An Electronic Recording Dough Mixer. V. Measurement of Energy Used in a Mixograph-Type Mixer[1]

PETER W. VOISEY, H. MILLER[2], and M. KLOEK, Ottawa Research Station, Research Branch, Canada Department of Agriculture, Ottawa, Canada

ABSTRACT

A new method of recording the torque to mix doughs in a mixograph is demonstrated with two types of flour. An electronic integrator is used to record the energy used to mix the dough, in digital form. The method is a useful technique which may allow rapid evaluation of dough development during mixing.

Dough mixers which record the mixing torque, in analog form on a strip-chart, are used to evaluate flours (AACC Methods 54–20, 54–21, and 55–40), and to study mechanical breadmaking methods (1,2). Recorders used in laboratory mixers are mechanical (3,4,5) and can be inaccurate and difficult to standardize (6). Wattmeters also are used to measure torque (4,5,7,8), by recording power input to the motor. In mechanical dough development methods (9,10) the energy used to mix the dough, as determined by a wattmeter (11), controls the commercial process. The wattmeter method, however, also can be inaccurate, especially on a micro scale, because the efficiency of the motor varies. The authors have described modified recording mixers which record the torque electronically (12,13,14). This principle can be adapted to other mixers such as the farinograph (15).

A recording mixer has many applications, ranging from testing plant breeders' samples to evaluating the development of dough to be processed in the newest bakery production methods. The cereal chemist thus can be called upon to test large numbers of samples. A quick, efficient method is indicated for this purpose, with the use of electronic integration (14). The purpose here is to demonstrate the use of a digital integrator to record the development of flour doughs during mixing.

The performances of three recording methods are compared, with the use of a mixer to evaluate two types of flour. The three recording methods are: mechanical analog, electronic analog, and electronic integration.

The following listing is given to clarify the nomenclature herein.

Nomenclature

cm.g.	Mixing torque in centimeter grams.
Mg	Mixing torque in meter grams.
MKg	Energy used in mixing, meter kilograms.
cm.g sec.	Dimensions of a unit area under a development curve, torque × time, or centimeter-gram seconds.
Mg min.	Dimensions of a unit area under a development curve, torque × time, in meter-gram minutes.

[1]Contribution No. 103 from Engineering Research Service, and No. 176 from Ottawa Research Station. Research Branch, Canada Department of Agriculture, Ottawa, Canada.
[2]Head, Wheat Quality Laboratory, Ottawa Research Station.

a and b	Constants.
A	Maximum torque during mixing (Mg).
B	Time to reach maximum mixing torque (min.).
C	Mixing torque after 7.5 min. (Mg).
D	Area under development curve converted to units of energy (MKg).
EA	Recording the mixing torque on a strip-chart by electronic methods.
EI	Recording energy used to mix doughs by electronic integration.
E_R	Rate that energy is used to mix the dough.
E_S	Energy used to mix the dough at some time in the mixing cycle.
E_T	Energy used to mix the dough in a complete mixing cycle.
MA	Recording mixing torque on a strip-chart by mechanical methods.
N	Number of counts recorded by an electronic integrator.
R	Recorder pen deflection or chart reading in chart units.
T	Mixing torque in meter grams.
t	Mixing time, sec.

MATERIALS AND METHODS

Description of Apparatus

Electronic recording dough mixers were described previously, where the torque required to mix the dough was detected by a strain-gage transducer whose output was amplified and recorded (12,13). Modification of a National Mixograph to record both mechanically and electronically was noted (13). For this experiment, the same mixograph was installed in a cabinet maintained at 30° ± 0.5°C. and arranged to record mixing torque by three methods: 1) the original MA system (i.e., a National Mixograph); 2) EA with a strain-gage torque transducer, an amplifier, and a potentiometer-type recorder, whose full-scale response time was 3.0 sec. (Fig. 1, A); and 3) with the same transducer and amplifier and a digital integrator (Fig. 1, B). The MA and EA recording systems were calibrated and operated by the techniques noted previously (12,13).

The digital integrator *F* (Fig. 1, B) converts the analog input to a constant amplitude signal whose frequency is proportional to the input amplitude. An electronic counter totals the number of cycles in the frequency-modulated signal. The number of cycles or counts accumulated is proportional to the integral of the input-time relationship, in this case torque time, or the energy used to mix the dough. The digital output of the integrator is recorded by a digital printer *G* (Fig. 1, B) and on a paper tape punch *H,* which enters the data into a computer for analysis. Thus the area under the development curve is recorded directly in digital form.

