Natural Maturing of Wheat Flour. II. Effect of Temperature on Changes in Soluble SH Content, and Some Rheological Properties of Doughs Obtained from the Flour

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ABSTRACT

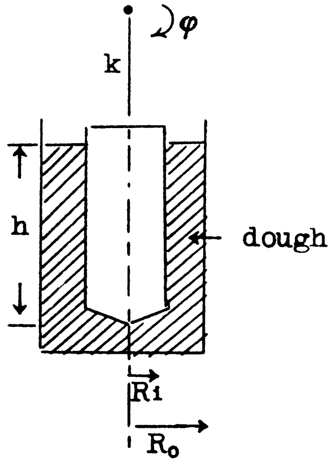
Freshly milled long-patent flour was stored at −30°, 0°, and 30°C. in air for 60 days. Changes in soluble SH content and rheological properties of the doughs prepared from the flour were measured. Viscoelastic coefficients for one rheological model were calculated from data determined by a Schwedoff-type coaxial rotational viscometer. Changes at 30°C. were reported previously (Cereal Chem. 46: 000; 1969). There was essentially no change in soluble SH and rheological properties for flour samples stored below 0°C. Accordingly, natural maturing of flour depends strongly on storage temperature and becomes extremely slow below 0°C. Viscoelastic properties of dough were described in terms of three elements: 1) a purely elastic element characterized by a modulus γ_1; 2) a Voigt element characterized by an elastic modulus (γ_2) and coefficient of viscosity (η_2); and 3) a viscous element of coefficient η_3. The values of the coefficients in the temperature range −30° to 30°C. for doughs from a long-patent flour are: $\gamma_1 = (1-4) \times 10^4$ dynes/sq. cm.; $\gamma_2 = (1-5) \times 10^4$ dynes/sq. cm.; $\eta_2 = (1-5) \times 10^6$ poises and $\eta_3 = (1-7) \times 10^7$ poises.

The previous paper (1) discussed a number of chemical changes that occur in flour during natural maturing under normal temperature (30°C.) and the concomitant changes in the physical properties of doughs obtained from the flour. Among the changes observed, the gradual decrease in SH content of the solubles in metaphosphoric acid solution seems to be the important change insofar as the maturing process is concerned. The concomitant changes in rheological properties seem to parallel the disappearance of soluble SH groups. This paper extends the study of changes in SH contents and rheological properties of one type of flour to samples stored at −30° and 0°C. In addition, the paper reports rheological data obtained with a Schwedoff coaxial viscometer.

MATERIALS AND METHODS

The flour used was unbleached, long-patent (ash 0.40%, protein 12.8%) milled from Canadian HRS wheat on a commercial mill. It was stored in air at −30°, 0°, and 30°C. Breadmaking quality was evaluated by a straight-dough baking test similar to the AACC procedure.

Soluble SH content was determined as described previously by the amperometric titration procedure of Sokol et al. (2). Structural relaxation data were derived by the method of Hlynka and co-workers as elaborated in the previous paper (1). Viscoelastic parameters for the dough were derived from data obtained by a Schwedoff-type coaxial rotational viscometer constructed in our laboratory.



R_i = 1.5 cm

R_o = 2.5 cm

φ = 3.16 radian

h = 9.0 cm

k = 2.51×10^4 dyne-cm

Fig. 1. Schematic diagram of a Schwedoff-type coaxial rotational viscometer.

The equipment is illustrated in Fig. 1. The theory of the Schwedoff viscometer has been described (3,4), but is presented here for easy reference.

If the top of torsion wire k is turned by angle Φ, the inner cylinder rotates by angle Θ (Θ<Φ) and is retarded by the elastic force of elasticity of the dough sample. Thus, the rotating force of the torsion wire and the force of elasticity of the dough are balanced. At equilibrium the relation between stress, p, at the wall of inner cylinder, strain e, the modulus of rigidity γ (dynes/sq. cm.) can be expressed by the following equations:

$$P = \frac{k(\Phi - \Theta)}{2\pi h R_i^2} \tag{1}$$

$$e = \frac{2 R_o^2 \Theta}{(R_o^2 - R_i^2)} \tag{2}$$

$$\gamma = \frac{P}{e} = \frac{k(\Phi - \Theta)}{4\pi h} \left(\frac{1}{R_i^2} - \frac{1}{R_o^2}\right) \frac{1}{\Theta} \tag{3}$$

