

Internal Pressure in Yeasted Dough II¹

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ABSTRACT

An automatic system for measuring and recording internal pressure in yeasted dough, an improved version of the manual system reported in a previous paper, is described. With this system, higher or increasing pressure was observed in dough oxidized with iodate, bromate, and L-ascorbic acid. Alternately, with reducing agents such as glutathione, pressure remained constant. Assuming Maxwell's rheological model for dough, it was calculated that viscosity and rate of expansion determine the tension of the gas cell membranes, and hence internal pressure in fermenting dough.

Rheological properties of dough should be studied under conditions of slow deformation and large strain, as much as 200 to 300%, in order to approach the conditions in practical baking science. As pointed out by Bloksma (1), the present dough-testing instruments, such as the extensigraph or alveograph, employ rates of deformation approximately 1,000 times more rapid than those encountered in practical dough expansion during yeast fermentation.

For the study of elasto-viscous properties of dough, the most suitable deformation should be that of expansion of dough itself by the carbon dioxide produced by yeast, provided that stress can also be measured as internal pressure.

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In a preliminary report (2) the present authors described a method for measuring internal pressure in dough. The apparatus utilized a rubber diaphragm as a pressure-sensing element, a manually adjusted leveling bulb for adjusting pressure, and a sensitive manometer on which the pressure in the system was read. This paper presents results obtained with an improved version of the apparatus with automatic pressure adjustment and an automatic pressure recording system. Some modifications were also made in the sample-holding cylinder in order to minimize friction between the dough sample and cylinder wall. Theoretical discussion of data obtained is also presented.

MATERIALS AND METHODS

The equipment used in this experiment is shown as a diagram in Fig. 1.

A sample of 90 g. of dough is inserted in the bottom of the cylinder C and pressed from below with the rubber diaphragm of the pressure detector D. The pressure-sensing electrolyte, one normal solution of cupric sulfate, is filled under this rubber diaphragm and is led out with a capillary tube to the rest of the pressure-adjusting system.

Without dough, the diaphragm is spread flat on the cylinder D, and the pressure-sensing electrolyte reaches the mark L in the capillary. With the dough sample in place, the rubber diaphragm is pressed downward by the weight of the dough itself and by the gas pressure developed in the dough, causing the level of the pressure-sensing electrolyte to rise above the mark L. Thus the electric circuit between Cu-wire (positive electrode) and Pt-wire (negative electrode) is closed by the electrolyte of cupric sulfate solution. This activates the peristaltic pump through the relay system to raise the opposing pressure in cylinder P. When the pressure in P becomes equal to or larger than the pressure of the dough on the rubber diaphragm, the level of the pressure-sensing electrolyte drops to L, or lower. Thus the circuit is opened and the pump works in the reverse way. By now the rubber diaphragm has recovered its original flat position. In this way, the pressure at point L and in P is indicated to be the same as that pressing on the rubber diaphragm.

This pressure is converted to electric potential by a differential transformer (TP31G) and converter (ATP3), made by Tokyo Kokukeiki. The potential is recorded by a Uvicon (TU200) recorder as change of pressure with time. The recorded pressure is calibrated with a manometer.

The potential provided by the relay to the positive electrode is 12 v. The Cu-wire electrode has a constantly renewed surface as a result of copper ions from the surface going into solution. One drop of kerosene on the surface of the pressure-sensing electrolyte in the capillary helps a sharp break of the circuit and makes for higher sensitivity.

Doughs for experiments were prepared by mixing 200 g. unbleached flour, 4 g. yeast, 5 g. sugar, and 2 g. salt in a GRL (Grain Research Laboratory) mixer with two straight pins and one curved pin at 64 r.p.m. for 7 min. at 30°C. The absorption was 61.5%, and was determined with a farinograph with 300 g. of the same flour and with the same ingredients, but at one and one half times the quantities shown above. A sample of 90 g. of dough was weighed and, after rounding by hand, was rested for 10 min. at 30°C. The dough was sheeted and folded by hand according to AACC procedure for the test baking method (3).

