Gasograph: Design, Construction, and Reproducibility of a Sensitive 12-Channel Gas Recording Instrument[1]

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ABSTRACT

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The gasograph is an instrument designed to measure and continuously record the gas produced in 12 fermenting doughs (of about 10 g of flour). Values are recorded as gasograph units (GU), which can be readily expressed as millimeters of mercury or cubic centimeters of gas. Gasograph channel to channel reproducibility is at least equal to that of different manometric-type and gauge-type nonrecording instruments. The first two gasographs produced essentially identical results on successive days at two research laboratories, comparing fermentation rates of two yeast levels (3.5 and 7.25%) and three straight grade baker's flours formulated in sponges containing 6% sucrose, 1.5% NaCl, and 150% water in addition to flour and yeast. The average of the coefficients of variability of treatments within laboratories was 0.55%, and within channels between laboratories was 0.75%. Thus, the excellent reproducibility between laboratories was somewhat lower than that within laboratories. Typical gasograms demonstrate the high reproducibility of the actions of formula ingredients, yeast, sugar, and diastatic malt. The coefficient of variability was 0.69%. The gasograph can be used to indicate the presence or absence of inhibitors or stimulators of yeast respiration and to investigate the interaction of formula ingredients and fermentation rates during various stages of the fermentation and proofing of dough. Traces of α-amylase in wheat and flour can be easily detected with the instrument.

Fermentation by yeast is essential in the production of many leavened foods such as bread, rolls, and crackers. Carbon dioxide, alcohol, organic acids, and many other compounds are produced as yeast metabolizes sugar in wheat doughs. Bakers and cereal scientists have long recognized the interdependence of sugar metabolized, total gas produced, and product quality.

Bailey and Johnson (1924) measured yeast gas production volumetrically. Others who described devices that measured gas volumetrically include Jorgensen (1931), Markley and Bailey (1932), Heald (1932), Sherwood et al (1940), Hullett (1941), Blish et al (1932), and Sandstedt and Blish (1934). Elion (1939) described an automated two-channel instrument that used weight as a method of measurement, and Working and Swanson (1946) produced a two-channel apparatus embodying similar principles that automatically recorded gas production by electric sparks that burned holes in a chart paper.

Since Eva et al (1937) demonstrated the practicability of measuring gas production under pressure, many scientists have used the pressure gauge method. Landis (1934) used gauges to measure gas pressure, and Mallock (1939) used a single gauge with several closable outlets to measure pressures in several fermentation vessels.

Recognizing the need for more practical and sensitive continuous recording, Miller et al (1943) designed and produced an apparatus that recorded light on a moving blueprint paper after it passed through a manometer. That instrument had three disadvantages: it required pressure engineering for the reaction chambers; it required expensive light-sensitive recording paper; and its error was just below 10%. Sutton (1950) used a Statham pressure transmitter to translate pressure into a voltage linearly proportional to pressure, which automated an electrical 12-channel recording pressuremeter. That instrument limited error to less than 1% but required rather bulky and elaborate instrumentation in addition to the transmitter.

Shogren et al (1976) showed the effect of flour-water ratio on total gas produced. Those researchers and many others today use instruments that require periodic or end-point readings. Periodic readings are labor intensive and therefore expensive, and end-point readings can miss rate changes that reflect fermentation chemistry