The integrator automatically records the number of counts accumulated after every 10 sec. of mixing, together with the accumulated total from the start of mixing. Alternatively, integration can be continued uninterrupted throughout the mixing cycle. Thus the rate at which energy is used (E_R),

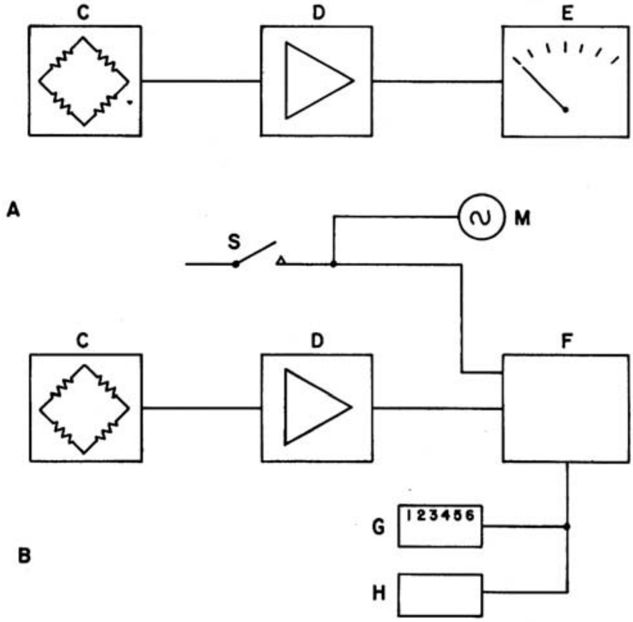


Fig. 1. A, electronic-analog recording system: C, strain-gage torque transducer; D, amplifier (Model 300CF-80, Daytronic Inc., Dayton, Ohio); E, potentiometer-type recorder 10-mV, 3.0-sec. full-scale response: B, electronic-integration recording system: F, digital integrator (Model CRS10X, Infotronics Inc., Houston, Texas); G, six-digit totalizing printer; H, tape punch; S, starting switch for integrator and mixing motor *M*.

the amount of energy used up to any 10-sec. increment in the mixing cycle (E_S), or the total energy used during a complete mixing cycle (E_T), can be recorded.

The integrator is calibrated by first adjusting the amplifier so that zero torque on the transducer produces zero counts. The maximum torque is then applied to the transducer by a gravity weight, and the sensitivity of the amplifier is adjusted until this torque produces 1×10^6 counts in 10 sec. The torque on the transducer is then raised from zero to the maximum in 10% increments. The number of counts in 10 sec. is noted at each torque level. The integrator is operated by adjusting the amplifier zero control until the integrator indicates zero input. The sample is then placed in the mixer and a switch *S* (Fig. 1, B) starts the integrator and mixing motor, which are switched off at the end of mixing by a timer.

Calibration and Interpretation of Data

Each recording system was calibrated, and curves of torque *vs.* recorder output were plotted in the increasing and decreasing directions (Fig. 2). These calibrations were checked periodically during the experiment and used to convert data to units of torque and energy. The best straight line was drawn for each calibration. The following conversion factors were noted: (a) the MA recording system chart reading (R) was related to the torque (T) at the bowl, by the equation $T = 5.0 + 9.2\ R$; the maximum deviation of ± 5.0% from this relationship occurred at midscale (Fig. 2, A); (b) similarly for the EA recording system, T = 10.0 R, the maximum deviation was ± 0.5% again at midscale (Fig. 2, B); (c) for the integrator 1×10^6 counts = 100 Mg torque applied for 10 sec. with a maximum deviation of ± 0.5% (Fig. 2, C).

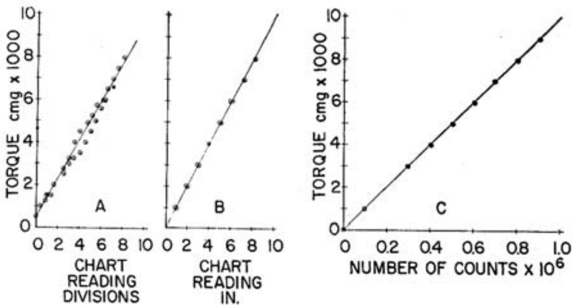


Fig. 2. Calibration curves. A, mechanical-analog recorder (National Mixograph); B, electronic-analog recorder; C, digital integrator. Points are shown for torque applied in the increasing and decreasing directions.

The analog records (MA and EA) were analyzed by drawing a curve at the estimated mean torque (13) and noting the maximum torque (A), the time to reach the maximum torque (B), torque after 7.5 min. of mixing (C), and the energy used in mixing (D) (from the area under the mean curve measured by a planimeter). To convert area in sq. in. to units of energy, taking into account the speed of the mixer (90 r.p.m.), factors were determined as follows by multiplying the area in Mg min. by $2\pi 90$: (a) MA records, 8.32 in.^{2} = 51 Mg torque for 5 min. (measured empirically), therefore, 1.0 in.^{2} = 30.7 Mg min., or 1.0 in.^{2} = 17.363 MKg; (b) EA records, torque axis 1.0 in. = 10.0 Mg; time axis 1.0 in. = 1 min. or 1.0 in.^{2} = 10 Mg min.; therefore, 1.0 in.^{2} = 5.656 MKg; (c) for the integrator (EI), 1×10^6 counts = 100×10 Mg sec. or 1 count = $16.667/10^6$ Mg min.; therefore, 1 count = $9.428/10^6$ MKg; and if the number of counts in 10 sec. is N, the rate that energy is used is $56.568/10^6$ N–MKg/min.