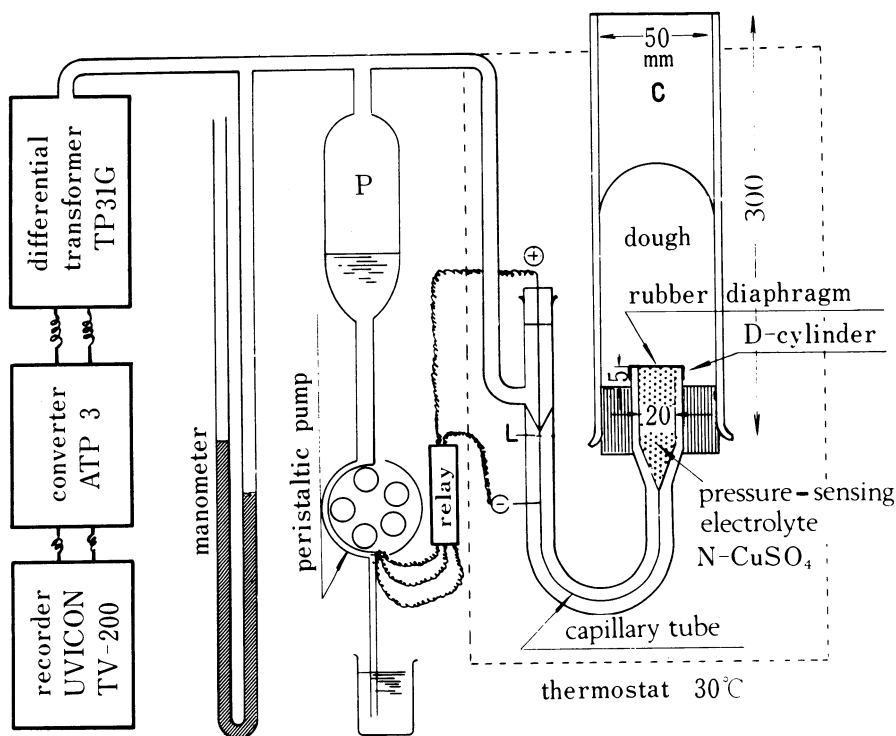


Fig. 1. Automatic recording apparatus for recording inside pressure of yeasted dough.

Finally, the dough sample was folded at the center and inserted into the glass cylinder from the bottom, keeping the spherical head up. This procedure is important in order to obtain reproducible results.

The glass cylinder was greased with liquid paraffin and the top of the dough sample in the cylinder was covered with 1 ml. of the same paraffin to minimize friction during expansion. The expansion of dough in a cylinder at a thermostat of $30^{\circ}\text{C.} \pm 0.01$ was measured with a cathetometer, and expressed as height in mm. A height of 10 mm. was equal to approximately a volume of 20.0 ml. of dough, depending on the cylinder used.

The flour used in this test was unbleached commercial strong flour containing 12.1% protein, 0.32% ash at 14% moisture basis, and was provided by Nissin Flour Mill Co.

RESULTS

Blank Test with Water

In order to check the accuracy of the system, tests were carried out with water instead of dough. The chart shown in Fig. 2 records the pressure after each of eight successive additions of 40 ml. of water to the cylinder. The additions were timed at 6 min. intervals.