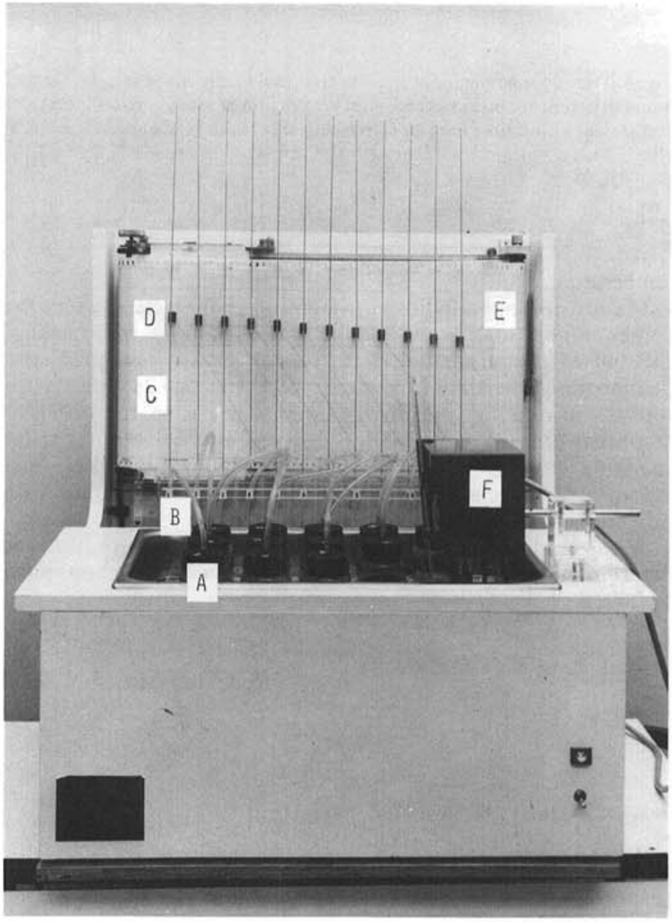

Fig. 1. Gasograph photo of stoppered reaction bottles **(A)** in waterbath, tubing **(B)** to reservoirs (not visible), aluminum rods **(C)** and attached plastic ink pens **(D)**, continuously moving chart **(E)**, and combination circulating pump, heater, and thermostat **(F)**. No. 1 channel (far left) is approaching 2 hr of fermentation.

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Specific instruments or trade names are mentioned only for identification and do not imply endorsement by the U.S. government.

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TABLE I
Replicated Gasograph Gas Productions (in GU)[a] of Three Bread-Making Flours After Fermentation with 3.5% Yeast at Two Locations

		Fermentation Time (hr) and Location					
		1		2		3	
Flour[b]	Gasograph Channel	WWQL[c]	HWQL[d]	WWQL	HWQL	WWQL	HWQL
B-Std-77	1	19.8	19.7	44.4	44.8	65.0	65.3
	2	19.9	19.8	45.3	45.0	66.1	65.3
	3	19.7	19.7	44.8	44.8	65.6	65.3
	4	19.7	19.4	44.7	44.4	65.4	64.6
	Average	19.78	19.65	44.80	44.75	65.53	65.13
BCS-77	5	19.9	20.4	46.5	47.0	67.9	68.0
	6	20.1	20.2	46.7	47.0	68.2	68.0
	7	20.3	20.3	47.5	47.0	68.7	68.3
	8	20.1	20.3	46.9	47.2	68.2	68.6
	Average	20.10	20.30	46.90	47.05	68.25	68.23
RBS-78	9	20.4	20.0	47.3	46.8	67.2	67.3
	10	20.4	19.9	47.5	46.5	67.8	67.0
	11	19.7	19.9	45.9	46.7	66.2	67.4
	12	20.4	20.1	47.0	47.1	67.5	67.0
	Average	20.23	19.97	46.93	46.78	67.18	67.18

[a] Gasograph units.
[b] B-Std-77 = an unmalted commercial straight grade flour, BCS-77 = a composite multomat flour from many commercial wheats grown in 1977, RBS-78 = a regional bread-making standard flour experimentally milled from many wheats grown in 1977.
[c] WWQL = Western Wheat Quality Laboratory, Pullman, WA.
[d] HWQL = Hard Wheat Quality Laboratory, Manhattan KS.

important to bakers and researchers alike.

We wanted to produce an instrument to continuously record gas production without expensive electronic devices. This article describes the instrument that we designed, built, and evaluated and documents its accuracy and reproducibility as it continuously records gas produced in 12 fermentation bottles. The instrument (gasograph) is now commercially available.