Experimental Evaluation of the Integration Method

For a simple comparison, commercial bread and cookie flours were blended in different proportions. The 11 blends were arbitrarily graded

TABLE I

FLOUR BLENDS TESTED

FLOUR	GRADE [a]										
	0	1	2	3	4	5	6	7	8	9	10
	%	%	%	%	%	%	%	%	%	%	%
Soft	100	90	80	70	60	50	40	30	20	10	0
Hard	0	10	20	30	40	50	60	70	80	90	100

[a] Assigned arbitrarily.

0 to 10 (Table I). Moisture absorption of each grade was determined by standard procedures and samples corrected to 14% m.b. One mixing bowl was used for all samples.

Experiment 1. To compare the results from MA, EA, and EI recording methods, three samples of each grade (0 to 10) were tested, using: (a) MA, (b) EA, and (c) EI recording E_T, in a 7.5-min. mixing test.

Experiment 2. To compare the variation of results within a grade of flour from MA, EA, and EI recording methods, 10 samples of grades 0 and 10 were tested; the same recording methods were used as in experiment 1.

Experiment 3. To establish the relation between the rate that energy was used, total energy used in mixing, and flour grade, three samples of each grade (0 to 10) were tested, using EI and recording E_R and E_S every 10 sec. for 7.5 min.

Experiment 4. To determine the variation in the rate that energy was used, and the energy used in mixing within a grade of flour, 10 samples of grades 0 and 10 were tested, using EI and recording E_R and E_S every 10 sec. for 7.5 min.

RESULTS

Typical MA and EA records for three flour grades are shown for comparison (Fig. 3).

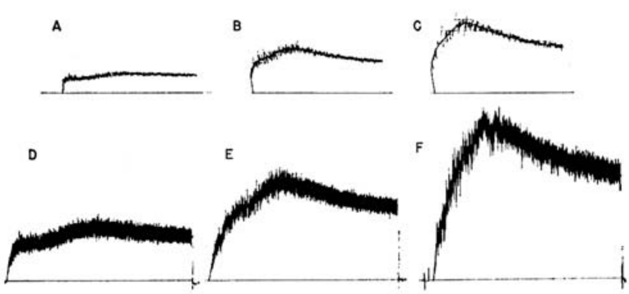


Fig. 3. Typical analog development curves. A, grade 0—MA; B, grade 5—MA; C, grade 10—MA; D, grade 0—EA; E, grade 5—EA; F, grade 10—EA.

Experiment 1

Results from three samples of each grade indicate that the measurements from analog records (A, C, and D) and the total energy used in mixing from the integrator (E_T) are linearly related to flour grade (Fig. 4). The small differences between the MA and EA results are assumed to be caused by errors in interpreting the analog records and the nonlinear calibration of the MA recorder. The time to reach the peak torque (B) is also related to grade (Fig. 5), but the relationship is not linear. Several grades have the same arrival time, indicating that this measurement is not reliable, as noted previously (13). Torque and energy measurements (A, C, D, and E_T) increased with increasing flour grade, and the time to reach maximum torque (B) decreased.

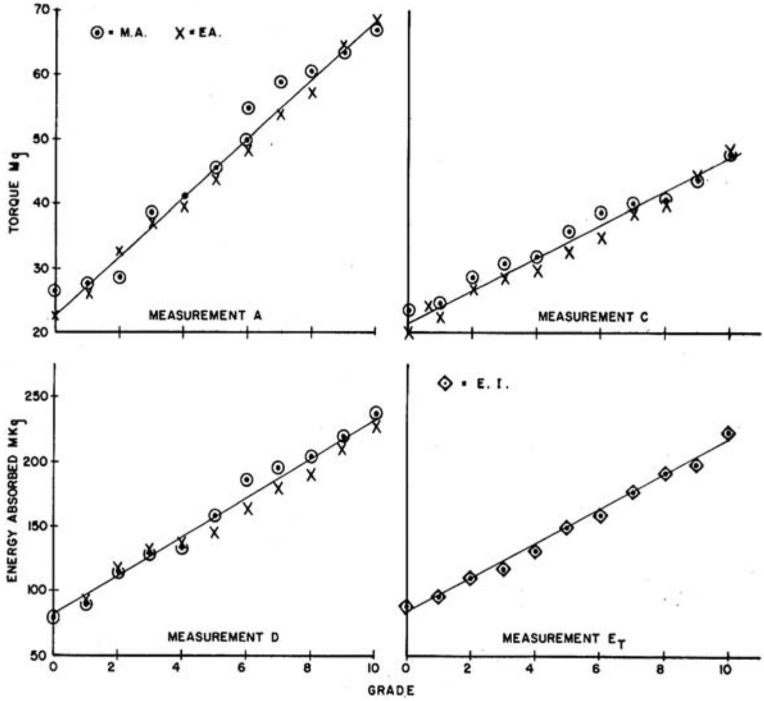


Fig. 4. Measurements (see text) from development curves recorded mechanically, electronically, and by integration for 11 grades of flour. Each point is the mean of three samples.

