Relaxation of Pressure in Dough

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ABSTRACT

The internal pressure of unyeasted dough was estimated with an automatic pressure recording system. The pressure decreased from an initial higher pressure to a lower final pressure. This relaxation of pressure was characterized by a linear relationship between time and the logarithm of the corrected pressure. The slope (k) of these straight lines toward the time axis was reproducible, and decreased in the order bromate, ascorbic acid and iodate at 2 to 4 mg.% levels. With bromate, there was a progressive decrease in slope with reaction time from 0 to 3 hr., whereas with iodate, after an immediate decrease, there was little change with reaction time. Cysteine, on the other hand, increased the slope. From these observations, it is suggested that relaxation of pressure in an unyeasted dough is represented by a simple Maxwell model. Relaxation times calculated from the slope were 25 to 27 min. for control doughs, 30 to 176 min. for oxidized doughs containing bromate, iodate, or ascorbic acid, and 23 min. for reduced doughs containing cysteine. The method is compared with other relaxation tests.

During fermentation, dough in a proofing cabinet undergoes stress increase due to expansion, coupled with a dissipation of stress through flow or relaxation. These phenomena were observed and discussed in previous papers (1,2). Before study of the complicated yeasted system, stress relaxation in unyeasted doughs was first studied in a control experiment.

Papers dealing with relaxation in unyeasted dough can be classified into four groups. The first deals with relaxation of dough samples in the form of cylinder on a mercury pool (3–6). A similar method was used by other workers in the study of dough rheology (7,8,9). The second deals with stress relaxation of a dough ball impaled on split pins (10,11). The third group comprises relaxation tests with the extensigraph where the dough hook is stopped at a fixed extension (12). The last deals with structural relaxation using an extensigraph, an alveograph, or the "Simon" water absorption meter (13–16). These works are reviewed by Bloksma (17). The present paper shows the relaxation of internal pressure in unyeasted dough with the apparatus described in a previous paper (2).

MATERIALS AND METHODS

The flour was unbleached baking flour, brand name "Milling," provided by Nissin Flour Mill Co. The protein content was 12.65% and ash 0.53% at 14% moisture.

Doughs were prepared by mixing 200 g. unbleached flour for 7 min. at 30° C. in a GRL (Grain Research Laboratory) mixer at 64 r.p.m. with the ingredients shown in Table I. The same ratio of ingredients was used when bromate, iodate, ascorbic acid, and cysteine were incorporated.

The medium shown by Atkin et al. (18) was found to be useful to keep the gassing power of the yeast constant (19). Though yeast was not used in this experiment, the medium was used as a control against the behavior of yeasted dough, which will be described in a subsequent paper.

The amount of Atkin's medium was determined initially with a farinograph in order to adjust the consistency of the sample dough to 500 B.U.

After mixing, the dough was divided into 100-g. samples. These samples were given a reaction time of 1 hr. in exp. 1, and 1~3 hr. in exp. 2, in a cabinet at 30° C. At the end of the reaction time, the dough was rounded 20 times on the rounder of an extensigraph. The rounded dough was sheeted manually with a rolling pin to 7 mm. thickness, and about 80 × 120 mm. size. The sheeted dough was rolled using a National-type dough molder. The rolled dough was 39 mm. in diameter, and 82 mm. in length. This roll was folded at the center and inserted into the bottom of a 50.4-mm. diameter glass cylinder, keeping the spherical head up. The dough in the bottom of cylinder was pushed up about 20 mm. by the pressure-sensing apparatus.

After placing the equipment into a thermostat at 30° C., the pressure estimating and recording systems were connected to the pressure-sensing apparatus with thick rubber tubes.

In this way it was possible to estimate and record the pressure or internal stress of the resting dough as described in the previous paper (2).

RESULTS

Pressure Relaxation in Unyeasted Dough and Effects of Bromate, Iodate, and Cysteine

The patterns of pressure recorded on the chart of the automatic recording system with the doughs with or without these improvers are shown in Fig. 1. Typical relaxation of pressure was observed.

Figure 2 shows the logarithm of corrected pressure ($P_t - P_o$) against time t, where P_t is the pressure at time t, and P_o is the pressure caused by the weight of the dough itself. To obtain precise results, P_t was estimated manually at each point on the curve in Fig. 2 with a manometer connected in parallel to the automatic recorder. P_o is calculated from the height (h) and density of the dough. The latter was 1.21. Height of the dough was estimated from the top of dough in cylinder to the level of rubber diaphragm at the bottom.