The height of water column in the cylinder after each addition is shown on the

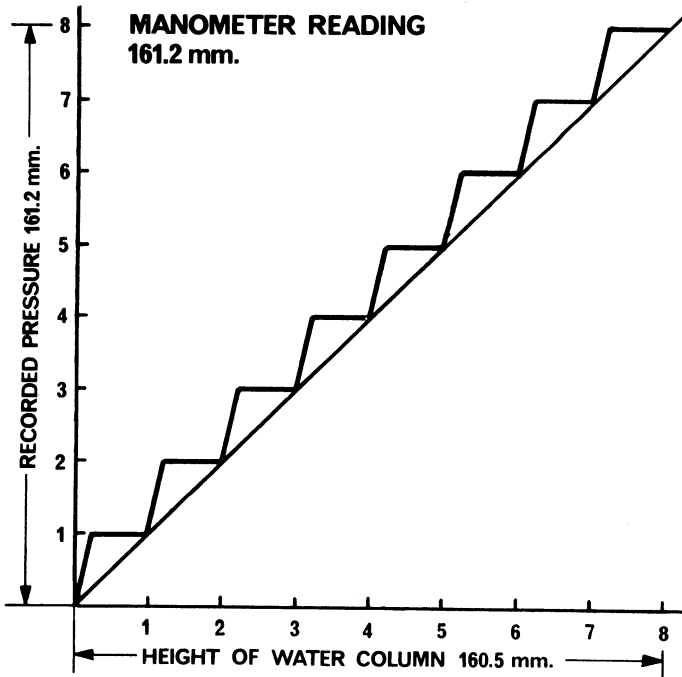


Fig. 2. Chart for blank test showing recorded pressure vs. height of water column for eight consecutive additions of water to dough cylinder.

abscissa as $n \times 20.3$ mm. where n is the number of the increment added. Similarly, the ordinate shows the pressure at each recorded level with the final pressure of 161.2 mm. checked with a manometer.

Table I compares the pressure calculated from the chart with the actual measurement of the height of water column in the cylinder after each addition of water. The results from automatic recording on the chart and from independent direct measurement of the height of water column are in good agreement (within 1 to 2% deviation), and show the reliability of the apparatus.

Figure 2 also indicates that the apparatus responded to a change of 20 mm. in pressure within 1.1 min. Thus the response time of the apparatus is 18 mm. per min. However, this slow response is entirely adequate because of the slow change in pressure normally encountered in fermenting dough.

The Effect of Oxidizing and Reducing Agents on Internal Pressure in Dough

Figure 3 shows the results obtained when doughs were treated with 40 p.p.m. of iodate, bromate, L-ascorbic acid, or glutathione, as well as for the control test.

In comparison with results from the control experiment, higher internal pressures were obtained with oxidizing improvers, and lower pressure with glutathione. An interesting difference is shown between the effect of bromate and iodate. Doughs treated with bromate and ascorbic acid showed an initial decrease in internal pressure, perhaps caused by relaxation, followed by increasing pressure with time. With iodate, which is known to be a rapidly acting improver, a high

TABLE I. RECORDED PRESSURE VS. HEIGHT OF WATER COLUMN

Increment No.	Height of Water Column ^a mm.	Calculated Pressure ^b mm.
1	20.3	20.8
2	40.6	40.6
3	60.3	61.4
4	80.4	82.0
5	100.2	100.1
6	120.2	122.0
7	140.6	141.5
8	160.5	161.2

^aMeasured with a cathetometer.

^bCalculated from chart levels (Fig. 2): final pressure, 161.2 mm.

initial pressure is obtained followed by a decrease with time, indicating over-oxidation or some other effect. This is confirmed in Fig. 4. Additions of 0 to 17.5 p.p.m. iodate showed increasing pressure with time, resembling the effect of bromate, and the curve for 20 p.p.m. is higher than that of 40 p.p.m. The results for both 20 and 40 p.p.m. iodate appear to indicate over-oxidation or over-treatment.

Expansion of Dough during Recording Pressure

The expansion of dough in the cylinder was followed with a cathetometer by measuring the height of the top. The top of the dough is not flat but, theoretically, parabolic. If the parabolic head is assumed to have fixed dimensions during the expansion test, an approximate measure of expansion may be obtained by subtracting from the height of the dough at time *t* the value of its original height.

