Internal Pressure in Yeasted Dough[1]

H. MATSUMOTO and JUNKO NISHIYAMA, Osaka Women's University, Osaka, Japan, and I. HLYNKA, Canadian Grain Commission, Grain Research Laboratory, Winnipeg, Manitoba, Canada

ABSTRACT

The pressure inside yeasted dough was obtained by measuring the pressure exerted by the dough in a glass cylinder on a flat rubber diaphragm connected to a manometer. The pressure was higher in doughs of lower absorption, and higher yeast content; for stronger flour; and in the smaller diameter cylinder of the apparatus. The pressure ranged from 35 to 200 mm. water column. It remained almost constant during expansion until breakdown of the gas cells, although some exceptions were noted.

During the past 20 years, dough rheology has been the subject of a considerable amount of research. Most of this work, however, was done with unyeasted dough in order to simplify, as much as possible, the complex dough system and in this way to identify, as unequivocally as possible, particular reactions or phenomena for study. But for practical application of dough rheology, the findings with unyeasted dough must be extended to yeasted dough systems.

Among the papers dealing with yeasted dough are those of Miller et al. (1,2) and Elling and Barmore (3), which describe dough-expansion tests in specially designed containers. These investigators suggested an intimate relationship between the expansion limit and the baking potential of dough. Halton (4) reported a test of dough extension with the Research Extensometer. Studies carried out by Marek et al. (5,6) with the Brabender Oven-Rise Recorder showed the effects on the expansion of dough of bromate and other improvers, enzymes, and method of processing. Bailey (7) estimated the gas pressure in yeasted dough by deflating the dough with a plunger in a closed system.

If the amount of extension of the dough by carbon dioxide produced by yeast, as well as the inside pressure of the gas in dough, could be measured, then

[1]Paper No. 306 of the Grain Research Laboratory, Canadian Grain Commission, Winnipeg 2, Manitoba.

extension-pressure curves could be obtained. Such curves could then be interpreted in a way similar to that of the alveograph or extensigraph curves.

This method for estimating the change in internal pressure of gas in fermenting dough was improved by Baker and Mize (8), and was applied to a study of dough properties with increasing temperature. The present paper describes a sensitive manometer by means of which the internal pressure in fermenting dough can be measured. Preliminary results obtained with it are presented.

MATERIALS AND METHODS

The flour was an unbleached one from hard red spring wheat. The protein content was 11.7% and ash 0.36% at 14% moisture. A commercial soft wheat flour was also used for comparison. It contained 8.1% protein and 0.35% ash. The doughs were mixed in the GRL mixer at 64 r.p.m. for 7 min. at 30°C. with ingredients as shown below. Absorption used was that obtained with the farinograph at a standard consistency of 500 B.U. The dough formula was:

Flour	100
Yeast (compressed)	3.0
Sugar	2.5
Salt	1.0
Water (strong flour)	56.3
Water (soft flour)	53.0

Mixing was carried out with 200 g. of flour. The dough was divided into a 70-g. mass and rested for 45 min. at 30°C. in a thermostatically controlled cabinet. After the rest period, the dough was rounded 20 times on the rounding table of the extensigraph. The dough was then pushed in from the bottom of the glass cylinder of 52.3 mm. inside diameter and 300 mm. length, and pressed with a rubber stopper from the bottom, which is attached to a pressure measuring device, as shown in Fig. 1. The rubber stopper should be inserted carefully so that the rubber membrane makes contact with the dough without forming an air pocket. However, a small air bubble did not affect the pressure measurement of the dough. A concaving of the membrane during this process was avoided by closing the stopcock (S).

The pressure-measuring device consists of a glass cylinder (A) covered with a rubber membrane or diaphragm of 0.5 mm. thickness attached with the aid of rubber paste and cotton string, and a capillary tube leading from the bottom of the cylinder to the manometer outside. The tension of the rubber membrane did not affect the sensitivity of this apparatus as long as it was spread flat. This cylinder (A) was filled with Brody liquid up to the mark (L) in the capillary. This line (L) was marked at the same level as the rubber diaphragm as shown in the figure. The Brody liquid was prepared by dissolving 5 g. of sodium choleate and 23 g. of sodium chloride with a small amount of fuchsin in 500 ml. distilled water. The density of the liquid was 1.033.