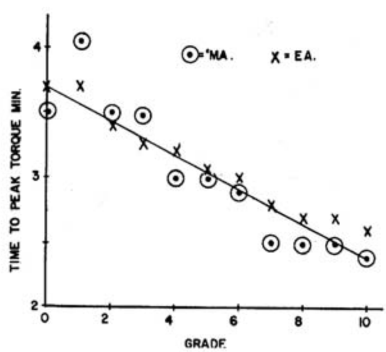


Fig. 5. Time to reach maximum torque during mixing, recorded by two analog methods (EA and MA), for 11 grades of flour. Each point is the mean of three samples.

Experiment 2

Results from 10 samples of grades 0 and 10 (Table II) show that the torque and time measurements (A, B, and C) from the two analog recording methods are comparable, except that the MA measurements, compared to the EA measurements, tend to be high for grade 0 and low for grade 10. The energy measurements from the analog curves (D) and the integrator (E_T) are comparable except for grade 0; E_T is 19% higher than D. The differences between these measurements may be caused by interpretation of the analog curves, differences in frequency response of the MA, EA, and EI recorders (12,13), and the nonlinear calibration line of the MA recorder. Energy used in mixing determined by electronic integration (E_T) has the least variation between samples of all measurements and is half the variation observed in the MA and EA results. Variation of MA and EA results are of the same order.

TABLE II

COMPARISON OF MEASUREMENTS FROM TEN DEVELOPMENT CURVES; THREE RECORDING METHODS USED, FOR TWO GRADES OF FLOUR

		Soft Flour (Grade 0)			Hard Flour (Grade 10)		
Recording Method[a]	Measurement[a]	Mean	Std. Dev.[b]	Coeff. of Variation	Mean	Std. Dev.[b]	Coeff. of Variation
MA	A	24.67	± 1.45	5.88	59.23	± 2.58	4.36
	B	3.92	± 0.45	11.50	2.40	± 0.12	4.79
	C	22.39	± 0.23	1.01	43.78	± 1.44	3.29
	D	78.48	± 6.64	8.46	214.33	± 8.34	3.89
EA	A	21.25	± 1.43	6.73	68.36	± 4.21	6.16
	B	3.74	± 0.30	8.11	2.66	± 0.11	4.06
	C	19.08	± 0.56	2.91	47.39	± 2.04	4.30
	D	78.76	± 4.01	5.09	227.20	± 10.59	4.66
EI	E_T	93.13	± 3.08	3.31	218.81	± 5.14	2.35

[a] See text.
[b] 9 Degrees of freedom.

Experiment 3

EI results for three samples of each grade are shown as the rate that energy is used (E_R) (Fig. 6) and energy used in mixing (E_S) (Fig. 7) during the 7.5-min. mixing cycle. The two families of curves show the relation between these measurements and flour grade. The two measurements grade the flours in ascending order 0 to 10, except that some reversals occur early in the mixing cycle. The time to reach maximum rate of energy used in mixing is related to flour grade (Fig. 8). In several grades, however, E_R is a maximum after the same mixing time, indicating that the time to peak energy rate is not a reliable measurement.

Simple correlation coefficients and regression equations were calculated for the relationships between grade E_R and E_S at 10-sec. intervals throughout the 7.5-min. mixing cycle (Table III). E_R and E_S were highly correlated with flour grade after 20 sec. of mixing when coefficients of 0.960 and 0.939 were obtained for E_R and E_S respectively. The coefficients increased as mixing progressed but were practically constant after 60 sec. Regressions of the form $Y = a + bx$ show the relationships between grade and energy measurements throughout the mixing cycle. The equations do not pass through zero, a being initially positive and finally negative for E_S and negative between 100 and 210 sec. for E_R.

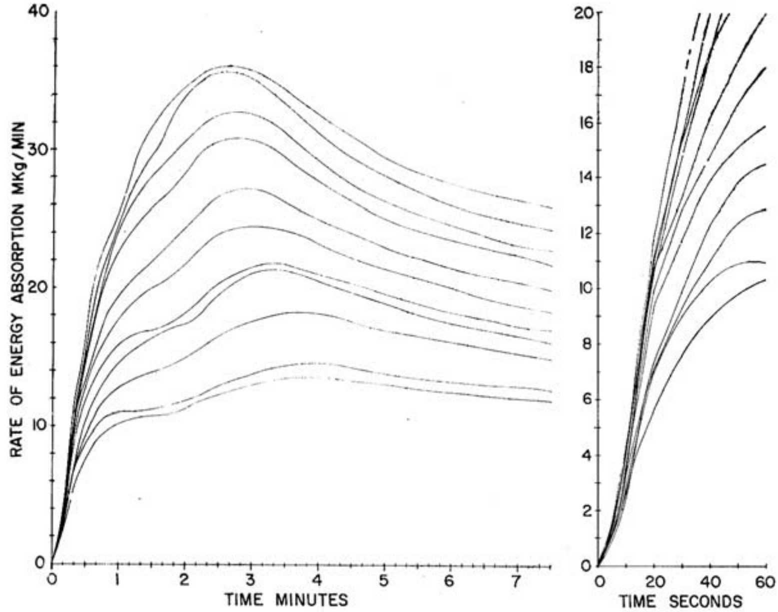


Fig. 6. Rate at which energy is used (E_R), recorded by EI for 11 grades of flour. Bottom curve grade 0 to top curve grade 10. Each curve is the mean of three samples. The first 60 sec. is shown at the right on an enlarged scale.