MATERIALS AND METHODS

Instrument Design

The gasograph (Figs. 1 and 2) contains 12 channels, each a complete unit, so that gas production can be determined simultaneously on 12 samples. Gas produced from a sponge or dough within a half-pint reaction bottle complete with a No. 10½ rubber stopper passes through tubing to a reservoir containing water. The water is forced from the bottom of the reservoir through tubing into the bottom of a precision-bored (3.175-cm diameter) plexiglass cylinder. The water lifts a light-weight float and its attached aluminum rod and plastic ink pen. Height of float is recorded on a continuously moving chart. The chart paper has 100 horizontal parallel lines. The distance between any two consecutive lines is one gasograph unit (GU). The distance between any consecutive vertical parallel lines is 10 min, but readily can be made 5 or 15 min by the substitution of suitable gears. The amount of water in the reservoir is less than the volume of the cylinder, so that the instrument can be left unattended without risking cylinder overflow. Because the column of water in the cylinder rises less than 11 in., pressure engineering is unnecessary. Microbial contamination is controlled by filling the reservoir with CO_2-saturated solution of one part 10% dimethyl benzyl ammonium chloride (Roccal) and 500 parts water. Waterbath temperature is controlled within less than ±0.05°C by a combination circulating pump, heater, and thermostat. Outside dimensions of the gasograph are 74 cm in length, 59 cm in width, and 74 cm in height.

Materials

An unmalted commercial straight grade flour, a composite multomat flour that represented many commercial wheat varieties grown in the Great Plains in 1977, and a regional bread-making standard flour experimentally milled from a composite of many wheat varieties harvested throughout the Great Plains in 1977 were tested as sponges for gas production during instrument evaluation and calibration. Flours (10 g, 14% mb) were slurried for 1.5 min in 15 ml of water that contained 0.15 g of NaCl, 0.60 g of sucrose, and either 0.20, 0.35, or 0.725 g of fresh baker's yeast, unless otherwise indicated. Subsamples from the same lot of yeast were shipped by air to each of the USDA wheat quality laboratories for the collaborative gasograph studies. National gauge or manometer types of gassing meters were zeroed and the gasograph reaction bottles stoppered 2 min after being placed in the waterbath. The three flours were tested for gas production in quadruplicate with both 3.5% and 7.25% yeast. In some studies, yeast, sugar, and malted barley flour (dextrinizing units = 60/g, 20°C) were varied as examples of the application and precision of the gasograph.

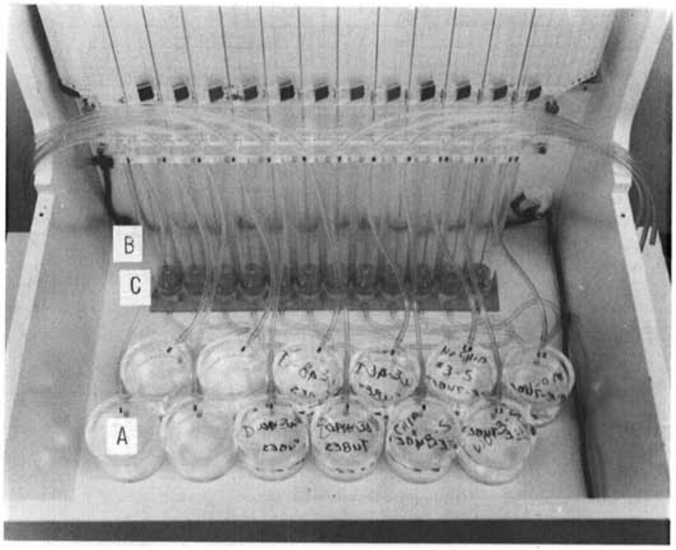

Fig. 2. Gasograph photo, after removal of waterbath, exposes water reservoirs **(A)**, precision bored plexiglass cylinders **(B)**, and floats **(C)** at bottoms of cylinders.

RESULTS AND DISCUSSION

In early evaluation studies of the gasograph and other gassing meters (three gauges and two mercury manometers) at the Western Wheat Quality Laboratory, Pullman, WA, gasograph channel to channel reproducibility was at least as good as that of the gauges and manometers (data not shown). After the second gasograph was completed for the Hard Wheat Quality Laboratory, U.S. Grain Marketing Research Laboratory, Manhattan, KS, we compared both instruments on successive days at 3.5 and 7.25% yeast levels. The data (Tables I and II) clearly show a high degree of reproducibility within gasograph channels and between channels of the two instruments at different laboratories. The average of the coefficients of variability (CV) of treatments at Pullman was 0.65% and at Manhattan 0.45% (average CV of laboratories, 0.55%). Average values (four replications) of the three flours varied only 0–0.58 GU between the two gasographs. The CV within a channel between laboratories was 0.68% for 3.5% yeast and 2–3 hr and 0.81% for 7.25% yeast and 1–2 hr (average CV of yeast levels, 0.75%). Thus, the excellent reproducibility between laboratories was somewhat lower than that within laboratories.