The pressure exerted by the dough on the surface of the rubber diaphragm can be measured with considerable sensitivity by maintaining the water level in the capillary tube at the fixed mark (L) by adjusting the pressure in (B) by raising the

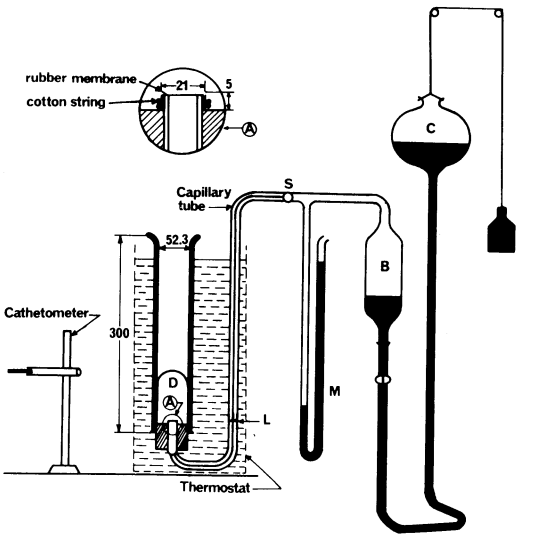

Fig. 1. Apparatus for determination of the inside pressure of yeasted dough.

water reservoir (C) to a definite level. The reading on the manometer (M) is the inside pressure of the dough (D). Adjustment of the water level (L) in the capillary and the measurement of dough height in the tube were carried out with a cathetometer. The temperature of the thermostat was fixed at 30°C.

RESULTS

Control Test with Water

The sensitivity of this equipment for measuring the pressure was tested by the addition of water instead of dough to a certain height over the rubber diaphragm in this cylinder. The pressure in (M) corresponding to each water level in the cylinder was also measured and the results are shown in Fig. 2. The curve passes a point near the origin, and the slope is about 1.04. This means that the manometer indicates

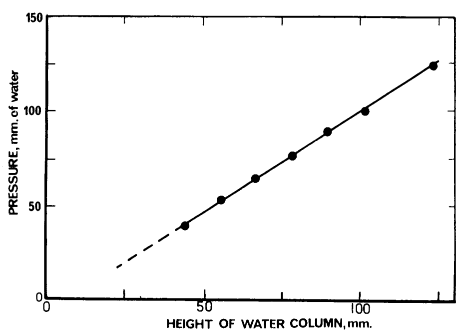

Fig. 2. Calibration of apparatus, showing the relation between the height of water level in the cylinder vs. water pressure.

the actual water pressure in the cylinder over the rubber membrane when a slight adjustment is made.

Effect of Absorption on the Inside Pressure of Dough

The dough with ingredients shown above required 56.3% of water (flour on a 14% moisture basis) to reach 500 B.U. on the farinograph. The inside pressures with this optimum absorption, and with 50 and 60% absorptions, are shown in Fig. 3. It is reasonable that higher pressures were obtained with doughs of lower absorption. The figure shows a plot of expanded volume vs. pressure. The expansion rate is shown in the figure as E.R. (ml. per min. per g. of dough) at the points indicated. A rapid decrease of E.R. was estimated at the part after pressure decreased. However, it is not shown as a figure, since it was irregular.

Effect of Yeast Content on the Inside Pressure of Dough

Determinations were carried out with doughs containing 1.5 and 4.0% yeast (flour basis). The other ingredients were the same as for the control dough given in the previous experiment. The results are shown in Fig. 4. It is interesting that higher pressure was obtained in the rapidly rising dough (E.R. = 0.049 ml. per min. per g. of dough) rather than in the slow rising dough (E.R. = 0.021). However, the difference between the pressure of the dough containing 4% yeast and that of 3% yeast, shown as a curve of 56.3% absorption in Fig. 3, was small.

