Factors Affecting Mechanical Dough Development. III. Mechanical Efficiency of Laboratory Dough Mixers[1,2]

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ABSTRACT

The "mechanical efficiency" (a measure of the energy available to the dough during mixing) of various laboratory mixers was determined using an electric clutch to apply the torque which was measured by a strain gage. The mixers studied included the GRL experimental mixer, the GRL pin mixer, the National Mixograph, and the Hobart-McDuffy mixer. The mechanical efficiency varied with the load on the mixer, but the overall range for the four mixers studied was 40 to 80%. The highest values were for the experimental mixer, and the lowest for the GRL pin mixer which has a more complex drive mechanism. After correction of gross energy measurements for mechanical efficiency, discrepancies between net work-input figures (when mixing to peak dough consistency as indicated by mixing curves) could then be attributed to differences in mixing efficiency, which relates to the portion of the energy available to the dough that contributes to mechanical development. The GRL pin mixer, while having a low mechanical efficiency, was found to have a high mixing efficiency. Mixing efficiency was also affected by dough temperature.

In short baking processes, such as the Chorleywood Bread Process (1), that rely on high-speed mixing to achieve mechanical dough development, the energy imparted to the dough must be greater than a minimum critical amount dependent on the flour used (2). One way of determining the work expended in mixing a dough is to measure the electrical energy consumed by the mixer motor. A watt-hour meter, after zeroing out the energy used by the mixer running empty, will give a reading in watt-hours that can be divided by dough weight to give a value in watt-hours per pound. A recorder linked by a transducer to the mixer motor can be used to produce a mixing curve showing peak dough consistency.

Studies carried out in this Laboratory have indicated discrepancies in energy requirements for the same flour in different mixers (2). Possible reasons for such discrepancies were investigated and a study was made of the relative mechanical efficiencies of several laboratory dough mixers. In this context, "mechanical efficiency" relates to the portion of the total energy consumed by the mixer motor during mixing that is available to the dough in the form of mechanical work. This is in contrast to "mixing efficiency", which refers to the portion of the energy available to the dough that actually contributes to mechanical development. Figure 1 shows a simplified diagram of the relation between "mechanical efficiency" and "mixing efficiency".

This paper describes the methods used to determine mechanical efficiency of four laboratory mixers: the GRL experimental mixer (3), the GRL pin mixer (4), the National Mixograph, and the Hobart-McDuffy mixer. Mixing efficiencies of the four mixers were compared using data obtained from a mixing study carried out on

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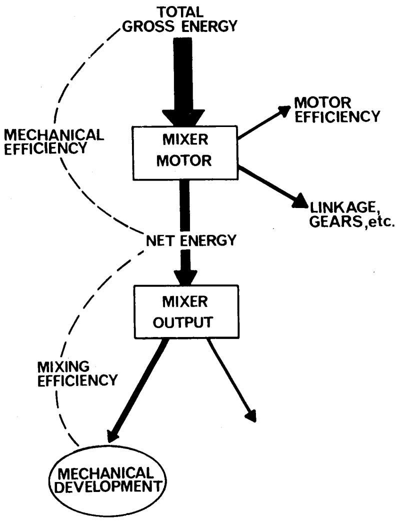


Fig. 1. Diagram showing relation between the terms "mechanical efficiency" and "mixing efficiency" as used in this paper.

a series of flours of widely differing mixing characteristics, and the effect of dough temperature on mixing efficiency was also examined. Results obtained are discussed in relation to their significance in laboratory and commercial breadmaking practice.

MATERIALS

Equipment Used

1. An energy-input meter (5), with constant voltage supply of 118 volts provided by the voltage regulator, was used to measure the total energy consumed by the mixer motor (see Fig. 2). The pulse sensing and counting mechanism was modified to allow a resolution of 0.02 w-hr. A Bausch and Lomb VOM 5 Recorder was used to record a signal representing energy level.

2. The four mixers used in this study were: a modified Mixograph fitted with strain gage arm (6); experimental mixing unit (3); GRL pin mixers (4); and the Hobart mixer (Model C-100) with McDuffy attachment. A check-line Photo-Tak Tachometer, Model A30, was used to obtain shaft speeds. The technique used for linking the mixer to the measuring system, and shown in Fig. 2 as "mixer and spool" and "clutch and spool", is described in detail in the Experimental and Results section.

3. A Warner electric clutch, type EC-375, with a variable torque controller, was used to impart a braking action to the mixer output. An electrical impulse counter, energized by a micro switch, was used to count the revolutions of the shaft attached to the clutch.

4. The torque arm consisted of a stainless-steel strap, fitted with four strain gages in a bridge configuration (7), fastened to an extension arm of bar aluminum (see "A" in Fig. 4). The extension arm was fitted with a tray for holding weights, with the distance of the tray from the fulcrum determined so that weights placed

on the tray could be used for calibrating the torque arm. A strain gage amplifier, Daytronic type 93-300D, and a Hewlett Packard type 7035B, X-Y recorder, were used for recording torque.

Over each range of torque studied, response of the recording system was linear, and the resolution was sufficient to allow detection of changes in torque of less than 1% of full scale. Recorder full scale was adjusted by amplifying the strain gage signal according to the range in torque appropriate for a particular mixer. For example, much higher signal amplification was used for the mixograph where maximum practical levels of torque were only about one-tenth of those measured with the experimental mixer.

Flours

Mixing efficiencies were studied using 18 flours. Two were commercially milled, one from Ontario soft white winter (SWW) wheat and one from Canadian hard red spring (HRS) wheat. Fifteen flours were laboratory-milled: nine from Canadian HRS wheat grade composites; four from experimental varieties; one from U.S. hard red winter (HRW) wheat; and one from Ontario SWW wheat. One flour represented a blend of Ontario SWW and Canadian HRS wheat. Protein contents of the 18 flours ranged from 7.9 to 14.6%; farinograph peak development times ranged from 0.8 to 8.5 min. All mixing studies were carried out at farinograph absorptions (500 B.U. consistency) which ranged from 50 to 64%.