TABLE II

Replicated Gasograph Gas Productions (in GU)[a] of Three Bread-Making Flours After Fermentation with 7.25% Yeast at Two Locations

		Fermentation Time (hr) and Location			
		1		2	
Flour[b]	Gasograph Channel	WWQL[c]	HWQL[d]	WWQL	HWQL
B-Std-77	1	39.4	39.7	75.7	76.7
	2	39.3	39.4	75.9	76.6
	3	39.1	39.4	75.6	76.6
	4	40.1	39.2	75.8	76.3
	Average	39.48	39.43	75.75	76.55
BCS-77	5	41.6	42.2	78.0	79.0
	6	41.6	41.2	78.0	78.7
	7	41.5	40.6	77.7	78.0
	8	41.5	40.6	77.8	78.4
	Average	41.55	41.15	77.88	78.53
RBS-78	9	41.3	40.5	77.8	77.6
	10	41.5	40.4	77.7	77.4
	11	40.8	40.6	76.9	77.8
	12	41.3	41.1	77.4	78.0
	Average	41.23	40.65	77.45	77.70

[a] Gasograph units.

[b] B-Std-77 = an unmalted commercial straight grade flour, BCS-77 = a composite multomat flour from commercial wheats grown in 1977, RBS-78 = a regional bread-making standard flour experimentally milled from many wheats grown in 1977.

[c] WWQL = Western Wheat Quality Laboratory, Pullman, WA.

[d] HWQL = Hard Wheat Quality Laboratory, Manhattan, KS.

Applications of the Gasograph

The gasograph may be used to measure the gas-producing

TABLE III

Replicated Gasograph Gas Productions (in GU)[a] of RBS-78[b] After Fermentation with Different Levels of Yeast, Sugar, and Malt

	Replications			
Variable (%)	1	2	3	Average
Yeast				
0	0.7	0.6	···	0.65
1	12.7	12.8	···	12.75
2	27.3	27.3	···	27.30
3	39.0	39.4	···	39.20
5	59.5	60.4	···	59.95
10	89.2	90.0	···	89.60
Sugar				
0	28.1	28.0	27.8	27.97
1	38.1	38.6	38.2	38.30
3	57.8	58.3	57.9	58.00
6	76.3	76.6	76.4	76.43
Malt				
0	28.0	28.0	27.7	27.90
0.1	45.0	44.9	44.6	44.83
0.6	58.7	58.9	58.7	58.77
2.4	67.0	67.8	67.3	67.37

[a] Gasograph units.

[b] RBS-78 = a regional bread-making standard flour experimentally milled from many wheats grown in 1977.

