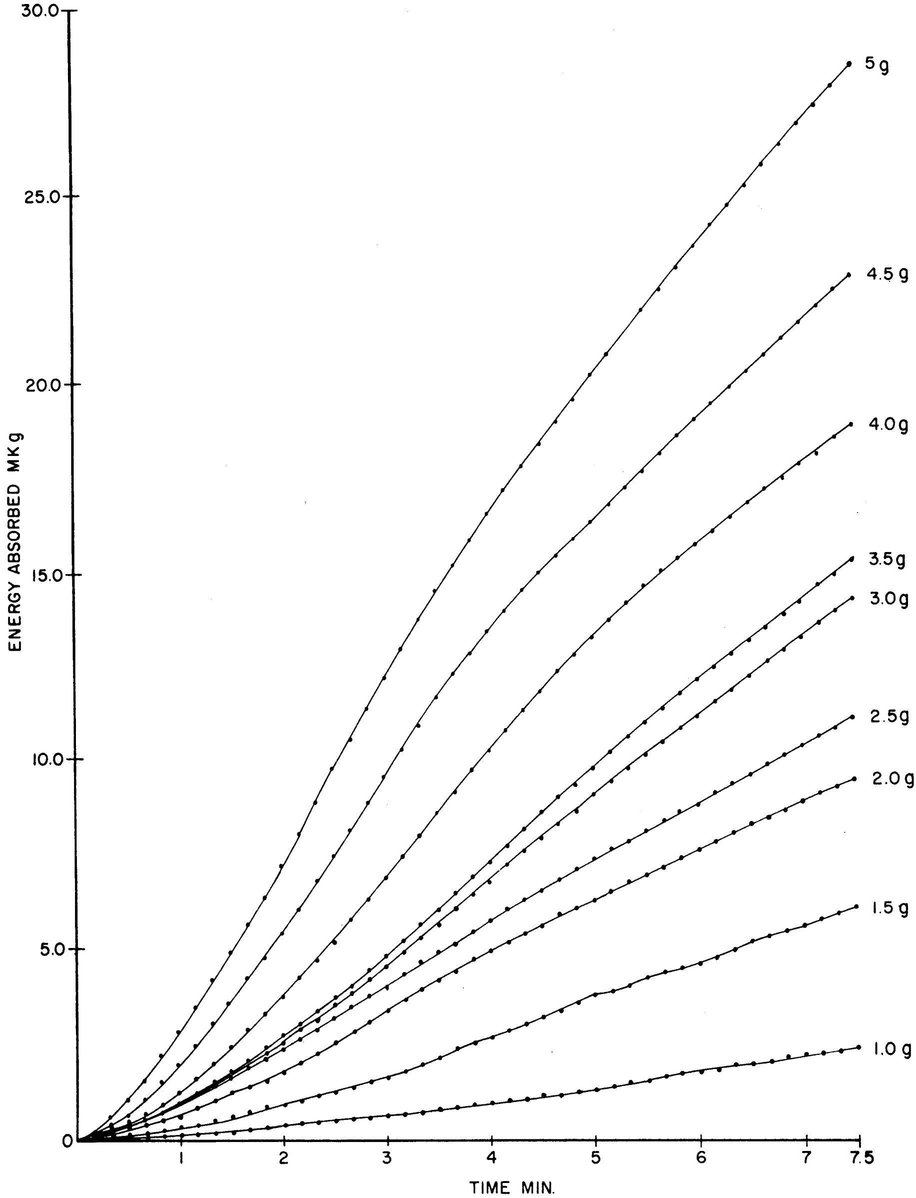

Fig. 5. Effect of sample size (1.0 to 5.0 g.) on energy used in mixing bread flour for 7.5 min.