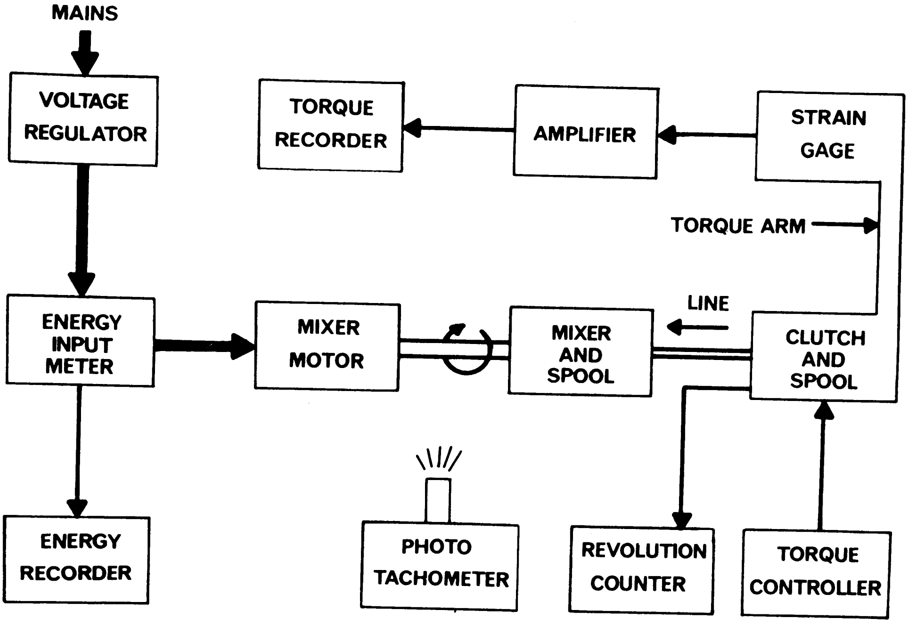


Fig. 2. Block diagram showing the relationship between the various components used in this study for measuring mechanical efficiency of dough mixers.

EXPERIMENTAL AND RESULTS

Measurement of Work at Mixer Output

Most dough mixers consist of (a) an electric motor; (b) a drive linkage generally including a gear system, belt or chain drive, bearings, etc.; (c) an output-shaft or shafts connected directly to the dough-mixing blade or pins, etc.; and (d) a container for the dough (mixing bowl). If a mixer is run with no dough at a fixed speed, a certain base level of electric energy is consumed by the motor. When a dough is mixed, the motor requires more electric energy to overcome the resistance offered by the dough to the movement of the blade or pins. This increased energy requirement is proportional both to the mass of dough and to the consistency of the dough. A stiffer dough will offer more resistance to mixing (e.g., both temperature and absorption significantly affect dough consistency), and any given dough will vary in consistency during mixing, depending on the stage of development. Normally, dough consistency increases during mixing to a maximum corresponding to peak dough development. While the energy to the motor required to operate the mixer running empty is zeroed out in making energy measurements, significant energy losses occur depending on the efficiency of the motor and of the mixer drive mechanism. These losses are generally proportional to load, provided the motor or mechanism is not overloaded.

Although it is relatively simple to measure the electric energy consumed by the mixer motor during mixing, it is more difficult to determine the net (output) energy available to the dough.

To determine the energy losses between the electrical input to the motor and the mechanical output to the dough, it was necessary to devise a means of loading the mixer with forces in the range normally encountered when mixing the dough, and to know precisely the loads applied in equivalent units of electric energy. A Warner electric clutch with revolution counter attached and a variable torque control provided a means of loading the mixer output. A torque arm attached to the clutch and fitted with strain gages provided an accurate means of measuring the work done. It was possible to attach the input shaft of the clutch directly to the output shaft of the Varidrive of the experimental mixing unit. However, with the mixograph there was no facility for attaching the clutch directly to the mixer output, and with the GRL pin mixer and the Hobart-McDuffy mixer, the final output does not have a fixed center of rotation. To overcome these problems, a "spool-and-line" system was devised.

The "Spool-and-Line" Technique

A torque loading adapter consisting of a plastic spool, 10.2 cm. in diam., was attached to the mixer head. Figure 3 shows a spool ("S") fitted to the mixing head of the mixograph. A similar spool ("C" in Fig. 4) was attached to the input shaft of the clutch which was mounted on a mandrel 2.5 m. from the mixer head. The shaft of the clutch was fastened to the torque sensing arm ("A" in Fig. 4). Nylon monofilament fishing line was wound onto the clutch spool and the free end was attached to the take-up spool on the mixer head. When the mixer was started, the line was wound up from the clutch spool to the take-up spool. The length of line used permitted runs of up to 4.5 min. The distance between the two spools eliminated errors that might have occurred with deviations from a direct 90° pull at the take-off spool. This was particularly important when working with the GRL pin

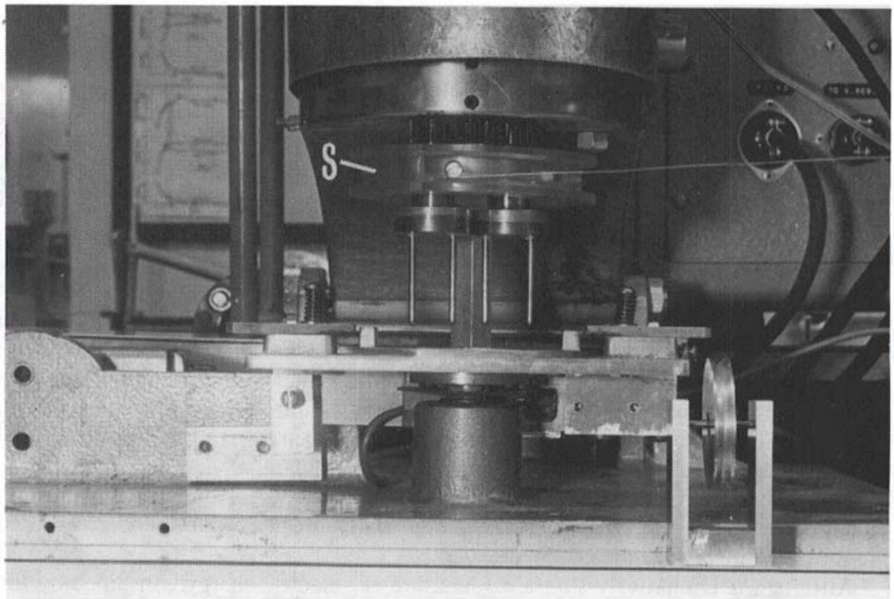


Fig. 3. Mixograph showing plastic spool (S) (torque loading adapter) attached to mixer head.