The logarithmic plots in Fig. 2 were found to be linear between 10 and 50 min. The slope of the straight lines was decreased by oxidizing agents such as bromate and iodate, and was increased by reducing agent such as cysteine.

The straight portion of the logarithmic plots can be described by the following equation:

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

where k and c are constants.

TABLE I. SAMPLE DOUGH (UNYEASTED)

Ingredient	Quantity
Flour	100 g.
NaCl	1 g.
Sucrose	3 g.
Atkin's medium[1]	59.3 ml. (consistency 500 B.U.)

[1]Medium (per liter): $NaH_2PO_4 \cdot H_2O$ 3.0 g., $MgSO_4 \cdot 7H_2O$ 2.0 g., KCl 0.8 g., asparagine 10.0 g., thiamine 4 mg., pyridoxine 4 mg., niacin 40 mg., M/3 sodium citrate buffer 120 ml. (pH 5.5).

From these linear semilogarithmic graphs, assuming a simple Maxwell model, a relaxation time τ was calculated by the eqs. 2 and 3, where τ is the relaxation time and P_l is the corrected pressure at time zero:

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

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

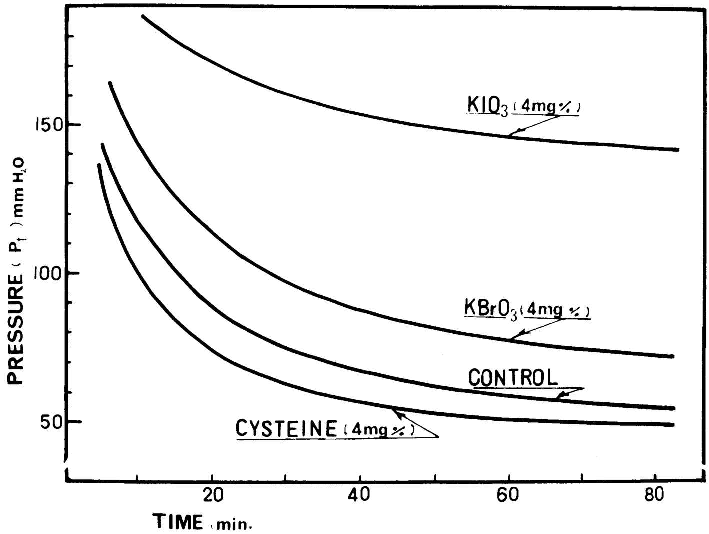

Fig. 1. Relaxation of internal pressure in oxidized or reduced dough.

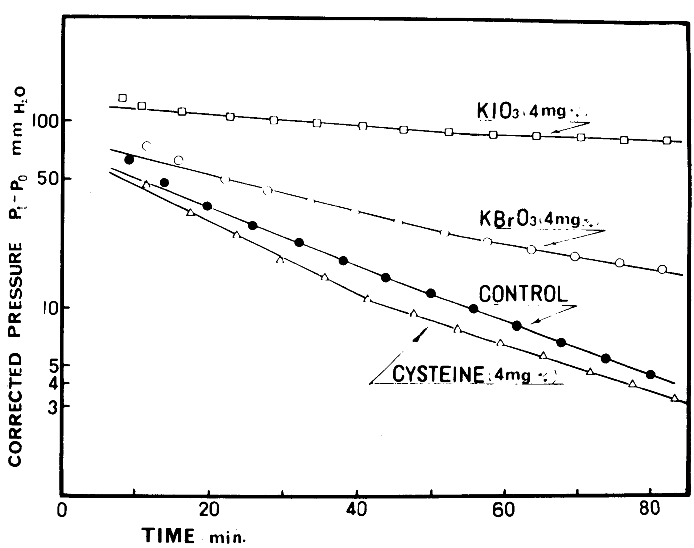

Fig. 2. Corrected internal pressure on logarithmic scale graphed against time.

Effect of Reaction time on Relaxation Constant and Relaxation Time

The relaxation constant k and the relaxation time τ in eqs. 1, 2, and 3 calculated from pressure relaxation curves of the control dough, and the oxidized and reduced dough at various reaction times, are shown in Table II. Data for ascorbic acid and cysteine are also shown for comparison. The reaction time, that is the rest period from mixing to molding, was 0, 1, 2, and 3 hr. The relaxation constants and relaxation times are mean value of three experiments for each reaction time. For the standard test, a reaction time of 1 hr. was given. The standard deviations at this reaction time were calculated and shown in the right column of the table. These standard deviations are comparatively low for this kind of experiment.