The results for the three flours were similar and were therefore averaged and expressed as a percentage of the values for the correct added water. The measurements from the development curves and digital energy records decreased as the water added was increased, with the exception of the arrival time B and the energy used up to the maximum torque D (Table V). The changes were similar for both methods of recording and ranged up to 3.5% per % of added water. It would thus appear necessary to measure the added water within 0.1% of the required amount to reduce errors from this source. The effect on the shape of development curves and digital energy records was similar; the peak was delayed by increasing the added moisture (Fig. 6) and accentuated by decreasing the added moisture. Thus it appears that a current procedure of mixing at a fixed absorption can lead to errors.

TABLE V. EFFECT OF ADDED WATER

Measurement[a]	Change in Measurement, %/% of Added Water		Measurement[a]	Change in Measurement, %/% of Added Water	
	Recorder	Integrator		Recorder	Integrator
A	−1.95	−2.27	H	...	−3.52
B	2.18	3.02	X	−1.95	−2.62
C	−1.74	−1.41	A−E	−2.23	−2.01
D	0.12	0.41	A−F	0.00	−2.66
E	−1.56	−1.51	A−E+A−F	−1.78	−4.47
F	−1.97	−2.57	G+F−E	−3.08	−2.96
G	−2.84	−1.77	X−D	−2.72	−2.98

[a]See Table I.

[b]Expressed as a percentage of the value at the correct added moisture and averaged for three flours.

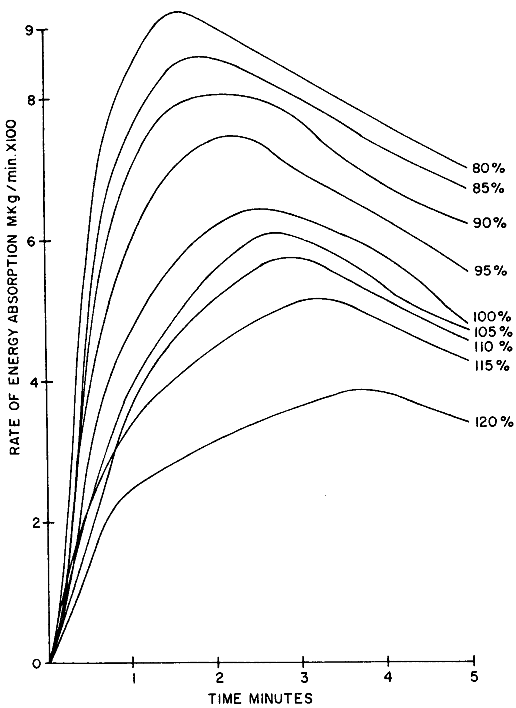

Fig. 6. Effect of added water on the rate of energy absorption in mixing bread flour.

Samples of the three flours were tested at speeds ranging from 75 to 300 r.p.m., increasing in increments of 50 r.p.m., to determine the effect of mixing speed. The results for the three flours were similar and were therefore averaged and the changes expressed as a percentage of the values at 100 r.p.m., the mixing speed arbitrarily selected for the mixer. The majority of the measurements increased with higher mixing speed (Table VI). However, the arrival time B, energy used in 7.5 min. of mixing X, and the torque 1 min. before the peak E decreased. The change per r.p.m. ranged up to 1.29% but for most measurements the change was less than 1%. It is therefore necessary to control the mixing speed within at least 1 r.p.m. to reduce errors from this source. The curve peak was accentuated as the mixing speed increased.

TABLE VI. EFFECT OF MIXING SPEED

	Change in Measurement, %/r.p.m.[b]			Change in Measurement, %/r.p.m.[b]	
Measurement[a]	Recorder	Integrator	Measurement[a]	Recorder	Integrator
A	0.13	0.12	H	...	1.29
B	−0.31	−0.31	X	0.80	0.78
C	−0.06	−0.06	A−E	0.93	0.74
D	0.29	0.32	A−F	1.29	1.10
E	−0.50	−0.50	A−E+A−F	0.75	0.82
F	...	...	G+F−E	0.80	0.29
G	0.22	0.29	X−D	1.08	0.92

[a]See Table I.

[b]Expressed as a percentage of the value at 100 r.p.m. and averaged for three flours.

