

RHEOLOGY OF FERMENTING DOUGH

H. MATSUMOTO, J. NISHIYAMA, T. MITA, and T. KUNINORI, Osaka Women's University, Tezukayama, Sumiyoshi-Ku, Osaka, Japan

ABSTRACT

An apparatus was developed for measuring the internal pressure of dough. The apparatus was used to record the pressure of fermenting and nonfermenting doughs containing oxidizing and reducing agents. Oxidizing agents (KBrO_3 and KIO_3) increased, while reducing agents (glutathione) decreased the internal pressure of fermenting doughs. In nonfermenting doughs, internal pressure decreased during stress relaxation; the decrease was slower in oxidized, and faster in reduced doughs. A relation between internal pressure and some rheological properties of the membrane of dough gas cells was developed from the equation for the Maxwell rheological element assuming hemispherical symmetry for the gas cell.

Most rheological studies on dough during the past 30 years were done on unyeasted dough. However, the findings with unyeasted dough must be extended to yeasted dough for the practical application of dough rheology.

Special features of yeasted dough in comparison with unyeasted dough are as follows:

(1). Fermenting dough is comprised of a large number of small gas cells. The membranes of these cells are subjected to a slow extension by the pressure of carbon dioxide produced by the yeast. The rheology of fermenting dough is the rheology of cell membranes and that of multicell systems.

(2). The rate of extension of the gas cell membrane is very slow; in comparison with the rate of extension with the Brabender Extensograph it is about $1/300 \sim 1/1000$.

(3). The deformation of the membrane is relatively larger than that experienced by a dough test piece in a usual rheological test; at times it reaches 100 to 200% of the original area.

Considering these features, research on rheology of yeasted dough must be carried out with special methods and the data must be interpreted from a different viewpoint than those used for unyeasted doughs. The additional effect of yeast on this complex system can be overcome to some extent by comparing each result to that for the control dough and by examining one variable while all others are kept constant.

This article deals with a method developed by the authors to estimate the inside pressure of dough during the fermentation. Some conclusions on the rheological properties of yeasted doughs are made on the basis of model systems for small and large deformations.

METHODS

The pressure measuring and recording system used is shown in Fig. 1 (1).

In the actual experiment, the dough sample is inserted in the bottom of the cylinder C and pressed from below with the rubber diaphragm of the pressure detector D. The space under the rubber diaphragm is filled with the pressure-sensing electrolyte (1N cupric sulfate). The electrolyte is connected with the pressure-adjusting system through a capillary tube.

Without dough, the diaphragm is flat inside the cylinder C (diameter 20 mm), and the pressure-sensing electrolyte reaches the mark L in the capillary. With the dough sample in place, the rubber diaphragm is depressed 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 P₁-wire negative electrode is closed by the electrolyte solution. This activates the peristaltic pump through a 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. The circuit is opened and the pump operates in reverse. The rubber diaphragm then recovers its original flat position. At this moment, the pressure at point L and in P is the same as that pressing on the rubber diaphragm. This pressure is converted to electric potential by a differential transformer (TP31G) and converter (ATP3) (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 was 12V. 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 promotes a sharp break of the circuit and makes for higher sensitivity.

Dough was prepared by mixing 200 g unbleached flour, 4 g yeast, 5 g sugar, and 2 g salt in the GRL mixer (2) for 7 min at 30°C. Doughs for the relaxation experiment were mixed without yeast. A 90-g sample of dough was weighed, and after rounding by hand, was rested for 10 min at 30°C. The dough was sheeted

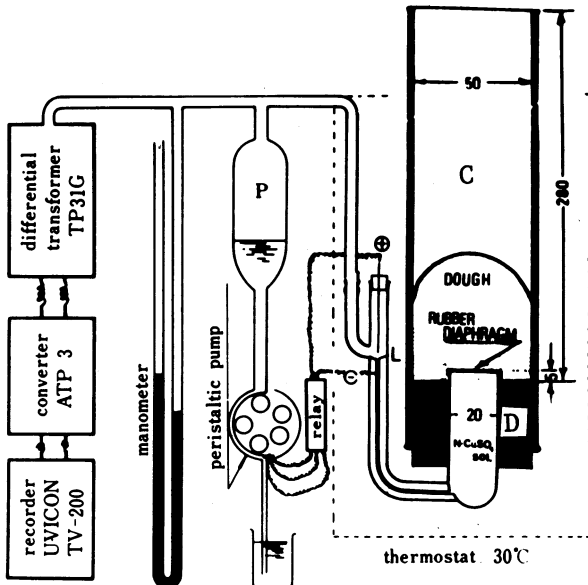


Fig. 1. Automatic recording apparatus for recording inside pressure of dough.

and folded by hand as in the AACC test baking procedure. Finally, the dough sample was folded at the center and inserted into the glass cylinder C from the bottom with the spherical surface up. This procedure for inserting the dough test piece is important in order to obtain reproducible results. The dough was brought into contact with the rubber diaphragm by pressing up from the bottom of cylinder. The pressure inside the cylinder was calibrated by increasing stepwise the level of the water in the cylinder.