Effect of Diameter of Cylinder on the Inside Pressure of Dough

The results obtained when the cylinder used was of 52.3 mm. diameter and when the cylinder was of 71.7 mm. diameter, for the same amount of dough (70 g.), are shown in Fig. 5. A lower inside dough pressure was obtained with the cylinder of larger diameter. The pressures were also determined with various amounts of dough with a cylinder of 52.3 mm. diameter. The maximum pressure and initial height of dough in the cylinder were as follows:

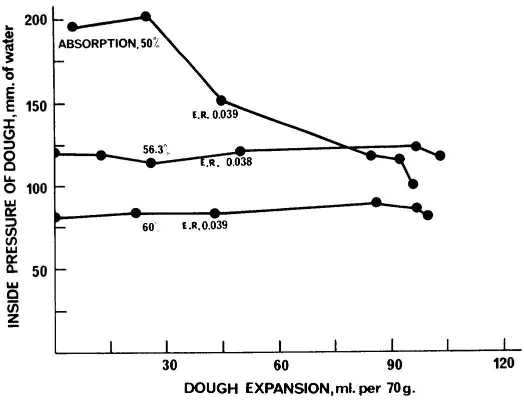

Fig. 3. Plots of dough expansion vs. inside pressure for three levels of absorption: 50, 56.3, and 60%. (E.R. is expansion rate (ml. per min. per g. of dough) at the point indicated.)

Amount of Dough (g.)	*Height of Dough (mm.)*	*Maximum Pressure (mm.)*
90	52	146
70	32	120
60	27	92

Differences in maximum pressure are larger than those calculated from the height of the dough. The higher friction of dough at the glass wall in the smaller tube is probably the main factor for the higher pressure observed.

Effect of Flour Strength on the Inside Pressure of Dough

Two flours which have different strength, as stated in the paragraph on "Materials", were used for the preparation of doughs. The absorption was adjusted with the farinograph at standard consistency. The results are shown in Fig. 6. Higher pressure was found in the dough made from the stronger flour.

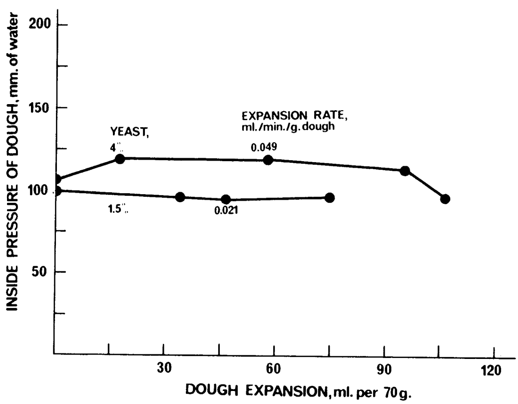

Fig. 4. Plots of dough expansion vs. inside pressure for levels of 1.5 and 4% yeast.

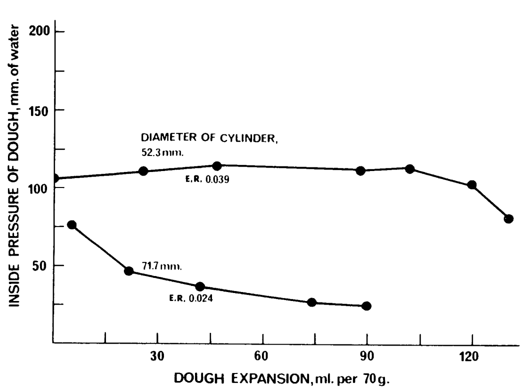

Fig. 5. Plots of dough expansion vs. inside pressure for two different cylinders, 52.3 and 71.7 mm. diameters. (E.R. is expansion rate (ml. per min. per g. of dough) at the point indicated.)