In the control dough, the relaxation constant and the relaxation time are essentially constant as the reaction time increases from 0 to 2 hr.; however, with bromate the relaxation constant decreased and the relaxation time increased both with reaction time and bromate concentration. The effect of iodate was instantaneous as reflected in the initial low value of the relaxation constant and the higher relaxation time. Their variations were not appreciable with reaction time. A higher relaxation constant and lower relaxation time than those of the control were observed with dough containing cysteine. The effect of L-ascorbic acid is similar to that of oxidizing agents in this pressure relaxation test. It is well-known behavior of ascorbic acid in dough tested with the extensigraph though it is a reducing agent.

DISCUSSION

In this work, the relaxation of dough stress which was caused initially by rounding, molding, and shaping into a cylinder was studied with unyeasted dough by an internal pressure recorder (2).

The linear relation between time and the logarithm of the corrected pressure was found at times ranging from 10 to 50 min. after filling into the cylinder. These plots make it possible to calculate the relaxation time if a Maxwell model is assumed.

The effects of oxidizing and reducing agents, and various reaction times on

TABLE II. RELAXATION CONSTANT (k) AND RELAXATION TIME (τ) OF OXIDIZED OR REDUCED DOUGH AT VARIOUS REACTION TIMES

Additives	Reaction Times (hr.)								Std. Dev.
	0		1		2		3		
	k[1]	τ[1]	k	τ	k	τ	k	τ	$s = \sqrt{[1/n\Sigma(x_i - \bar{x})^2]}$
Control	1.69	25.6	1.67	26.0	1.60	27.1			0.017
$KBrO_3$ 2 mg.%	1.43	30.4	1.38	31.5	1.24	35.0	0.889	48.8	0.010
$KBrO_3$ 4 mg.%	1.14	38.1	0.910	47.7	0.828	52.5	0.606	71.6	0.018
$KBrO_3$ 6 mg.%	1.12	38.8	0.862	50.4	0.681	63.7	0.468	92.8	0.013
KIO_3 4 mg.%	0.314	138	0.280	155	0.247	176	0.252	172	0.023
L-AsA 4 mg.%			0.771	52.1					0.008
Cysteine 4 mg.%			1.86	23.4					0.06

[1]unit: k 10^{-2}, min. τ

relaxation constants, or on relaxation times which were obtained in the present study are in reasonable agreement with these obtained by previous workers (13,14) though methods were different. It is interesting that characteristic oxidative reactions of iodate, e.g., fast reaction, higher resistance and shorter extensibility, can be found in this test, too.

Cunningham et al. (11) and Matsumoto et al. (4) showed that the behavior of dough could not be represented by a single Maxwell model, but by a large number of models distributed among a range of relaxation times between 1 and 1,000 sec., and 100 and 500 sec. depending on the stress range. Shelef and Bousso (5) indicated mean relaxation times of 14, 102, 168, and 198 sec. for each sample. Their relaxation tests were different from the present study in the method which estimates the relaxation of internal pressure caused by various manipulation of the dough, and in which no special extension was applied to the sample except during insertion of the dough into the cylinder. These workers observed a relatively short time of relaxation of a few seconds to several minutes after strain application. The present authors have estimated pressure relaxation from several minutes to 40 to 50 min. with a resting dough. It is assumed that a single Maxwell element may dominate the total system during relatively long time of observation from this straight line of half logarithmic plot.

The behavior of dough as a single Maxwell element found in this study agrees with the observation by Halton and Scott Blair (8) and with the results obtained by Dempster et al. (13) in their early work of structural relaxation with an extensigraph, though their later work (14) has shown that the relaxation curve approximates closely to a hyperbola. Their relaxation constants with or without oxidizing agents were found to be of the same order of magnitude as those by the present authors. Data of both groups were obtained with resting doughs, though methods of estimation of relaxation were different from each other. The relaxation of resting dough, i.e., the stabilization of dough properties, is presumed to progress in the similar manner to that of a single Maxwell model which has a relaxation time of 25 to 90 min.

The deformation of bread dough proceeds very slowly, and it is possible that the components which have long relaxation times affect mainly the total system by cancelling out the elements with short relaxation time. The relaxation times shorter than 5 min. and longer than 50 min. are not discussed here; however, they should be analyzed by the method showed by Mohsenin (20). The work described in this paper seems to be unique insofar as the doughs are tested after molding as in the AACC test baking method. Thus, the behavior of this unyeasted dough may illustrate the behavior of bread dough in the baking pan.

Although this work does not yield rheological parameters in terms of fundamental physical units, it does yield relaxation times. Results of this test, with work on yeasted doughs which will follow, may lead to a bridge between dough rheology and loaf expansion.

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[Received November 1, 1973. Accepted April 16, 1974]