RESULTS

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

Figure 2 shows the results obtained for a control dough, and doughs treated with 40 ppm of iodate, bromate, or glutathione.

In comparison with results for the control dough, higher initial internal pressures were obtained for doughs treated with oxidizing improvers, and lower pressures for the dough containing glutathione. An interesting difference was observed between the doughs containing bromate and iodate. Dough treated with bromate showed an initial decrease in internal pressure, perhaps caused by relaxation, followed by increasing pressure with time. The iodate-treated dough had a high initial pressure which was followed by a rapid decrease after about 20 min. The initial difference between the effects of bromate and iodate is attributed to the more rapid reaction of the latter reagent. Decrease of internal pressure after 20 min in dough containing 40 ppm iodate is attributed to overoxidation. This was confirmed in another experiment (results not shown). Additions of 0 to 17.5 ppm iodate showed increasing pressure with time, resembling the effect of

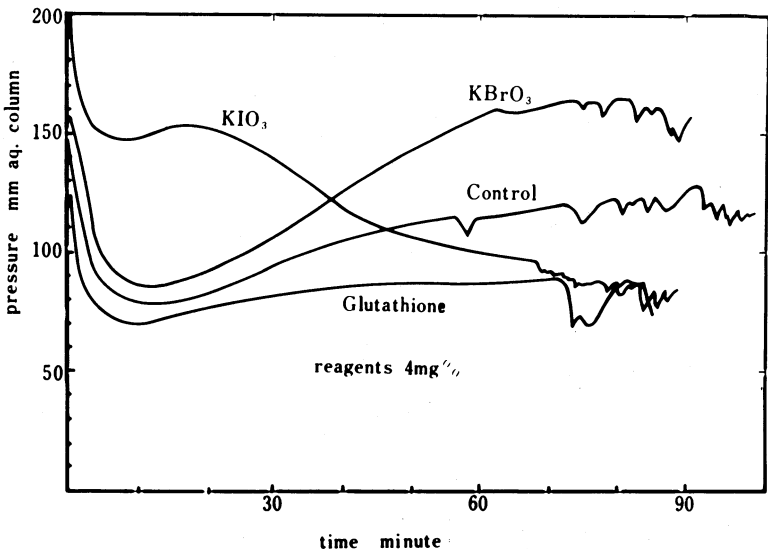


Fig. 2. Chart curves showing inside pressure of yeasted doughs treated with 40 ppm of oxidizing (potassium iodate and potassium bromate) and reducing (glutathione) agents during 90-min fermentation.

bromate; the curve for 20 ppm is higher than for 40 ppm. The results for both 20- and 40-ppm-iodate appear to indicate overoxidation or overtreatment.

The Effect of Oxidizing and Reducing Agents on Relaxation of Internal Pressure of Unyeasted Dough

Figure 3 shows the relaxation of pressure of unyeasted doughs that were initially pressed against the rubber diaphragm at the same pressure. The ordinate is logarithm of corrected pressure ($P_t - P_o$) and abscissa is time in minutes, where P_t is pressure at time, t and P_o is pressure caused by the weight of dough itself (product of height of dough and density, 1.21).

The logarithmic plots in Fig. 3 were essentially linear from 10 to 50 min. The slope of the straight lines was decreased by adding bromate and iodate (oxidizing agents) and increased by adding cysteine (reducing agent).