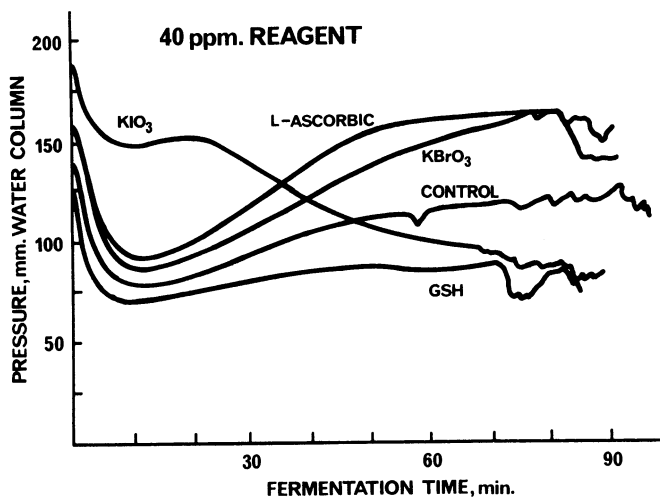


Fig. 3. Chart curves show inside pressure for yeasted doughs treated with 40 p.p.m. oxidizing and reducing agents during 90 min. fermentation.

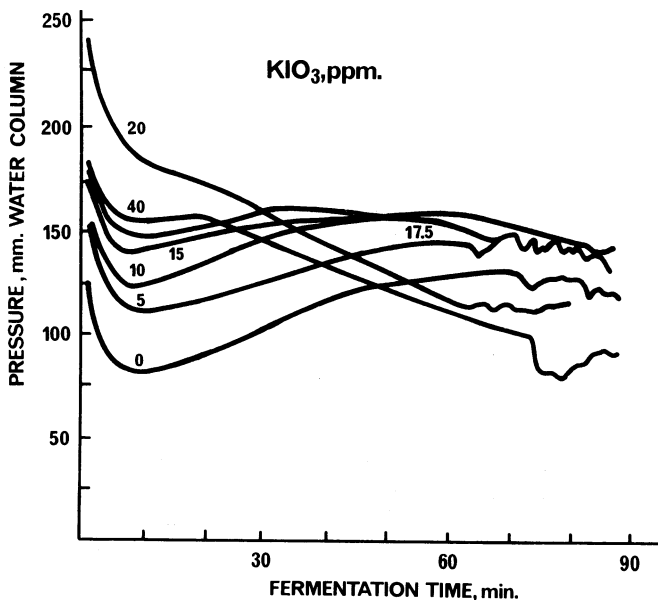


Fig. 4. Chart curves show inside pressure for yeasted doughs treated with 0 to 40 p.p.m. iodate during 90 min. fermentation.

The height of dough with a parabolic head at the beginning of the test is about 45 to 47 mm. above the rubber stopper level, depending on the size of the air bubble occluded.

The curves in Fig. 5 indicate that the rates of expansion are similar for all four doughs during the first 70 min., though some differences were observed in the expanded volume. The curve with iodate is not shown here, but it is similar to that of bromate.

DISCUSSION

As shown previously (2), the pressure measured with this method is assumed to be the sum of the weight of dough itself and of the internal pressure in the gas cells. The initial height of dough in the cylinder is about 45 mm., and the specific gravity of dough is 1.1. Thus, the measured pressure minus the pressure due to the weight of dough (45×1.1) may be considered representative of the pressure inside the gas cells, as long as the rubber diaphragm is flat over the cylinder D (Fig. 1).

A model spherical gas cell, diagramed in Fig. 6a, shows the general relation between the inside pressure P and the tension on diagram T as equation 1,

$$P = \frac{2T\Delta}{R} \quad (1)$$

where Δ is the thickness and R the radius of the spherical diaphragm (4). When numerous vertical cylindrical gas cells, with spherical heads as shown in Fig. 6b, are assumed for dough, equation 1 may also be applied to the relation between tension on the diaphragm and inside pressure.

This equation can also be applied to a multi-cell system shown in Fig. 6c, provided that extension occurs only in vertical cell membranes.

Thus the relationship between internal pressure and tension on the membrane can be obtained by modifying equation 1 for the multi-cell system in flour dough as shown in Fig. 6d if fusion or division of cells does not occur.