To examine the accuracy of digital energy measurements in relation to measurements from development curves, 74 flour samples from the Canada Department of Agriculture's wheat-breeding programs were collected. These samples provided a wide range of baking quality. A 4-g. sample of each flour, on 14% m.b., was then tested, with the corrected flour weight and added water. This was then repeated at a constant flour weight of 4 g., and water was added equal to the average absorption of the 74 samples. The 13 measurements from the development curves and 14 from the integrator records (Table I) were then noted, and correlation coefficients for all possible combinations of measurements were calculated.

Correlation between development curve and integrator energy measurements was high for all measurements in both the corrected absorption and fixed absorption tests (Table VII). On the average, the correlation coefficient was 0.92. This, however, indicates that the two methods of measurement do not produce identical results. These differences occur because measurements taken from development curves are based on the mean torque during mixing. The true mean of the randomly fluctuating torque cannot be estimated accurately from strip-chart records. This is the result of the condensed time scale, where fluctuations are not visible or where the frequency response of the recorder damps out the fluctuations as in this experiment (2,6). It has been shown that in this case the estimated mean can be 15% in error (3). The integrator, on the other hand, records the true integral of the 4-cps. torque signal with an accuracy of 0.5% (13).

TABLE VII. CORRELATION COEFFICIENTS BETWEEN THE SAME TRAITS MEASURED FROM DEVELOPMENT CURVES AND FROM THE INTEGRATOR

	Correlation Coefficient[b]			Correlation Coefficient[b]	
Measurement[a]	Corrected Absorption	Fixed Absorption	Measurement[a]	Corrected Absorption	Fixed Absorption
A	0.994	0.989	X	0.991	0.987
B	0.892	0.983	A–E	0.824	0.763
C	0.995	0.988	A–F	0.865	0.850
D	0.879	0.897	(A–E)+(A–F)	0.828	0.812
E	0.936	0.872	G+F–E	0.913	0.923
F	0.990	0.978	X–D	0.901	0.909
G	0.998	0.994	Mean	0.924	0.919

[a]See Table I.

[b]Based on 74 samples.

The characteristics commonly used to evaluate development curves from conventional mixograms are the peak height (A, Table I), the arrival time B, the area under the curve (total energy used to mix the dough) X, and the angles at the apex of the curve which correspond to A–E, A–F and A–E + A–F. These measurements and the others used in this experiment (Table I) can be generated from the digital energy records by computer techniques. Correlation between these six measurements and all others were of approximately the same order for the correct and fixed absorption tests (Table VIII). In some cases, however, using a fixed absorption tended to decrease or increase the degree of correlation, and in some cases the relationship was inverted. Correlation between the arrival time B and other measurements was particularly affected in this respect.

The arrival time B was only highly correlated with D, the energy used up to the maximum torque A, the torque after 1 min. of mixing C, and the combinations of measurements D, E, F, G, and X.

The maximum torque A was highly correlated with the torque after 7.5 min. of mixing C, the torque 1 min. before E and after F, and the total energy used during mixing X. However, the only combination of measurements highly correlated with A was the energy used after the peak X–D. The total energy used during mixing X was highly correlated with the torque after 7.5 min. of mixing C, the torque 1 min. before E and after F the peak, and the energy used after the peak X–D.

The combined indexes A–E, A–F, and A–E + A–F were only highly correlated among themselves. Therefore it was assumed that the use of these combinations of measurements to evaluate the measurements normally used was superfluous. The only index which appeared useful was the energy used after the peak X–D which is a measure of the weakening rate of the dough.

CONCLUSIONS

In testing dough development with 4-g. samples, the flour weight, added moisture, bowl temperature, and mixing speed all affect the development of dough during mixing. These factors should therefore be controlled as closely as possible. For some purposes, however, it may be useful to vary one of them to accentuate a particular characteristic of the development curve.