The straight portion of the logarithmic plots of Fig. 3 can be represented by the equation,

$$\log (P_t - P_o) = -kt + c \quad (1)$$

where k and c are constants, and t is time. If a simple Maxwell's model is assumed, the relaxation time, τ , for the dough can be calculated from equations (2) and (3). P_i in equation (2) is the corrected pressure for time zero.

$$P_t - P_o = P_i \exp (-t / \tau) \quad (2)$$

$$\tau = 1/2.303 k \quad (3)$$

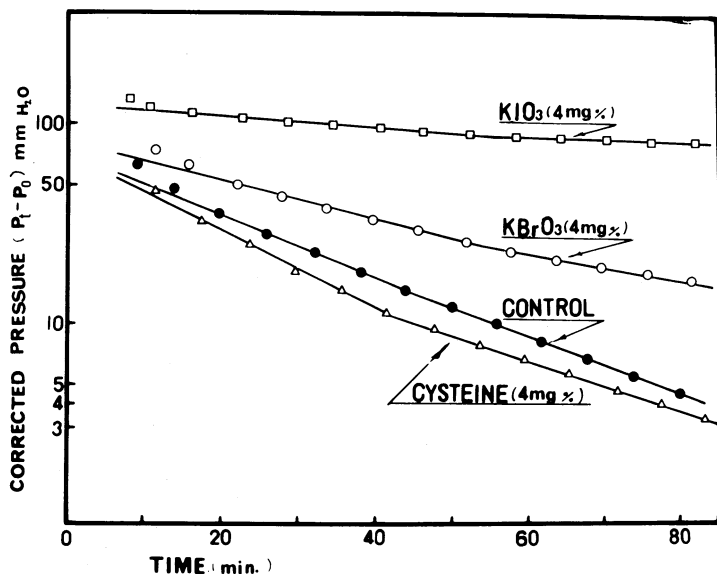


Fig. 3. Change of inside pressure during relaxation of unyeasted doughs treated with 40 ppm of oxidizing (KIO_3 and $KBrO_3$) and reducing (cysteine) agents.

The data obtained for various doughs at three reaction times (time between mixing and testing) are shown in Table I.

DISCUSSION

The elements that act on the rubber diaphragm at the bottom of the dough in the glass cylinder are discussed first. When the diaphragm is flat, the pressure on it will pass directly through to the pressure-sensing liquid. This was confirmed using water instead of dough in a blank test (1).

The pressure caused by resistance during the extension of dough in the cylinder, that is, the downward pressure produced as a reaction of the upward extension, must also be considered.

Gas cells in dough (Fig. 4c) are too numerous to consider theoretically. Accordingly, the authors have adopted the hemisphere (a) as the simplified model (Fig. 4). The actual experimental arrangement used is shown in Fig. 4b.

The relationship between pressure and tension of dough membrane in a gas cell is shown in Fig. 5. Various experimental data are required to confirm this relationship for dough. However, it is reasonable to assume that a direct relationship may exist between tension of membrane (T) and the inside pressure of a gas cell (P). This relationship may be simple like equation (4), or more complex.

The assumption that the pressure (P), measured with the apparatus shown in Fig. 1, can be converted to the tension of membrane (T) by some equation is justified by the following discussion.

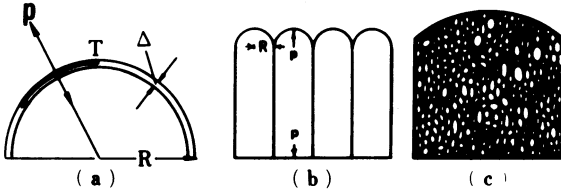
Halton and Scott Blair (3) assumed a Maxwell model for dough which is represented by equation (4). This model is applicable to the system investigated in the present study during relaxation of pressure for the range of relaxation times (10 to 50 min) used (4). The differential equation for the Maxwell model (5), is solved to give equation (6) for membrane tension. 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 , equation (7) is obtained; ($\dot{\gamma} = d\gamma/dt$, the change of strain with time).

Equation (7) shows that tension of dough-cell membranes is brought about by

TABLE I
Relaxation Constant (k) and Relaxation Time (τ) of Various Doughs at Four Reaction Times

Additives	Reaction Times (hr)							
	0		1		2		3	
	$k \times 10^2$	τ min	$k \times 10^2$	τ min	$k \times 10^2$	τ min	$k \times 10^2$	τ min
Control	1.59	25.6	1.67	26.0	1.60	27.1	...	...
KBrO ₃ 2 mg %	1.43	30.4	1.38	31.5	1.24	35.0	0.889	48.8
KBrO ₃ 4 mg %	1.14	38.1	0.910	47.7	0.828	52.5	0.606	71.6
KBrO ₃ 6 mg %	1.12	38.8	0.862	50.4	0.681	63.7	0.468	92.8
KIO ₃ 4 mg %	0.314	138	0.280	155	0.247	176	0.252	172
L-AsA ^a 4 mg %	...	...	0.771	52.1	...	...	...	...
Cysteine 4 mg %	...	...	1.86	23.4	...	...	...	...