The maximum rate that energy is used (E_R) is related to flour grade and the relationship is linear (Fig. 9). Similarly, E_R maximum is linearly related to the value of E_S at the end of the 7.5-min. mixing cycle (Fig. 10).

The mean values of E_R and E_S of the 11 grades tested were calculated at 10-sec. intervals to establish a general relationship between these measurements and time. The rate of energy curve increases to a maximum and then gradually decreases (Fig. 11). This is similar to the mean line estimated on a conventional development curve. The energy used in mixing increases almost linearly throughout the mixing process (Fig. 11). The maximum nonlinearity occurs at the start of mixing. The standard deviation of these mean values of E_R and E_S is a measure of dispersion between grades and indicates the resolution possible with the measurements. The resolution of E_S increases throughout the mixing cycle, but E_R has a maximum resolution at 150 sec. of mixing (Fig. 11).

Experiment 4

The mean values of E_R and E_3 during mixing and the coefficient of variation for 10 samples of grades 0 and 10 (Fig. 12) indicate that variation between samples of the same grade is higher for grade 0 than for grade 10. The variation between samples decreases rapidly in the first 50 sec., after which the variation is relatively constant.

Comparison of E_S, E_T, and D

The energy during mixing, recorded by three methods, is compared for the 11 grades tested (Table IV). At the end of the mixing cycle, E_S should

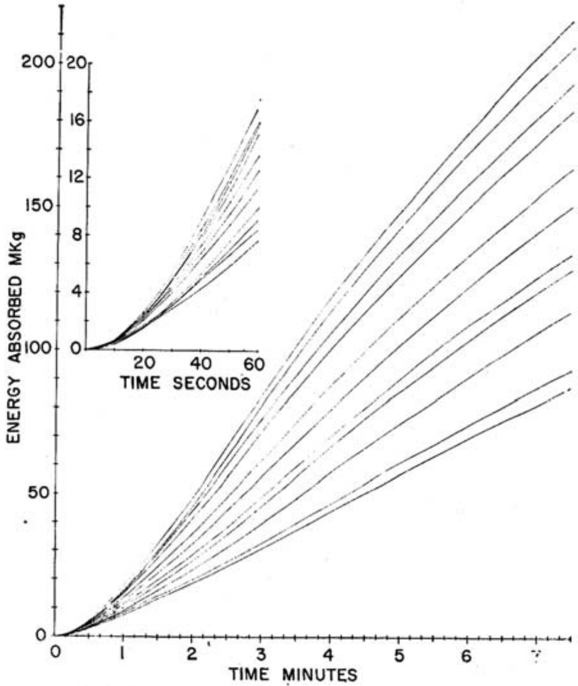


Fig. 7. Energy used during mixing (E_S) recorded by EI for 11 grades of flour. Bottom curve grade 0 to top curve grade 10. Each curve is the mean of three samples. The first 60 sec. is shown at the left on an enlarged scale.

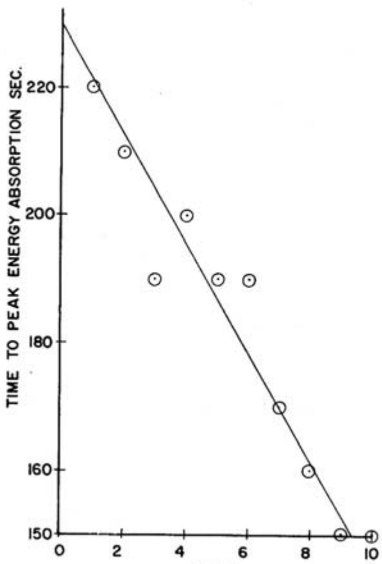


Fig. 8. Time to reach maximum rate of energy to mix the dough (E_R) *vs.* flour grade. Mean of three samples.

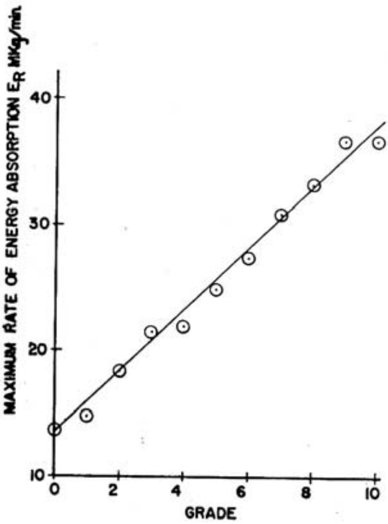
TABLE III

CORRELATION COEFFICIENTS FOR ENERGY USED AND RATE AT WHICH ENERGY IS USED ON FLOUR GRADE AND REGRESSION COEFFICIENTS OF THE FORM Y = a + bx AT 10-SECOND INTERVALS[a]