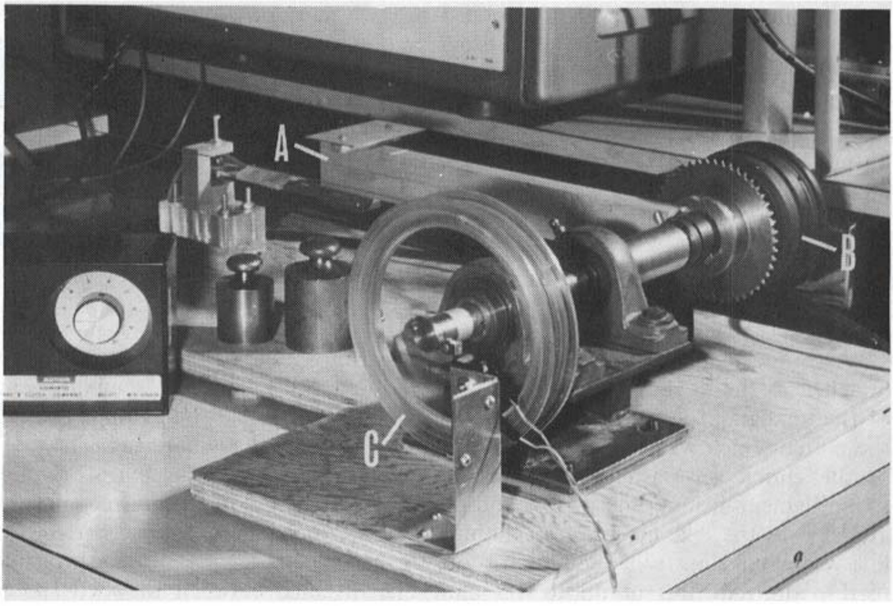


Fig. 4. Torque sensing arm (A) anchored to clutch (B) output shaft, with plastic spool (C) attached to input shaft of clutch.

mixer, where the planetary-gear drive caused the take-up spool to make a 3.5-cm. excursion at its axis when the mixer was running.

Procedure. The general procedure for determining mechanical efficiency by the line-and-spool technique was as follows:

1. The read-out on the torque recorder was calibrated by placing, on the torque arm, weights corresponding to the desired range of torque to be measured.
2. The free end of the line, wound on the clutch spool, was attached to the take-up spool. The mixer was started without energizing the clutch. The energy required to run the mixer and to wind the line onto the take-up spool was zeroed out on the energy input meter. At the same time, the deflection on the torque recorder (caused by the movement of the spool and clutch mechanism) was adjusted to zero. Figure 5 shows a typical trace obtained for the mixograph. A check was then made on the calibration with the mixer running. This agreed with the original static calibration of the torque recorder (step 1).
3. The clutch was energized, using the controller to produce a desired level of torque on the recorder (in Fig. 5 the level is 6 kg.cm.). When this level had been achieved, the pulse counter and interval timer on the energy meter and the clutch revolution counter were all reset to zero ("start" in Fig. 5).
4. Because there was a small change in the effective diameters of the two spools as line was wound from one to the other, and because some heating occurred in the clutch due to the friction produced, it was necessary to maintain the preselected torque level at the clutch by making a small continuous adjustment with the clutch controller.
5. The system was run in this way for as long a time as was practical with the length of line. The mixer was then switched off ("finish" in Fig. 5) and readings from the interval timer, pulse counter, and revolution counter were noted.
6. The operation was repeated at the same torque level as many times as was considered necessary to obtain reliable average data.

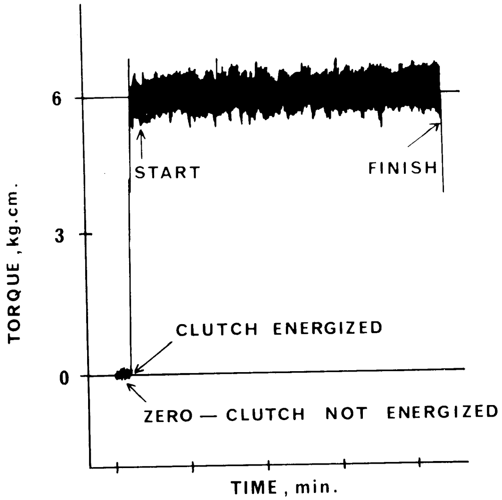


Fig. 5. Typical torque recorder trace from mixograph, using electric clutch.

7. The "energy in" was obtained from the pulse counter readout (12.2 pulses = 1 w-hr.).

8. The electrical equivalent of the energy expended at the clutch ("energy out") was calculated according to the following equation:

$$\frac{2\pi Tns}{36{,}700} = \text{Electrical equivalent, w-hr.} \qquad (1)$$

Where T = torque in kg.cm. (from torque recorder),
n = number of turns of the clutch during the time that the measurement was being made (from clutch revolution counter),
s = correction factor applied for stretching of line in spool-and-line technique (see below), and
36,700 = the equivalent in cm.kg. of 1 w-hr.

9. Mechanical efficiency was the "energy out" expressed as a percentage of the "energy in".

The method of measurement used was essentially a variation of the Prony brake system.

Spool-and-Line Correction Factor(s). The nylon monofilament line stretched when put under tension to an extent proportional to the amount of tension applied. This introduced a small source of error since the number of turns of the take-up spool was greater than the number of turns of the clutch spool, owing to the greater length of line presented to the take-up spool. A small amount of energy was thus used at the mixer head for stretching the line, but was not recorded at the clutch.