^aAscorbic acid.



$$p\pi R^2 = 2\pi RT\Delta$$

$$p = \frac{2T\Delta}{R} \dots\dots\dots (4)$$

T : Tension of Cell wall
 Δ : Thickness of Cell wall
 R : Radius of Cell
p : INTERNAL PRESSURE

OVERALL PRESSURE

$$P = p + \rho gh$$

AT THE BOTTOM

ρ : density of dough
 h : height of dough
 g : velocity acceleration of gravity

Fig. 4. A simplified model for gas cells in dough and equations for internal (p) and overall (P) pressures.



Maxwell Model

$$T = G\gamma_1 \quad T = \eta \frac{d\gamma_2}{dt}$$

$$\gamma = \gamma_1 + \gamma_2$$

$$\frac{d\gamma}{dt} = \frac{1}{G} \frac{dT}{dt} + \frac{T}{\eta} \dots\dots\dots (5)$$

γ₁, γ₂ : deformation
 T : tension
 G : Elasticmodulus η : Viscosity

$$T = \exp\left(-\frac{t}{\tau}\right) \left[T_0 + \int_0^t G \dot{\gamma} \exp\left(\frac{t}{\tau}\right) dt \right] \dots\dots\dots (6)$$

τ : relaxation time t : time
 T₀ : tension at time zero
 when $\frac{d\gamma}{dt} = \dot{\gamma}$ is fixed as C

$$T = \eta c + (T_0 - \eta c) \exp\left(-\frac{t}{\tau}\right) \dots\dots\dots (7)$$

T₀ = ηC T-keeps constant
T₀ < ηC T-increases with time

Fig. 5. A schematic representation of the Maxwell rheological model and equations for the variation of tension of dough membranes during extension derived from the mathematics of the model.

a product of extension rate C and viscosity η , and also by the relaxation factor, $\exp(-t/\tau)$. The change of pressure with time, shown in Fig. 2, can now be discussed with the aid of equation (7).

The increase of tension T with time t in equation (7) can be calculated for the case $T_0 < \eta C$. If this increment of T is cancelled by h_0/h , the thickness decrease (h_0 is initial height of dough and h is height at time t), the pressure will remain constant for 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, extensive assumptions were made in applying equation (4) to gas cells in dough. Further basic research on expanding doughs is required to obtain a more rigorous equation.

In addition to the phenomena discussed above, elastic modulus and viscosity of the dough membrane may undergo changes during the experiment. The increase of internal pressure in oxidized doughs and decrease of pressure in reduced dough during dough fermentation are interesting and deserve further study. Increase and decrease of extensigraph resistance (5, 6) have been reported for unyeasted oxidized and reduced doughs, 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 which the stress is brought about by gas pressure within the cells of yeasted dough. The higher pressure in oxidized dough can be explained by higher relaxation times. This was confirmed with the apparatus used in the present study to examine unyeasted dough (see Fig. 3 and Table I).

The deformation of dough brought about by yeast fermentation is generally associated with practical breadmaking. Nevertheless, the present study shows that it can be analyzed in terms of basic dough rheology. The simple model used should be modified to apply to the complex multicell system of dough and verified by appropriate experimental data. This article is only the first step in the research which attempts to apply basic dough rheology to practical breadmaking.

Literature Cited

1. MATSUMOTO, H., NISHIYAMA, J., and HLYNKA, I. Internal pressure in yeasted dough. II. *Cereal Chem.* 50: 364 (1973).
2. HLYNKA, I., and ANDERSON, J. A. Laboratory dough mixer with an air-tight bowl. *Cereal Chem.* 32: 83 (1955).
3. HALTON, P., and SCOTT BLAIR, G. W. A study of some physical properties of flour doughs in relation to their bread making qualities. *Cereal Chem.* 14: 201 (1937).
4. MATSUMOTO, H., ONO, H., and MITA, T. The relaxation of pressure in dough. *Cereal Chem.* 51:758 (1974).
5. SMITH, D. E., and ANDREWS, J. S. Effect of oxidizing agents upon dough extensograms. *Cereal Chem.* 29: 1 (1952).
6. VILLEGAS, E., POMERANZ, Y., and SHELLENBERGER, J. A. Effects of thiolated gelatins and glutathione on rheological properties of wheat doughs. *Cereal Chem.* 40: 694 (1963).