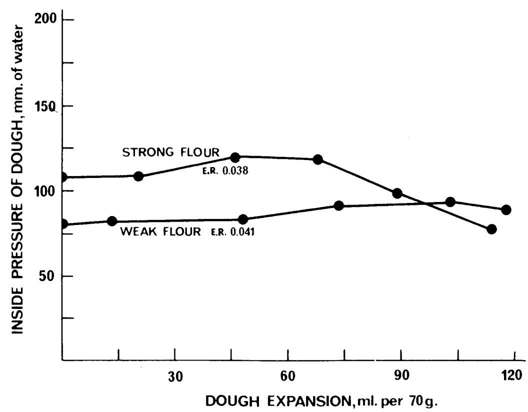

Fig. 6. Plots of dough expansion vs. inside pressure for a weak and strong flour. (E.R. is expansion rate (ml. per min. per g. of dough) at the point indicated.)

DISCUSSION

Fermenting dough is composed of a great number of small gas cells. The membranes of the gas cells are the continuous phase of gluten scattered with starch granules, yeast cells, and other ingredients, as shown by Sandstedt et al. (9). This membrane, or gluten film, is subjected to gradual extension by the pressure of carbon dioxide produced by yeast.

On the assumption that gas cells have a spherical top, the pressure (p), caused by the tension of cell membrane σ, is expressed by equation 1,

$$\rho = \frac{2\sigma\Delta}{r} \tag{1}$$

where r is the radius of gas cells and Δ is the thickness of the membrane (10). Thus the excess pressure (P) over the atmospheric pressure in dough at the bottom is expressed as equation 2, where h is initial height of dough, P_1 is the density of dough, and g is the acceleration due to gravity.

$$P = \frac{2\sigma\Delta}{r} + P_1 gh \tag{2}$$

Although there are numerous gas cells of various shapes, they have a definite inside pressure under equilibrated conditions. Equation 2 can be applied to each gas cell, assuming a spherical top with radius r. One should be able to derive the pressure in the complicated multicell system based on this simple hypothesis, but it is not discussed here.

The rubber film on (A) in Fig. 1 transmits the pressure in dough to the Brody liquid in the capillary tube as long as it is extended flat on the inside tube which occupies only the center part of bottom stopper. The tension of the rubber film and the dough film at the bottom will not affect the pressure, since the radius of these membranes is infinite in equation 1 while they are flat, and p is nearly zero when no convexing or concaving is observed. It is also confirmed in experiment 1.

The tension of the dough membrane on top is assumed to be one of the factors causing pressure P, since pressure falls down on collapsion at the extension limit of membrane. The pressure-expansion relationship in this experiment can be considered analogous to the alveogram, but with numerous gas cells instead of a single gas cell as in the alveograph test. It is also utilized for the rheological study of a gas-cell membrane, using equation 2.

Experiment 2 indicates that the inside pressure of dough remains essentially constant during a definite time range of expansion except when the larger cylinder of 71.7 mm. diameter is used. Relatively constant bubble pressure was also calculated by Hlynka and Barth (11) in the expansion of the alveograph bubble, and by Tschoegl et al. (12) in dough-extension tests with a Statham load cell. Baker and Mize (8) also reported this phenomenon with an expanding rubber balloon.

Extrapolation of this experiment to the condition of no effect on the cylinder wall could lead to a new field of dough rheology.

However, as the estimation of dough pressure is carried out in a glass cylinder, the friction between dough and wall of cylinder, and between layers of dough, must be considered as factors of dough pressure. Data relating to this friction of cylinder might also be of value in studying the practical problem of dough expansion in the baking pan. The friction in capillary flow is expressed by Poiseuille's law for Newtonian liquids, as shown in equation 3,

$$\eta = \frac{P\pi R^4}{8\ vl} \tag{3}$$

where P is pressure pushing the liquid from one end of the capillary tube of radius R, v is the velocity of flow through the tube expressed as volume per sec., l is the length of the tube, and η is the viscosity.