To investigate the discrepancy between measurements made with the spool-and-line method and those made by direct coupling, both techniques were used with the experimental mixer which was the only mixer tested where direct linkage of the clutch to the mixer output could be achieved. When the spool-and-line technique was used with a special 63-lb. test braided line, at a torque level of 40 kg.cm., there was a loss of 2.9% in the total energy measured at the clutch, compared with that measured by the direct coupling method at 40 kg.cm. torque. This percentage loss in energy corresponded exactly to the percentage increase in the length of the line when weights producing the same tension were suspended from it. A line stretching correction factor(s) was incorporated into equation 1 for subsequent mechanical efficiency calculations. Because different lines were used for different applications (e.g., 8-lb. test monofilament for the mixograph; 40-lb. test monofilament for the GRL mixer; and 63-lb. test braided line for the Hobart-McDuffy mixer), the stretch factor varied with both the tension applied and the type of line used. The extent to which the various lines stretched under different loads was determined experimentally. Tables I, III, and VII show the actual s values used in mechanical efficiency calculations.

Example: The following is a typical mechanical efficiency calculation using data for the mixograph as an example:

Raw data: Torque (selected) = 6 kg.cm.
Number of turns of clutch (n) = 332
Energy meter pulses = 7.5
Tension of line at 6 kg.cm. torque (with spools of

$$10.2 \text{ cm. diam.}) = \frac{\text{Torque}}{\text{Spool radius}} = 588 \text{ g.}$$

Amount of stretch of 8-lb. monofilament line at 588 g. tension (from graph of stretch vs. weight applied, determined experimentally) = 8%
s (spool-and-line correction factor) = 1.08

"Energy in": (energy-input meter)

$$= \frac{\text{pulses}}{12.2} = 0.615 \text{ w-hr.}$$

"Energy out": (from equation 1)

$$= \frac{2\pi Tns}{36{,}700} = 0.368 \text{ w-hr.}$$

$$\text{Mechanical efficiency: } = \frac{\text{“energy out”} \times 100}{\text{“energy in”}} \% = 59.8\%$$

It was difficult to obtain good watt-hour resolution with the mixograph, particularly at very low torque levels, due to the limitation of the length of line, coupled with the small number of pulses recorded during a run. It was, therefore, necessary to carry out more determinations at each torque level (e.g., four or five) than for the other mixers studied, where much closer agreement was obtained between replicate determinations.

Mechanical Efficiency of the Mixograph

The mixograph drive consists of a 1/20-h.p. motor, having an integral 20:1 worm-gear reduction. Output torque rating is 1.5 lb.ft. (20.7 kg.cm.). The coupling to the mixer head shaft is a 1:1 pulley V-belt drive. The mixer head shaft turns the housing of the mixing head, forcing two spur gears to rotate about a fixed stationary gear. Each of the moving spur gears is attached to a separate circular plate holding two mixing pins. With no load, output speed of the housing was 90 r.p.m. With torque levels of 7 kg.cm. at the bowl (peak consistency of mixograms typically falls between 4 and 7 kg.cm.), output speed dropped to 87 r.p.m.

Table I shows mean mechanical efficiency values for the mixograph, calculated for various torque levels. At practical levels of torque (around 6 kg.cm.), the mechanical efficiency, as measured at the mixing head of the mixograph, was about 60%. Data for a second mixograph studied agreed closely with these results.

Energy Measurements at the Mixograph Bowl. As mentioned previously, the mixograph used was modified according to the strain gage technique described by

TABLE I. MECHANICAL EFFICIENCY OF MIXOGRAPH AT VARIOUS TORQUE LEVELS

	Torque, kg.cm.				
	2	3	4.5	6	8
Line stretching factor, s	1.033	1.052	1.068	1.084	1.094
Mechanical efficiency, %	61	60	60	60	54

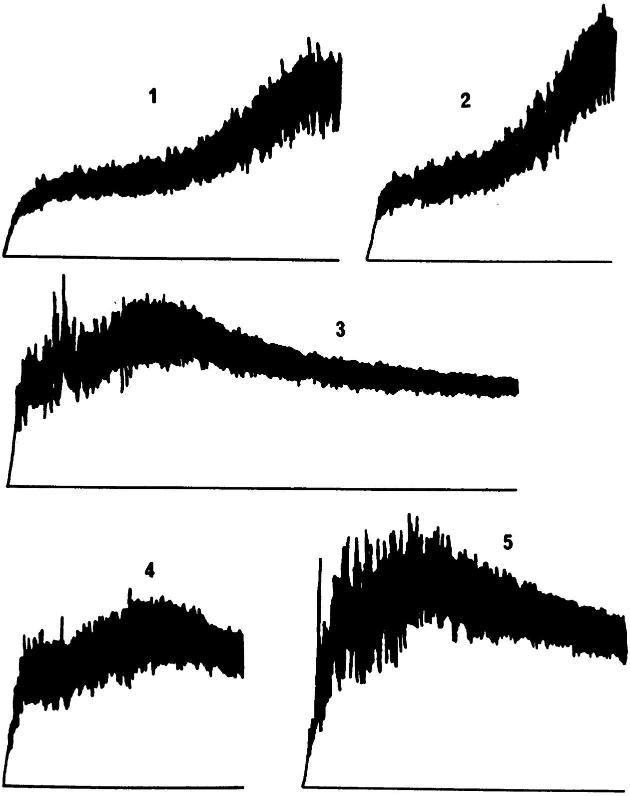


Fig. 6. Examples of mixograms obtained using the strain gage technique.

Voisey et al. (6). It was thus possible to measure work transmitted to the mixing bowl during mixing.

Several mixograms were recorded (Fig. 6) with this technique. The average torque level of each mixogram was determined from the area under the curve. During each test, energy measurements were made using the energy-input meter. Results are shown in Table II.

The energy transmitted to the mixing bowl averaged 46% of the total energy consumed by the mixer motor compared with the figure of 60% (mechanical efficiency) measured at the mixing head. The actual percentage of net energy available to the dough would fall somewhere between these two values. The 46% detected at the bowl would not take into account the fact that with the mixograph action a heart-shaped pattern is produced by each of the top four rotating pins, and all motion is not in the direction of the general line of torque being recorded. Also, some energy may be imparted to the dough between the top four pins since some forces reacted between the pins are not transmitted via the dough to the pins in the bowl.