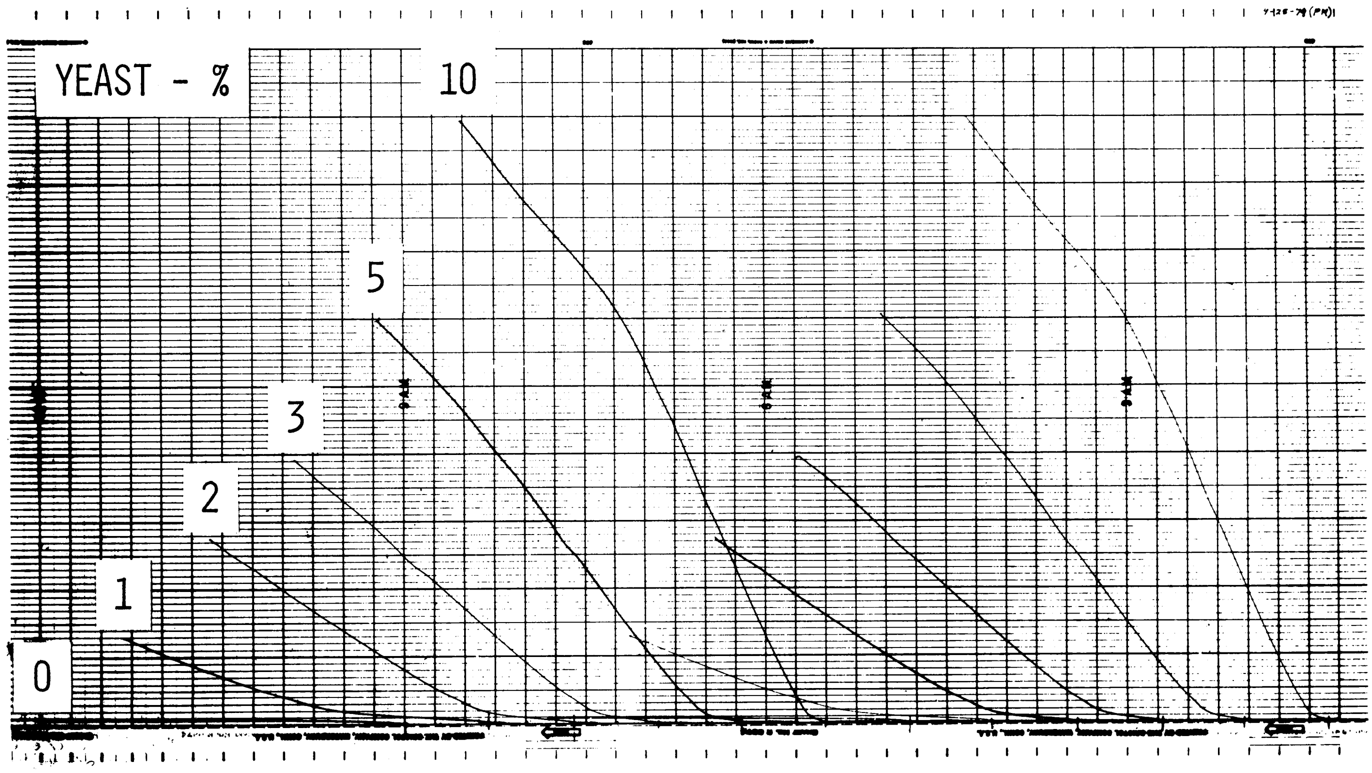

Fig. 3. Replicated gasograph gas productions of RBS-78 (a regional bread-making standard flour) after 2-hr fermentation with 0, 1, 2, 3, 5, and 10% yeast.

activity of yeast, to indicate the presence of inhibitors or stimulators of yeast respiration, and to investigate the action of formula ingredients such as sugar and diastatic malt. Doughs can be mixed by any desired method and added to the reaction bottles before or after any amount of fermentation time to measure gas production during any stage of fermentation and dough development. Traces of α-amylase activity in wheat and flour can be easily detected by end-point gasograph readings.

For example, when yeast content was varied from 0 to 10%, gas production (Fig. 3, Table III) varied from 0.65 to 89.6 GU. Maximum variations between duplicates was 0.9 GU. Gas production of 0–6% sugar (Fig. 4, Table III) varied from 27.97 to