TABLE VIII. CORRELATION COEFFICIENTS BETWEEN MIXOGRAM CHARACTERISTICS AND OTHER MEASUREMENTS[a]

	Measurement from Recorder[b]											
	A		B		X		A−E		A−F		A−E + A−F	
	C[c]	F[c]	C	F	C	F	C	F	C	F	C	F
Recorder Measurements[d]												
B	0.126	−0.263	...	...	...	...	...	...	...	...	...	...
C	0.893	0.815	0.335	0.183	0.961	0.867	−0.000	−0.033	0.095	−0.103	0.034	−0.046
D	0.608	0.186	0.797	0.865	0.703	0.205	−0.313	−0.506	−0.005	−0.313	−0.230	−0.502
E	0.806	0.675	0.385	0.155	0.925	0.738	−0.271	−0.460	0.053	−0.003	−0.179	−0.359
F	0.957	0.938	0.205	−0.117	0.974	0.950	0.172	0.193	0.179	0.041	0.189	0.181
G	0.649	0.616	−0.462	−0.828	0.651	0.662	0.197	0.394	0.285	0.354	0.246	0.431
X	0.940	0.920	0.206	−0.267	...	...	0.064	0.166	0.200	0.120	0.118	0.182
A−E	0.351	0.338	−0.404	−0.514	0.064	0.166	...	...	0.653	0.463	0.963	0.954
A−F	0.453	0.384	−0.200	−0.443	0.200	0.120	0.653	0.463	...	...	0.833	0.699
A−E + A−F	0.418	0.408	−0.366	−0.553	0.118	0.182	0.963	0.954	0.833	0.699	...	...
G + F−E	0.620	0.579	−0.584	−0.821	0.519	0.585	0.595	0.687	0.351	0.309	0.559	0.652
X−D	0.844	0.737	−0.185	−0.688	0.859	0.793	0.261	0.412	0.308	0.257	0.301	0.421
Integrator Measurements[d]												
A	...	...	0.103	−0.327	0.941	0.930	0.342	0.344	0.423	0.364	0.400	0.407
B	0.181	−0.265	...	...	0.260	−0.270	−0.317	−0.466	−0.215	−0.461	−0.308	−0.518
C	0.898	0.803	0.343	0.195	0.966	0.867	0.003	−0.038	0.105	−0.140	0.040	−0.062
D	0.635	0.179	0.657	0.774	0.712	0.210	−0.191	−0.412	0.001	−0.340	−0.139	−0.430
E	0.801	0.691	0.315	0.051	0.914	0.789	−0.178	−0.278	0.001	−0.070	−0.129	−0.234
F	0.958	0.936	0.207	−0.183	0.977	0.958	0.155	0.204	0.211	0.090	0.188	0.204
G	0.671	0.603	−0.421	−0.824	0.683	0.659	0.172	0.381	0.253	0.335	0.216	0.416
H	0.505	0.547	−0.511	−0.796	0.498	0.587	0.169	0.376	0.319	0.351	0.237	0.413
X	0.952	0.932	0.197	−0.291	...	...	0.099	0.160	0.202	0.144	0.145	0.185
A−E	0.226	0.202	−0.359	−0.440	−0.043	0.003	...	...	0.655	0.507	0.835	0.776
A−F	0.474	0.440	−0.313	−0.490	0.214	0.204	0.751	0.481	...	...	0.857	0.671
A−E + A−F	0.304	0.287	−0.426	−0.548	0.041	0.058	0.801	0.735	0.684	0.684	...	...
G + F−E	0.612	0.530	−0.518	−0.821	0.518	0.526	0.485	0.598	0.416	0.372	0.502	0.599
X−D	0.870	0.752	−0.160	−0.724	0.874	0.785	0.256	0.389	0.271	0.333	0.284	0.424

[a]Based on 74 flours.

[b]Corresponding to conventional mixogram characteristics.

[c]Corrected (C) or Fixed (F) absorption.

[d]See Table I.

As measurements from development curves and digital records of energy used to mix the dough are highly correlated, it is possible to make full use of computer techniques to store and analyze dough development characteristics. Where quality evaluation is required on a large number of samples, these techniques present a means of increasing testing efficiency and precision and simplifying the maintenance of records.

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