Energy Measurements at the Mixograph Pins. The torque measurements made in calculating mechanical efficiency were taken at the mixing head and not at the mixing pins, and thus did not allow for the efficiency losses of the plate bearings and spur gears. An attempt was made to determine the mechanical efficiency at the pins of the mixograph. One set of pins was removed and a spool was fitted to the other set of pins. A figure of 52% was obtained by the spool-and-line technique. It is probable that if both sets of pins could have been loaded simultaneously, as occurs when mixing a dough, mechanical efficiency would have been higher than 52% because the load would have been shared by both sets of pins and the thrust on the sleeve bearing on the head would have been more balanced. It is, therefore, concluded that the true mechanical efficiency of the mixograph is higher than the 52% measured at one set of pins but lower than the 60% measured at the mixing head. A figure of 56% was arbitrarily used in mixing efficiency studies described in a subsequent section.

Mechanical Efficiency of the GRL Pin Mixer

The GRL mixer (4) consists of a motor—either 1/4 or 1/3 h.p.—with variable-pitch pulleys and V-belt drive to a worm-gear reducer, which in turn drives a planetary-type six gear system. The final driven gear holds the two outside mixing pins which in normal operation rotate at 130 r.p.m. This gear is concentrically mounted below the drive gear (to which the curved center pin is attached) which meshes with a much larger stationary ring gear. The result is that there is not a fixed center of rotation with respect to the driven gear, i.e., the gear center changes with the position of the driven gear as it follows the ring gear. It was, therefore,

TABLE II. SUMMARY OF ENERGY DATA FOR FIVE MIXOGRAMS (FIG. 6) USING STRAIN GAGE AND ELECTRICAL ENERGY MEASUREMENTS

	Mixogram Number				
	1	2	3	4	5
Energy					
a. Consumed by mixer motor (energy meter), w-hr.	0.696	0.656	1.390	0.696	1.310
b. Transmitted to mixing bowl (detected by strain gage)					
Average torque, kg.cm.	3.50	4.37	4.73	5.17	7.04
Electrical equivalent, w-hr.	0.312	0.295	0.635	0.338	0.615
$\frac{\text{Electrical equivalent}}{\text{Energy meter, w-hr.}} \times 100$, %	45	45	46	49	47

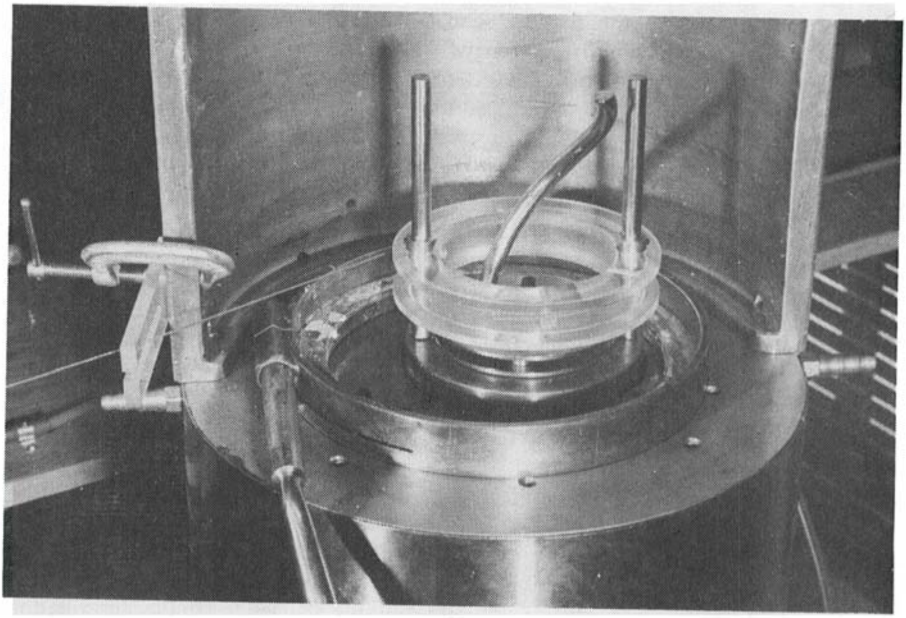


Fig. 7. Spool attached to GRL mixer.

TABLE III. MECHANICAL EFFICIENCY OF GRL MIXER AT VARIOUS TORQUE LEVELS

	Torque, kg.cm.				
	9	12	20	27.5	30
"Energy in" (energy meter), w-hr./min.	0.45	0.66	1.12	1.47	1.70
Line stretching factor, s	1.039	1.052	1.079	1.099	1.104
Mechanical efficiency, %	45	43	41	40	39

necessary to use the spool, line, and clutch technique, described earlier, to determine efficiency. The spool for the mixer was made with two holes corresponding to the pin spacing, and the center removed to enable the spool to be attached to the two straight pins without removing the center mixing pin (Fig. 7).

Results of mechanical efficiency determinations for one GRL mixer are shown in Table III. Each value is based on the mean of two to three tests. The average mechanical efficiency was 42% at torque levels corresponding to 200-g. flour mixes. Similar results were obtained for two other GRL mixers examined. Because all efficiency measurements were made at the two outside pins, the effect of the center pin was not taken into account. If measurements could have been made at all three pins simultaneously, which was not practical, mechanical efficiency would probably have been a little higher. The gear carrying the two outside pins is three gears further along in the gear train from the initial drive than that carrying the center pin, and involves three more bearing surfaces. The portion of energy transmitted by the center pin would thus be subject to a somewhat higher mechanical efficiency. Hence, although much of the apparent work is done by the outside pins, the true mechanical efficiency of the GRL mixer is probably slightly higher than the 42% determined.

Rate of Energy Input–GRL Mixer. When working with the GRL-Chorleywood method (2), a typical average rate at which work is done by the GRL mixer at 130 r.p.m., as indicated by the energy-input meter, is between 0.56 and 0.75 w-hr./min. (0.75 to 1.0 w-hr./min./lb. dough). Energy rate at peak dough consistency is around 1.0 w-hr./min. Surges of energy required at points of maximum dough shear produce "spikes" in the mixing curve, estimated to correspond to about 1.3 w-hr./min. at peak consistency. These figures relate to 200-g. flour mixes (dough weight approximately 340 g.) and maximum baking absorption coupled with a dough temperature of 95°F. The net work required to run the mixer empty was 0.9 w-hr./min. (work to motor driving mixer less the work to motor disconnected from mixer). A motor adequate to handle spike torque without undue slowing or overloading would require a usable rating of 0.9 + 1.3 w-hr./min., or 2.2 w-hr./min. (1/4 h.p. = 3.1 w-hr./min.). Lower dough absorption or temperatures would increase the power requirements significantly.