If this modification is carried out by introducing a constant, and calculating thickness Δ as a function of h_0/h , then equation 2 is obtained,

$$p = \frac{2T}{R} \cdot \frac{kh_0}{h} \tag{2}$$

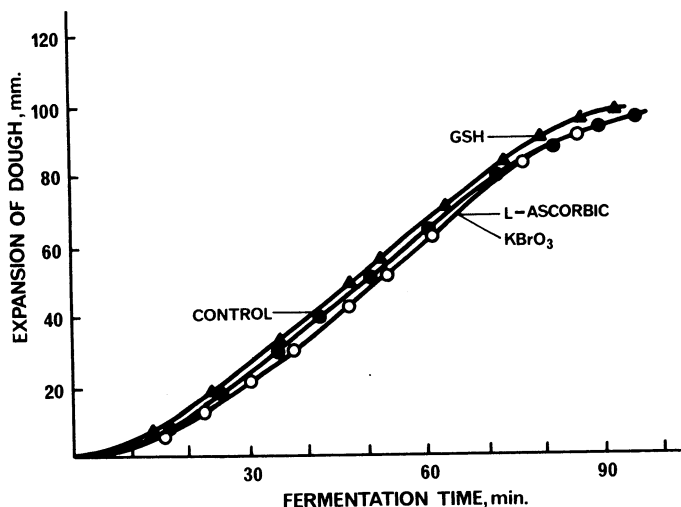
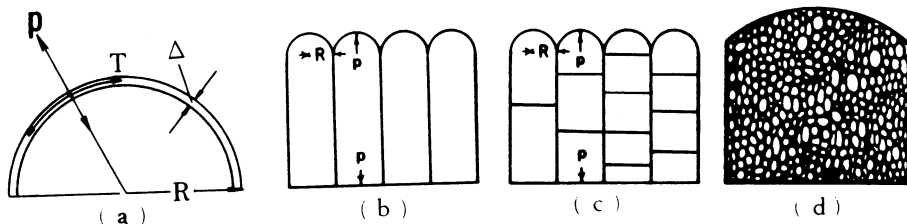


Fig. 5. Rate of expansion for yeasted doughs (90 g.) with oxidizing and reducing agents added during 90 min. fermentation; 10 mm. dough height is equivalent to 19.6 ml. volume.



T : Tension of Cell wall
 Δ : Thickness of Cell wall
 R : Radius of Cell

$$p = \frac{2T\Delta}{R}$$

p : INTERNAL PRESSURE

Fig. 6. Theoretical models illustrating relation between tension and pressure of gas cells in yeasted dough.

that is, the wall becomes thinner as dough expands longer in a cylinder, where k is a constant, h_0 the height of dough at the beginning of the test, and h the height at time t . Thus the inner pressure of dough is expressed in terms of variables h and T . R is constant as long as dough expansion takes place in the same cylinder without fusion or division of cells, and gas cells expand vertically to the top.

Some experimental results are required to test the validity of equation 2 and its applicability to dough. However, its validity will be assumed for the purpose of this discussion.

Halton and Scott Blair (5) assumed a Maxwell model for dough which is given by equation 3. This system is also provided with this equipment during relaxation of pressure.²

$$\frac{d\gamma}{dt} = \frac{1}{G} \cdot \frac{dT}{dt} + \frac{T}{\eta} \quad (3)$$

In this equation γ is deformation, T is stress, t is time, and η and G are viscosity coefficient and elastic modulus, respectively. Differential equation is solved as equation 4,

$$T = [T_0 + \int_0^t G\dot{\gamma}\exp\left(\frac{t}{\tau}\right) dt] \exp\left(-\frac{t}{\tau}\right) \quad (4)$$

where T_0 is tension at time zero, $\dot{\gamma}$ is a differential of γ with respect to t , τ is η/G or relaxation time, and \exp means exponential.

Thus the tension consists of a product of a relaxation component $\exp(-t/\tau)$ and the rate of increase in stress $\dot{\gamma}\exp(t/\tau)$.