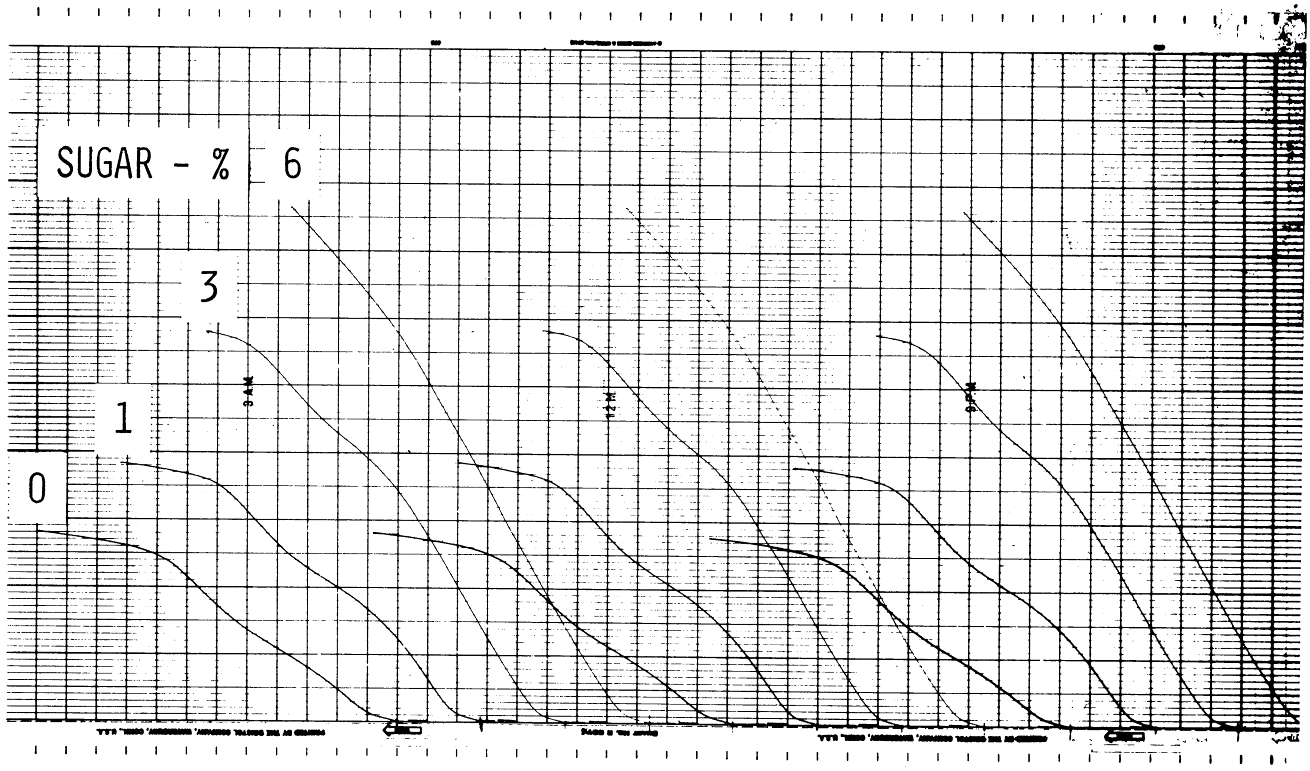

Fig. 4. Replicated gasograph gas productions of RBS-78 (a regional bread-making standard flour) after 2-hr fermentation with 0, 1, 3, and 6% sugar and 7.25% yeast.