Determining the Mechanical Efficiency of the Experimental Mixing Unit

The drive for the experimental mixer consists of a Varidrive and 3/4-h.p. motor. With the mixer removed, the electric clutch could be connected directly to the output of the Varidrive using the same coupling method as used for the mixing head (Fig. 8). The direct coupling to the mixer drive included two bearings of

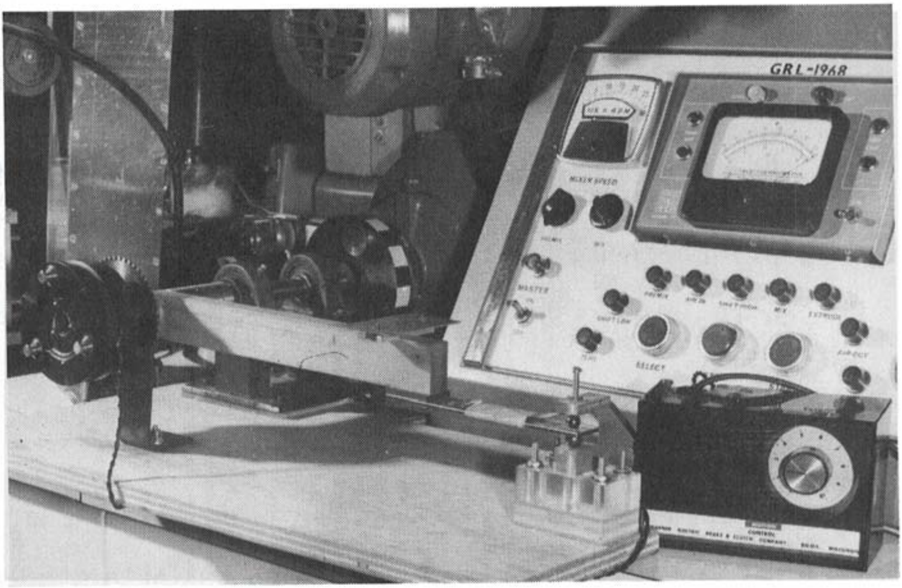


Fig. 8. Electric clutch connected to Varidrive in place of experimental mixer.

similar size and construction to those used with the experimental mixer. Because the mixer has a single blade, no gears are used and the blade has sufficient clearance that no rubbing of the bowl occurs. The small amount of friction generated from the "O"-ring, which supplies the seal between the shaft and the back of the mixing chamber, was not taken into account. Speeds and torque ranges examined were those which, in practice, related closely to the normal operation of the mixer. Results are listed in Table IV. Each value is the mean of two to three separate determinations. Very high speeds (above 240 r.p.m.), and the nominally high torque levels in dough which accompany these high speeds, exceeded the heat dissipation ratings of the clutch and were, therefore, not attempted.

The mechanical efficiency of the experimental mixing unit was the highest (over 80%) of the four mixers studied. Although efficiency tended to drop slightly with increasing speed (e.g., 85% at 80 r.p.m. to 81% at 240 r.p.m.), at any given speed, for levels of torque encountered in practice, efficiency remained essentially constant.

Mechanical Efficiency of the Hobart-McDuffy Mixer, Model C-100

This unit consists of an integrated 1/4-h.p. motor with a 3-speed transmission and planetary-gear drive terminating in a single output shaft located in a rotating housing. The housing speeds and output-shaft (which carried the two top pins for the McDuffy mixer) speeds are shown in Table V.

The mixing action of the McDuffy mixer was unsatisfactory for quantities of flour in excess of 600 g. For example, with 700 g. flour, the dough was not uniformly developed, that is, there were large pockets of "dry" dough within an otherwise shiny developed dough. With 600 g. flour, the dough appeared much more uniformly developed; however, some skipping in the mixing action was noticed, and at speed 2 a drop of 7% in speed occurred. The smoothest mixing action appeared to be in the range of from 300 to 500 g. of flour, at speed 2.

Amounts of flour ranging from 100 to 600 g. were mixed at three speeds, using the GRL energy-input meter and recorder to determine practical levels of average and peak torque.

Table VI(a) shows the average energy rates, in w-hr./min., required by the motor to mix doughs of various size. The figures in parentheses are requirements at peak torque (peak dough development). The second part of Table VI shows the same data expressed as rate of work per pound of dough.

The work required to run the mixer empty at three speeds was determined by subtracting the energy required to run the motor with the transmission gears disengaged from the values obtained with the gears engaged. The gears were disengaged by setting the speed shift lever at an intermediate position between two speed settings. The work required to run the mixer empty was 0.06 w-hr./min. at speed 1; 0.18 w-hr./min. at speed 2; and 0.44 w-hr./min. at speed 3. Considering the motor rating, this left an available or usable rate of 3.0 w-hr./min. at speed 1; 2.9 w-hr./min. at speed 2; and 2.6 w-hr./min. at speed 3.

Accordingly, the mixer motor was overloaded at speed 2 with 500-g. flour doughs, and maximum rating may be exceeded with 200-g. flour mixes at speed 3. If a reasonable allowance is made for "spike" torque, then, where energy measurements are important, the amount of flour used with the McDuffy mixer

TABLE IV. MECHANICAL EFFICIENCY OF EXPERIMENTAL MIXING UNIT AT VARIOUS SPEEDS AND TORQUE LEVELS

	Torque, kg.cm.								
	30	48	25	55	48	65	55	73	80
	80 r.p.m.		120 r.p.m.		160 r.p.m.		200 r.p.m.		240 r.p.m.
"Energy in" (energy meter), w-hr./min.	0.49	0.78	0.65	1.31	1.56	2.13	2.36	3.00	4.05
Mechanical efficiency, %	85	85	86	85	83	84	81	83	81

TABLE V. HOUSING SPEEDS AND OUTPUT-SHAFT SPEEDS FOR THE HOBART MIXER UNDER "NO-LOAD" CONDITIONS AT THREE SPEED SETTINGS

Mixer Speed Setting	Housing Speed r.p.m.	Shaft Speed r.p.m.
1	65	155
2	115	275
3	200	480