Mixing Time	Rate of Energy Used, E_R			Total Energy Used, E_S		
	Corr. Coeff.	a	b	Corr. Coeff.	a	b
10	0.792	+ 4.948	0.015	0.724	+ 4.999	0.002
20	.960	+ 4.456	.059	.939	+ 4.977	0.011
30	.991	+ 3.836	.092	.973	+ 4.891	0.026
40	.984	+ 3.105	.125	.984	+ 4.678	0.048
50	.992	+ 2.558	.145	.990	+ 4.314	0.072
60	.991	+ 1.912	.170	.992	+ 3.744	0.100
70	.991	+ 1.309	.192	.991	+ 2.960	0.129
80	.995	+ 0.766	.212	.995	+ 1.812	0.167
90	.994	+ 0.602	.215	.995	+ 0.433	0.203
100	.994	− 0.014	.237	.995	− 1.324	0.243
110	.993	− 0.283	.242	.996	− 3.433	0.284
120	.993	− 0.635	.251	.996	− 5.857	0.325
130	.992	− 1.097	.262	.995	− 8.758	0.369
140	.994	− 1.265	.262	.995	− 12.044	0.413
150	.995	− 1.394	.264	.995	− 15.704	0.457
160	.994	− 1.330	.257	.995	− 19.707	0.500
170	.993	− 1.145	.249	.996	− 23.958	0.541
180	.994	− 1.007	.243	.996	− 28.550	0.582
190	.994	− 0.865	.236	.996	− 33.370	0.621
200	.995	− 0.574	.227	.996	− 38.414	0.659
210	.995	− 0.285	.217	.996	− 43.611	0.695
220	.996	+ 0.005	.208	.996	− 48.981	0.730
230	.995	+ 0.241	.201	.996	− 54.510	0.764
240	.996	+ 0.488	.193	.996	− 60.105	0.796
250	.995	+ 0.698	.187	.996	− 65.815	0.827
260	.996	+ 0.841	.183	.996	− 71.720	0.858
270	.997	+ 1.074	.176	.996	− 77.611	0.887
280	.997	+ 1.141	.175	.996	− 83.775	0.917
290	.996	+ 1.293	.170	.997	− 89.920	0.945
300	.996	+ 1.419	.167	.997	− 96.210	0.973
310	.996	+ 1.543	.163	.997	− 102.632	1.001
320	.997	+ 1.572	.163	.997	− 109.057	1.027
330	.997	+ 1.747	.157	.997	− 115.696	1.054
340	.997	+ 1.816	.155	.997	− 122.371	1.080
350	.996	+ 1.891	.153	.997	− 129.062	1.105
360	.997	+ 1.962	.151	.997	− 135.884	1.130
370	.997	+ 2.029	.149	.997	− 142.839	1.155
380	.997	+ 2.092	.147	.997	− 149.929	1.180
390	.997	+ 2.164	.145	.997	− 157.005	1.204
400	.998	+ 2.185	.145	.997	− 164.205	1.228
410	.997	+ 2.226	.144	.997	− 171.673	1.253
420	.998	+ 2.290	.142	.997	− 178.975	1.276
430	.998	+ 2.327	.141	.997	− 186.543	1.300
440	.997	+ 2.382	.139	.997	− 194.119	1.324
450	0.998	+ 2.404	0.139	0.997	− 206.771	1.347

[a] Using the equation: Grade = a + bE_R or using the equation: Grade = a + bE_S.

equal E_T. This is not indicated in the results, since E_S differs from E_T by − 2 to + 10%. However, as the comparison is made between two separate experiments, it includes the combined variation between experiments and between samples. If it is assumed that E_T is a precise measurement of



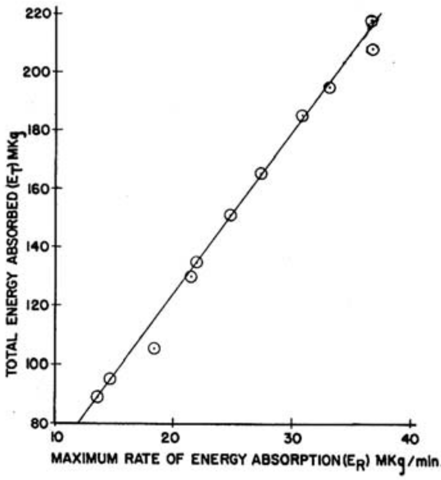


Fig. 9 (left). Maximum rate of energy to mix the dough (E_R) *vs.* flour grade. Mean of three samples.

Fig. 10 (right). Maximum rate of energy to mix the dough (E_R) *vs.* total energy used (E_S) in 7.5 min. of mixing. Mean of three samples of each of 11 grades.

energy used in mixing, then D recorded by MA has errors ranging from − 9 to + 18%. Similarly, D recorded by EA has a smaller error range of − 7 to + 6%. The difference between D from MA and D from EA ranges