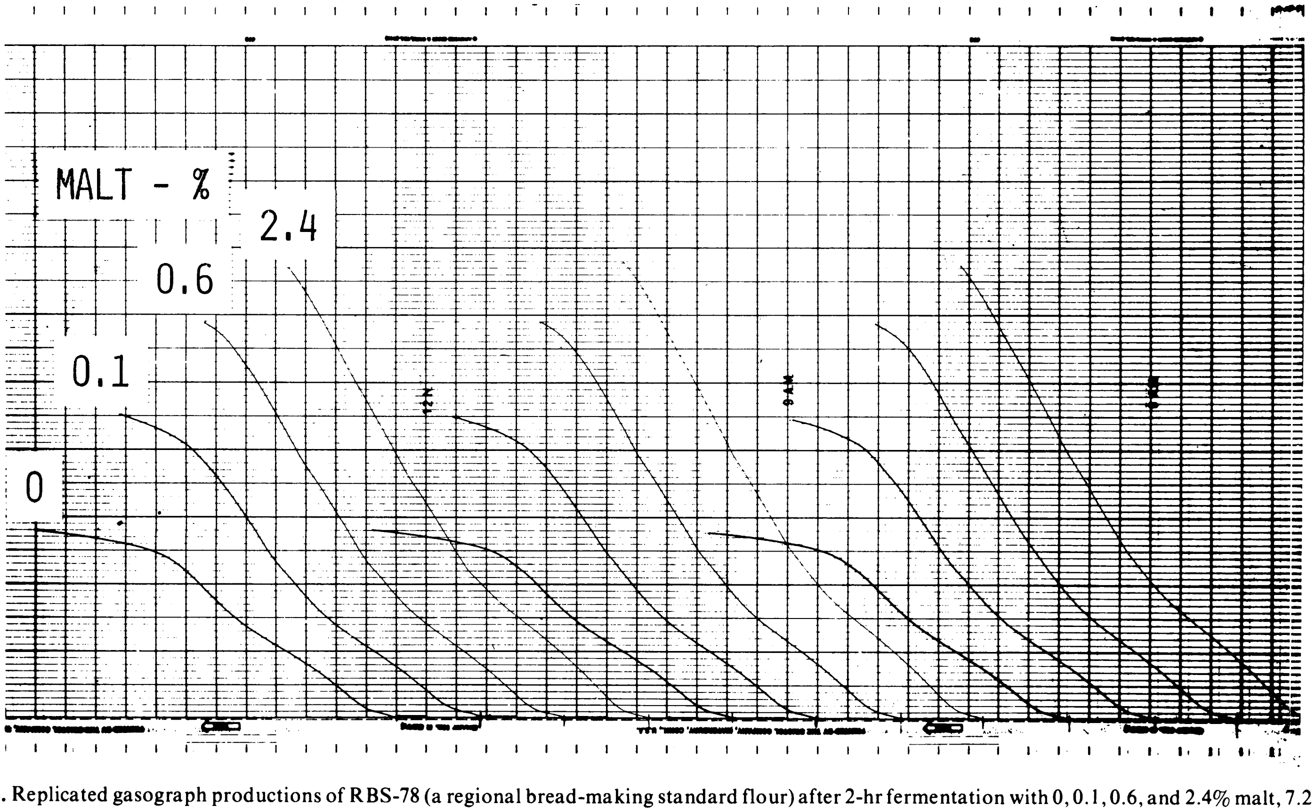

Fig. 5. Replicated gasograph productions of RBS-78 (a regional bread-making standard flour) after 2-hr fermentation with 0, 0.1, 0.6, and 2.4% malt, 7.25% yeast, and no added sugar.

TABLE IV
Effect of Fermentation Time and Yeast Concentration on the Factor F[a] for Expressing Gasograph Units as Millimeters of Mercury

Yeast (%)	F at Fermentation Time, (hr)						
	0.5	1.0	1.5	2.0	3.0	4.0	Average
2		7.26		7.14	*7.28*[b]	*7.37*	7.26
3.63		7.14		*7.25*	*7.35*		7.25
7.25	7.28	7.17	*7.21*	*7.27*			7.23

[a] F = mm Hg/GU.

[b] Figures in italics resulted from the fermentation times most likely to be used within a yeast concentration level. Average of italicized values = 7.29.

76.43 GU and that of 0–2.4% malt (Fig. 5, Table III) from 27.9 to 67.37 GU. Maximum variation between triplicates for both sugar and malt was 0.8 GU. Of course, averages of replicates could be plotted in the usual manner on cross sectioned paper.

GU Expressed as Millimeters of Mercury

When fermentation time was increased within a given yeast concentration (Table IV), the factor (F) representing the relationship of gasograph units and millimeters of Hg tended to increase. At 2% yeast, however, the factors for 1 and 3 hr were about equal, and at 7.25% yeast, the factors for 0.5 and 2 hr were essentially equal. Averages within yeast concentrations were essentially equal (F = 7.23–7.26). The average factor for the six fermentation times most likely to be used was 7.29. Thus, gasograph units can be converted to millimeters of Hg simply by multiplying by the factor F = 7.3.

Three new mercury manometer gauges were used in obtaining the factor F = 7.3. The difference between the low-reading and high-reading manometers was consistently about 10 mm of Hg. Readings for the third manometer usually were somewhat more than halfway between those of the other two. If lower-reading manometers than ours were used, F would be <7.3. For higher-reading manometers, F would be >7.3.

GU Expressed as CC of Gas

Gas production in gasograph units also may be expressed in cubic centimeters by multiplying GU by 2.38. That conversion factor was arrived at empirically by injecting precise increments of gas into the instrument.

Effect of Pressure on Gas Production

The effect of elevated pressure on production of gas by yeast has been questioned. Some authors have reported no effects (Sandstedt and Blish 1936), whereas others have reported that yeast gas production varies with pressure changes (Eisenberg 1940, Glabe 1942). The gasograph is a low pressure system in contrast to the relatively high pressure of about two atmospheres in the National manometers. The relative constancy of the slope or factor F (Table IV) indicates that elevated pressures do not significantly affect yeast gas production.

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