TABLE VI. AVERAGE ENERGY RATES REQUIRED TO MIX DOUGHS IN THE HOBART-McDUFFY MIXER AT THREE MIXING SPEEDS AND WITH FIVE DIFFERENT FLOUR WEIGHTS. FIGURES IN PARENTHESES ARE REQUIREMENTS AT PEAK TORQUE

Flour g.	(a) w-hr./min.		
	Speed 1	Speed 2	Speed 3
100	...	...	1.0 (1.3)
200	...	...	2.1 (2.7)
300	...	1.4 (1.8)	3.9 (5.1)
500	...	2.5 (3.25)	...
600	1.5 (1.9)	3.3 (4.3)	...
	(b) rate/lb. of Dough, w-hr./min./lb. of Work		
	Speed 1	Speed 2	Speed 3
100	...	...	2.8 (3.65)
200	...	...	2.85 (3.5)
300	...	1.25 (1.65)	3.5 (4.6)
500	...	1.35 (1.75)	...
600	0.67 (1.0)	1.45 (1.9)	...

should be restricted to a maximum of 300 g. at speed 2, and speed 3 should not be used for mixing bread doughs.

A take-up spool was made to fit the output shaft of the Hobart mixer. The spool-and-line method for determining mechanical efficiency was the same as that used for the mixograph and the GRL mixers, except that a special braided (63 lb. test) line was used instead of monofilament, and the spools were of different size (take-up spool 7.6 cm. diam.; clutch spool 12.4 cm. diam.). The results appear in Table VII, each value being the mean of two to three separate determinations.

Torque values at the mixer head and the clutch were not the same because of the difference in pulley size ratio. However, the energy equivalent proportional to torque X number of turns of the spool would be the same for both.

At torque levels corresponding to 300-g. flour mixes at speed 2, the average efficiency was 67% with speed variation of about 2%. Efficiency averaged 73% at speed 1 for a load of 600 g. of flour, with ample power in reserve for stiff doughs.

Comparison of Gross and Net Energy Requirements for a Series of Flours using Four Mixers

The GRL mixer (at 130 r.p.m. with 200 g. flour), the mixograph (with 35 g. flour), the experimental mixer (at 140 r.p.m. with 220 g. flour), and the Hobart-McDuffy mixer (at speed 2 with 300 g. flour) were used to mix doughs from 18 flours with the GRL-Chorleywood baking formula (2). A dough temperature of 86°F. was selected as being the most practical for all mixers, largely due to the difficulties involved in working with the mixograph at the usual temperature for this method of 95°F.

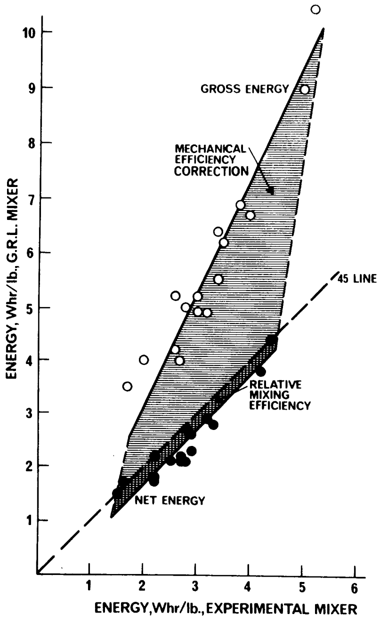
Gross energy measurements were determined with the energy-input meter. The mechanical efficiency values determined as described above were used to obtain net energy values.

Gross and net energy values obtained with the experimental mixer were plotted

TABLE VII. MECHANICAL EFFICIENCY OF HOBART-McDUFFY MIXER AT THREE SPEEDS AND VARIOUS TORQUE LEVELS

	Speed Setting								
	1st			2nd			3rd		
Torque, kg.cm. at clutch	30	55	90	25	55	95	40	50	60
Approx. torque, kg.cm. at mixing head	18	33	54	15	33	57	24	30	36
"Energy in" (energy meter) w-hr./min.	0.69	1.36	1.84	0.90	2.02	3.87	2.42	3.40	4.25
Line stretching factor, s	1.021	1.040	1.058	1.018	1.037	1.061	1.027	1.034	1.041
Mechanical efficiency, %	74	74	72	68	66	64	60	57	54

against energy values obtained with the GRL mixer (Fig. 9). The values shown corresponded to peak dough consistency for each flour. The difference between the "gross energy" plot and the "net energy" plot relates to corrections made for mechanical efficiencies of the two mixers. Had the net energy values been the same for each mixer for each flour, the resulting "net energy" plot would have fallen on the 45° broken line. In fact, the corrected net values for the GRL mixer were slightly lower than the corresponding values for the experimental mixer. This indicated that, compared with the experimental mixer, less energy was required at the mixing head of the GRL mixer to mix a dough to peak consistency. A larger portion of the net energy to the doughs in the experimental mixer was not contributing directly to mechanical dough development. This discrepancy may be attributed to a difference in mixing efficiency between the two mixers. Thus, although the experimental mixer had a much higher mechanical efficiency than the GRL mixer (84% against 42%), mixing efficiency was somewhat less. For a given flour, therefore, gross energy requirement with the GRL mixer would be considerably higher, whereas net energy would be slightly lower than that for the experimental mixer. For example, a flour requiring 6.0 w-hr./lb. gross energy on the GRL mixer would require ony 3.35 w-hr./lb. gross energy with the experimental



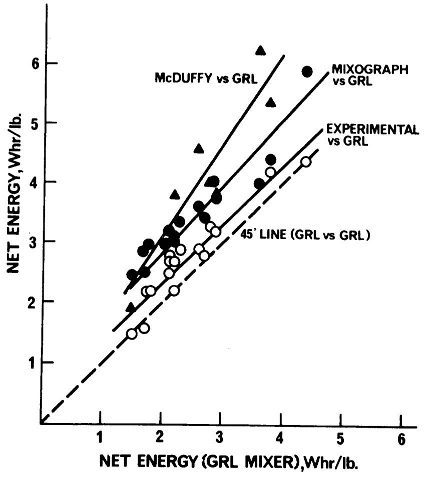
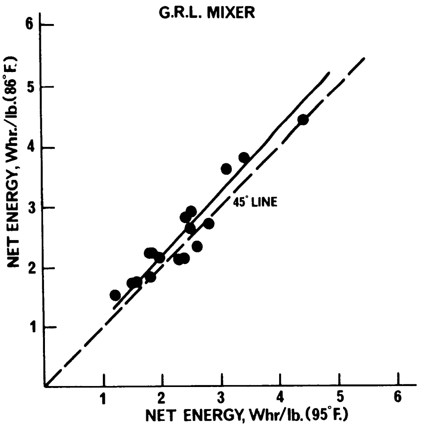


Fig. 9 (left). Relationship between energy measurements obtained for a series of flours with the GRL mixer and energy measurements obtained for the same flours with the experimental mixer. Dough temperature, 86° F.