Assuming that the behavior of expanding dough in a cylinder follows Newtonian behavior, the calculated value of η from equation 3 was about 2.3×10^6 poise, using $l = 1.69$, $v = 0.045$, $R = 2.6$, and $P = 9.8 \times 10^3$. A higher pressure than that expected from the height of the dough ρgh was found in the tube of smaller radius and with a larger amount of dough. This indicates that friction of viscous dough is one of the components of the estimated pressure. Higher pressure was also given by dough with lower absorption in experiment 2, and with rapidly rising dough with higher content of yeast in experiment 3. These phenomena are in agreement with Poiseuille's law, since higher viscosity of dough with lower absorption was shown by Halton and Scott Blair (13); and a larger value of v in equation 3 results in higher pressure when other components are constant.

When Maxwell's model is assumed in dough, equation 4 is established on deformation, γ, as a differential with time, t, under a force, F, where G is elastic modulus.

$$\frac{d\gamma}{dt} = \frac{1}{G}\frac{dF}{dt} + \frac{F}{\eta} \tag{4}$$

If pressure differential is small enough during a fixed time interval, dF/dt becomes small and the deformation can be considered Newtonian.

The deformation of dough in the cylinder is more complicated than indicated by these assumptions. The pressure remained almost constant in experiments 2,3. However, a decrease in pressure was observed with the cylinder of larger radius (Fig. 5), and increasing pressure was observed with a larger amount of dough with the normal cylinder.

These phenomena will be discussed in a subsequent paper showing the effect of improving agents on the pressure exerted by the dough.

Experiment 5 suggests that inside pressure-dough expansion tests can be used to evaluate flour strength, and further developments may be made here.

The pressure inside the dough measured in this investigation ranged from 35 to 200 mm. water column. This value is close to that reported by Baker and Mize (8) (20- to 50-mm. oil column with density 0.85 g. per $cm.^3$ and that by Bailey (7) (23.53-mm. mercury column). These values are close to each other, considering that the doughs, flours used, and the method of preparation of dough were no doubt considerably different.

Literature Cited

1. MILLER, H., EDGAR, J., and WHITESIDE, A. G. O. A small-scale dough expansion test for the estimation of wheat quality. Cereal Chem. 28: 188 (1951).
2. MILLER, H., EDGAR, J., and WHITESIDE, A. G. O. An improved small-scale dough expansion test for the estimation of wheat quality. Cereal Chem. 31: 433 (1954).
3. ELLING, H. R., and BARMORE, M. A. Microtests for flour quality. Cereal Chem. 38: 349 (1961).
4. HALTON, P. Significance of load-extension tests in assessing the baking quality of wheat flour doughs. Cereal Chem. 26: 24 (1949).
5. MAREK, CECYLIA J., and BUSHUK, W. Study of gas production and retention in doughs with a modified Brabender Oven-Rise Recorder. Cereal Chem. 44: 300 (1967).
6. MAREK, CECYLIA J., BUSHUK, W., and IRVINE, G. N. Gas production and retention during proofing of bread doughs. Cereal Sci. Today 13: 4 (1968).
7. BAILEY, C. H. Gas pressure in fermented doughs. Cereal Chem. 32: 152 (1955).
8. BAKER, J. C., and MIZE, M. D. Effect of temperature on dough properties. II. Cereal Chem. 16: 682 (1939).
9. SANDSTEDT, R. M., SCHAUMBURG, LORENE, and FLEMING, J. The microscopic structure of bread and dough. Cereal Chem. 31: 43 (1954).
10. BLOKSMA, A. H. A calculation of the shape of the alveograms of some rheological model substances. Cereal Chem. 34: 126 (1957).
11. HLYNKA, I., and BARTH, F. W. Chopin alveograph studies. I. Dough resistance at constant sample deformation. Cereal Chem. 32: 463 (1955).
12. TSCHOEGL, N. W., RINDE, J. A., and SMITH, T. L. Rheological properties of wheat flour doughs. I. Method for determining the large deformation and rupture properties in simple tension. J. Sci. Food Agr. 21: 65 (1970).
13. HALTON, P., and SCOTT BLAIR, G. W. A study of some physical properties of flour doughs in relation to their breadmaking qualities. Cereal Chem. 14: 201 (1937).

[Received October 26, 1970. Accepted June 21, 1971]