TABLE IV

COMPARISON OF ENERGY USED DURING 7.5 MINUTES OF MIXING RECORDED IN MKg BY THREE METHODS

Flour Grade[a]	Measurement: Recorder EI[b]			Measurement: Recorder MA[b]		Measurement: Recorder EA[b]		Measurement: Recorders MA and EA[b]
	Exp. 1 E_T	Exp. 3 E_S	Difference[c]	Exp. 1 D	Error[d]	Exp. 1 D	Error[d]	Exp. 1 Difference[e]
			%		%		%	%
0	87.3	88.8	+ 1.72	79.0	− 9.51	81.1	− 7.10	− 2.59
1	95.8	94.7	− 1.15	87.9	− 8.25	94.0	− 1.88	− 6.49
2	110.2	115.3	+ 4.63	114.3	+ 3.72	115.9	+ 5.17	− 1.38
3	117.9	129.9	+ 10.18	128.8	+ 9.25	126.3	+ 7.12	+ 1.98
4	132.4	135.2	+ 2.11	133.8	+ 1.06	135.7	+ 2.49	− 1.40
5	148.9	152.1	+ 2.15	157.5	+ 5.78	144.3	− 3.09	+ 9.15
6	157.5	165.5	+ 5.08	185.8	+ 17.97	161.3	+ 2.41	+ 15.19
7	176.6	185.2	+ 4.87	195.1	+ 10.48	179.3	+ 1.53	+ 8.81
8	192.4	195.2	+ 1.46	205.2	+ 6.65	188.8	− 1.87	+ 8.69
9	198.1	208.5	+ 5.25	220.5	+ 11.31	209.9	+ 5.96	+ 5.05
10	223.3	218.1	− 2.33	236.8	+ 6.05	226.1	+ 1.25	+ 4.73

[a] See text.
[b] Mean of three samples: See text.
[c] Percent difference = $((E_S - E_T)\,100)/E_T$.
[d] Percent error = $((D - E_T)\,100)/E_T$.
[e] Percent difference = ((MA — EA) 100)/EA.

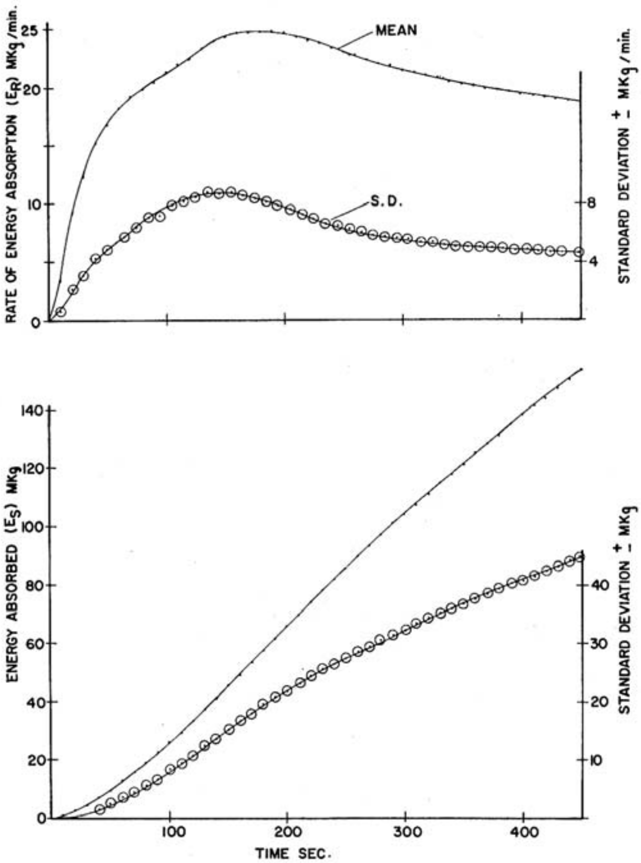


Fig. 11. Mean values and standard deviations of E_R and E_S for 11 grades of flour at 10-sec. intervals throughout mixing cycle. In each case the lower curve is the standard deviation.

from – 2 to + 15%, which indicates the effect of curve interpretation and the inaccuracy of the MA system.

DISCUSSION

The new method demonstrated, for evaluating dough development during mixing, has several advantages. The data are recorded in digital form and can be processed directly by a computer. The relation between energy measurements and dough development characteristics is similar to that of measurements from conventional analog records. Energy measurements are less variable, and the minimum variation between samples is achieved early in the mixing cycle.

In recording the rate that energy is used to mix doughs, a development curve consisting of a single line is obtained, which is easier to interpret than conventional development curves. The energy used to mix doughs is almost