Fig. 10 (right). Relationship between net energy measurements obtained for a series of flours with the GRL mixer and net energy measurements obtained with the experimental mixer (open circles), the mixograph (closed circles), and the Hobart-McDuffy mixer (triangles). Dough temperature, 86° F.



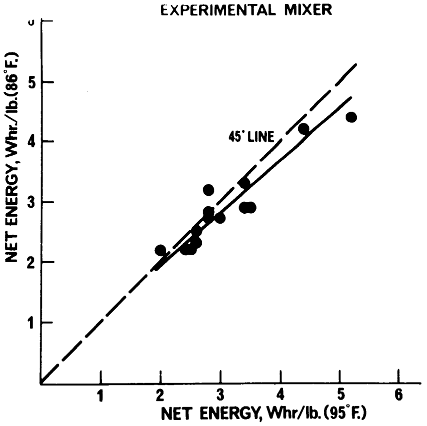


Fig. 11 (left). Relationship between net energy measurements obtained for a series of flours with the GRL mixer at 95° F. and net energy measurements obtained at 86° F.

Fig. 12 (right). Relationship between net energy measurements obtained for a series of flours with the experimental mixer (140 r.p.m.) at 95° F., and net energy measurements obtained at 86° F.

mixer. Net energy requirements, however, would be 2.5 w-hr./lb. for the GRL mixer and 2.8 w-hr./lb. for the experimental mixer.

Figure 10 shows net energy requirements (at 86°F.) for this series of flours, using the GRL mixer plotted against net values obtained with the other three mixers. Relative to the GRL mixer, plots for the other mixers all fell above the 45° broken line, indicating that mixing efficiency was highest for the GRL mixer and progressively lower for the experimental mixer, mixograph, and Hobart-McDuffy mixer, the last-mentioned having the lowest mixing efficiency of the four mixers studied.

Effect of Dough Temperature on Mixing Efficiency

The previous section related to studies carried out with dough temperatures of 86°F. The dough temperature normally used in the GRL-Chorleywood method is 95°F., and the two mixers commonly used for this method in our Laboratory are the GRL pin mixer and the experimental mixer. To investigate the effect of dough temperature on the relative mixing efficiency of these two mixers, the same flours were mixed at 95°F. Net energy measurements were then compared with those made at 86°F.

For the GRL mixer net energy values were slightly higher at 86° than at 95°F., and the difference between the calculated regression line and the 45° (dashed) line in Fig. 11 reflects the slightly higher mixing efficiency of this mixer at the higher dough temperature.

For the experimental mixer, however, the reverse trend was noted, and net energy values were slightly lower at 86° than at 95°F. (Fig. 12), indicating that the mixing efficiency of this mixer decreased with increasing dough temperature.

The net effect of these differences was that since the GRL mixer was shown to have a slightly higher mixing efficiency than the experimental mixer at 86°F., the difference was even greater at 95°F. as illustrated in Fig. 13. The plot of net energy

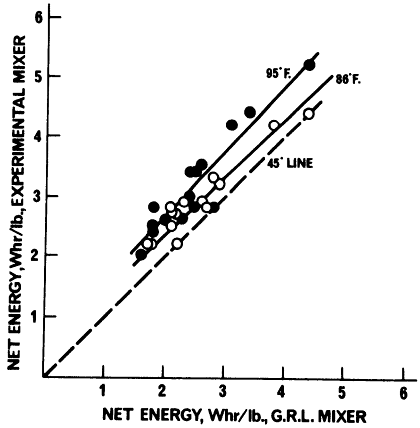


Fig. 13. Relationship between net energy measurements obtained for a series of flours with the GRL mixer and net energy measurements obtained with the experimental mixer at two different dough temperatures, 86° and 95° F.

values for the GRL mixer vs. those for the experimental mixer was even further away from the 45° line at 95° than it was at 86°F.

Although the differences illustrated in Figs. 11–13 are not great, they do suggest that dough temperature is another factor that should be taken into consideration when interpreting energy-input measurement.

DISCUSSION

These tests indicate the wide range in mechanical efficiency that exists between laboratory mixers of different design. It is logical to speculate that there may be distinct differences in mechanical efficiency between large commercial mixers of different design. In the United Kingdom there are at least ten manufacturers offering batch- or continuous-type mixers of widely differing design and mixing action for Chorleywood bread production (8). For the Chorleywood Bread Process, a fixed (gross) work-input level of 5 w-hr./lb. of dough is recommended (1) by the originators of the process, and it follows that if mechanical efficiencies vary, the net amount of work available to the dough will vary with mixer. It further follows that when a fixed level of gross energy is used, doughs from a given flour will be mixed to different degrees of development depending on the mixer used and its mechanical efficiency.

Knowing the mechanical efficiency permits a comparison of mixing efficiency to be made between mixers. Differences in net energy requirement between mixers for a given flour relate to differences in mixing efficiency. A high net energy requirement (for one mixer compared with another for the same flour) indicates that a large proportion of the energy going to the dough is not directly contributing to mechanical dough development, and suggests a low mixing efficiency.

It has also been shown that dough temperature may affect mixing efficiency. The direction and magnitude of the influence of temperature on mixing efficiency may vary for mixers of different design.

With the progressive trend toward shorter breadmaking processes and the increasing importance of flour mixing characteristics, any attempt to arrive at specific energy-input requirements for test flours (e.g., in terms of w-hr./lb. or h.p. min./lb.) must first include a consideration of the factors examined above. This would be essential where mixers of different design are used and where a meaningful comparison of results for a given flour between laboratories or mixers (or both) may be desirable.

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