When $\dot{\gamma}$ is assigned a fixed value C , based on data shown in Fig. 5,

$$\int_0^t G\dot{\gamma}\exp\left(\frac{t}{\tau}\right) dt = GC\tau \left[\exp\left(\frac{t}{\tau}\right) - 1 \right] \quad (5)$$

From equations 4 and 5, equation 6 is obtained:

$$T = \left\{ T_0 + GC\tau \left[\exp\left(\frac{t}{\tau}\right) - 1 \right] \right\} \cdot \exp\left(-\frac{t}{\tau}\right) = \eta C + (T_0 - \eta C)\exp\left(-\frac{t}{\tau}\right) \quad (6)$$

This means that tension of cell membranes is brought about by a product of extension rate of dough C , and viscosity η , and also by the relaxation factor $\exp(-t/\tau)$.

The change of pressure with time, shown in Fig. 3, can now be discussed with the aid of equations 6 and 2, as they have the same C .

The increase of tension T with time t in equation 6 may be calculated for the case $T_0 < \eta C$. If this increment of T is just canceled by h_0/h in equation 2, the pressure will remain constant during a limited time interval. When the time increment of T exceeds the decrease of h_0/h , the pressure will increase. The higher viscosity is assumed to bring about this condition at constant C . In this discussion, equation 1 is applied to gas cells in dough with rather large assumptions. However, substantial modification of this equation should be carried out on the basis of further basic research work on expanding dough.

Elastic modulus and viscosity may undergo changes during the experiment over

²Matsumoto, H., and Nishiyama, J. Unpublished data (1972).

a long time interval such as 90 min. Equation 5 also may be applied over short time intervals, for example, from 30 to 33 min., or from 90 to 93 min. The model used in this discussion may eventually be extended to four elements or a 4-parameter rheological model. For the time being, however, the relation between dough rheology and the inside pressure of dough may be clarified in more detail through further work in the present direction, since the rate of deformation is slow in this case.

The increase of internal pressure in oxidized dough and constant pressure in reduced dough, shown in Fig. 3, seem to be interesting phenomena during dough fermentation. Although increase and decrease of extensigraph resistance (7,8) are reported for oxidized dough and for reduced dough, respectively, the results of present experiments are significant in that measurements were made over a long time interval, as long as 90 min., in which both relaxation and deformation progress simultaneously and in that stress is brought about by gas pressure in the gas cells of yeasted dough.

The deformation of dough brought about by yeast fermentation is directly associated with practical breadmaking. At the same time, the results may be analyzed in terms of basic dough rheology if equations 1 and 2, with appropriate modifications, are assumed to be applicable to gas cells in dough.

In view of pressure-time curves in Figs. 3 and 4, leakage of gas from the dough can be observed as a drop in pressure at the final part of estimation. This phenomenon shows interesting correlation with the zymotachygraph curve, though the latter indicates volume of CO₂ produced or air displaced during unit period.

Literature Cited

1. BLOKSMA, A. H. Slow creep of wheat flour doughs. *Rheol. Acta* 2: 217 (1962).
2. MATSUMOTO, H., NISHIYAMA, J., and HLYNKA, I. Internal pressure in yeasted dough. *Cereal Chem.* 48: 669 (1971).
3. AMERICAN ASSOCIATION OF CEREAL CHEMISTS. AACC Approved methods. The Association: St. Paul, Minn. (1962).
4. BLOKSMA, A. H. Calculation of the shape of alveograms of some rheological model substances. *Cereal Chem.* 34: 126 (1957).
5. 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).
6. YANAGISAWA, N., et al. Deformation and flow. An elementary introduction to theoretical rheology. Transl. by M. Reiner. Colona Pub.: Tokyo (1957).
7. SMITH, D. E., and ANDREWS, J. S. Effect of oxidizing agents upon dough extensograms. *Cereal Chem.* 29: 1 (1952).
8. VILLEGAS, E., POMERANZ, Y., and SHELLENBERBER, J. A. Effects of thiolated gelatins and glutathione on rheological properties of wheat doughs. *Cereal Chem.* 40: 694 (1963).

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