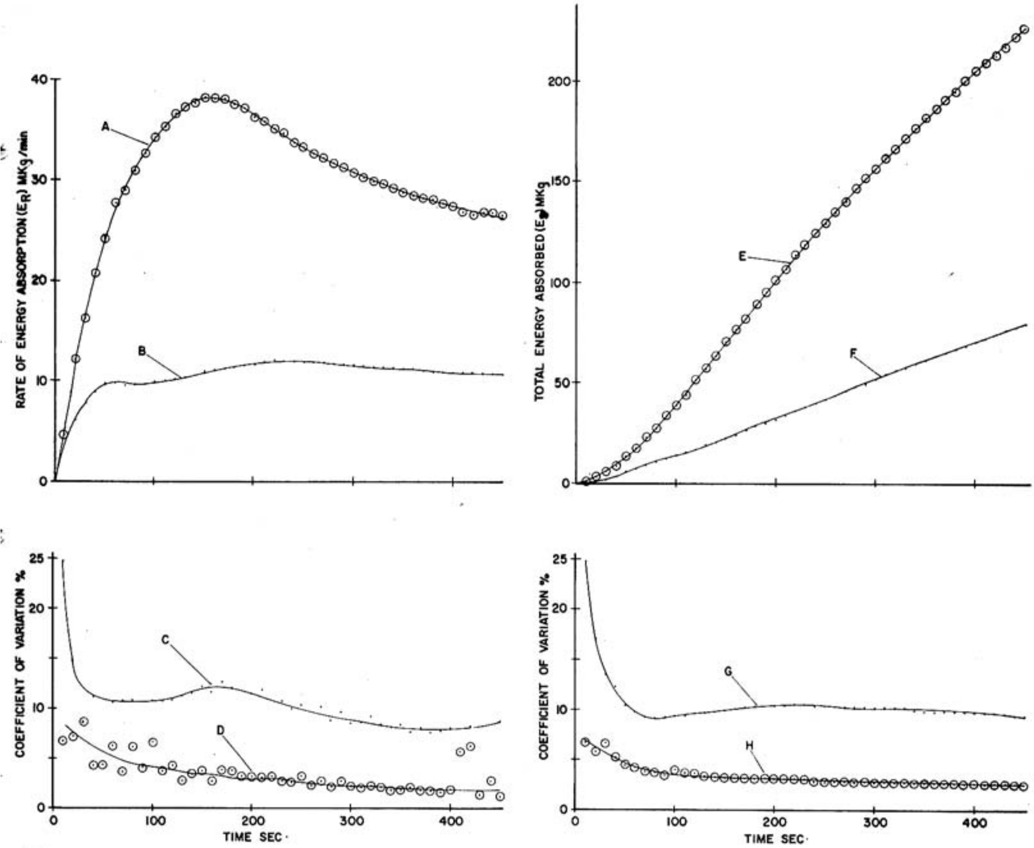


Fig. 12. A, E_R *vs.* time, mean of 10 samples of grade 10; B, the same for grade 0; C, coefficient of variation of E_R for grade 0, and D, for grade 10; E, E_s *vs.* time, mean of 10 samples of grade 10; F, the same for grade 0; G, coefficient of variation of E_S for grade 0, and H, for grade 10.

linearly related to mixing time. This may be a useful characteristic for prediction purposes.

Literature Cited

1. BUSHUK, W., KILBORN, R. H., and IRVINE, G. N. Studies on continuous-type bread using a laboratory mixer. Cereal Sci. Today **10**: 402–405 (1965).
2. CHAMBERLAIN, N., COLLINS, T. H., and ELTON, G. A. H. The Chorleywood bread process. Baker's Dig. Oct. (1962).
3. SHOGREN, M. D., and SHELLENBERGER, J. A. The design, construction, and use of micro baking equipment. Cereal Chem. **31**: 475–482 (1954).
4. SWANSON, C. O., and WORKING, E. B. Mechanical modification of dough to make it possible to bake bread with only the fermentation in the pan. Cereal Chem. **3**: 65–83 (1926).
5. SWANSON, C. O., and WORKING, E. B. Testing the quality of flour by the recording dough mixer. Cereal Chem. **10**: 1–29 (1933).
6. HEIZER, H. K., MOSER, L., BODE, C. E., YAMAZAKI, W. T., and KISSELL, L. T. Studies concerning mixograph standardization. Trans. Am. Assoc. Cereal Chemists **9**: 16–25 (1951).

7. ANDERSON, R. A., and LANCASTER, E. B. Recording apparatus for measuring some mixing characteristics of flour-water batters. Cereal Chem. **34**: 379–388 (1957).

8. KILBORN, R. H., and DEMPSTER, C. J. Power-input meter for laboratory dough mixers. Cereal Chem. **42**: 432–435 (1965).

9. AXFORD, D. W. E., and ELTON, G. A. H. The mechanical development of bread doughs. Chem. Ind. (London) **41**: 1257–1258 (1960).

10. ELTON, G. A. H. Mechanical dough development. Proc. Roy. Australian Chem. Inst. **32**: 25–31 (1965).

11. CHAMBERLAIN, N., COLLINS, T. H., ELTON, G. A. H., and CORNFORD, S. J. The Chorleywood bread process; commercial applications. 3. Methods of measuring work. British Baking Industry Res. Assoc., Rept. 62 (1962).

12. VOISEY, P. W., MILLER, H., and KLOEK, M. An electronic recording dough mixer. I. The apparatus. Cereal Chem. **43**: 408–419 (1966).

13. VOISEY, P. W., MILLER, H., and KLOEK, M. An electronic recording dough mixer. II. An experimental evaluation. Cereal Chem. **43**: 420–432 (1966).

14. VOISEY, P. W., MILLER, H., and KLOEK, M. An electronic recording dough mixer. III. Additional methods of recording. Cereal Chem. **43**: 433–437 (1966).

15. VOISEY, P. W., MILLER, H., and KLOEK, M. An electronic recording dough mixer. IV. Applications in farinography. Cereal Chem. **43**: 438–446 (1966).

[Received July 8, 1966. Accepted February 28, 1967]