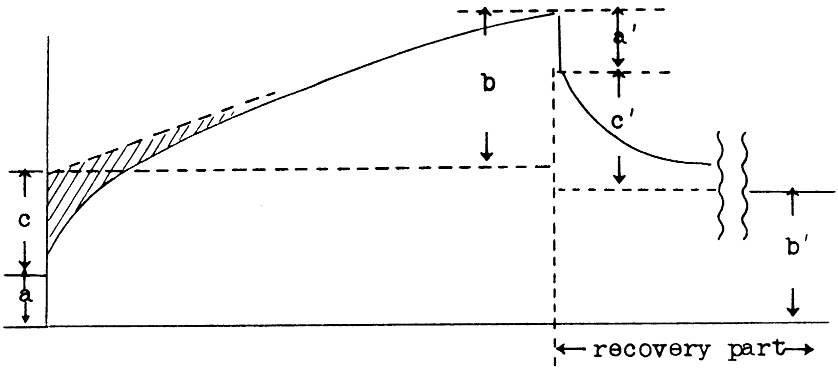


Fig. 2. Representative diagram of a creep curve obtained with the Schwedoff viscometer.

Angle Φ was adjusted to 3.16 radians by a scale fitted at the fixed top of the torsion wire. Angle Θ was measured by reflecting a light on a scale from a mirror fixed to the wire at the point where it was connected to the inner cylinder. In general, $\Theta < \Phi$, so that $\Phi - \Theta$ can be set equal to Φ.

Because our experiment can be considered as a creep experiment, where stress is constant, then equation 1 gives $P = 6.18 \times 10^2$ dynes/sq. cm.

The value of e at time t was read from a spotlight on the lamp scale, and the creep curve shown in Fig. 2 was drawn by calculation. It can be shown that the viscoelastic properties of dough can be expressed by three fundamental elements: 1) a purely elastic element of modulus γ_1; 2) a Voigt element which contains time of retardation, τ_k, and is characterized by elastic modulus and coefficient of viscosity γ_2 and η_2, and a Newtonian viscosity element with a coefficient of viscosity, η_3.

Therefore, the creep equation can be written as

$$e = \frac{P}{\gamma_1} + \frac{P}{\gamma_2}\left(1 - e^{-\frac{t}{\tau_k}}\right) + \frac{P\,t}{\eta_3} \qquad (4)$$

From equation 4 and the curve in Fig. 2, equations 5, 6, and 7 are obtained.

$$\gamma_1 = \frac{P}{a}\ \text{(dynes/sq. cm.)} \qquad (5)$$

$$\eta_3 = \frac{Pt}{b}\ \text{(poises)} \qquad (6)$$

$$\gamma_2 = \frac{P}{c}\ \text{(dynes/sq. cm.)} \qquad (7)$$

Furthermore, equation 4 can be rearranged to equation 8.

$$\ln\left(-e+\frac{P}{\gamma_1}+\frac{P}{\gamma_2}+\frac{P}{\eta_3}t\right)=\ln\frac{P}{\gamma_2}-\frac{t}{\tau_k} \quad (8)$$

Now if the left side of equation 8 is plotted against time, τ_k can be obtained from the slope which is equal to $-1/\tau_k$. The coefficient of viscosity of the Voigt element can then be calculated from equation 9.

$$\eta_2=\tau_k \cdot \gamma_2 \quad (9)$$

In this manner the five fundamental parameters can be derived from a single creep experiment.

The doughs used for the creep experiments were mixed for 5 min. in air in the 300-g. farinograph bowl using 60% absorption and 2% sodium chloride. The viscometer cylinder was filled with 150 g. of dough and allowed to rest for 30 min. at 30°C. During the creep experiment the temperature of the dough was held at 30°C. A small quantity of liquid paraffin was poured into the cylinder to prevent the exposed dough from drying.

RESULTS AND DISCUSSION

Soluble SH Groups

As indicated previously and shown in Fig. 3, soluble SH groups decreased markedly during the first 10 days of storage when flour was stored at 30°C. For the flour stored at –30° and 0°C., soluble SH groups decreased slowly but continually during 90 days' storage. This result indicates that the oxidation of soluble SH groups by air depends greatly on the temperature during storage of the flour. This information is quite pertinent in relation to practical problems experienced in the flour-milling industry. Natural aging of flour would be slow in winter and extremely fast in summer.

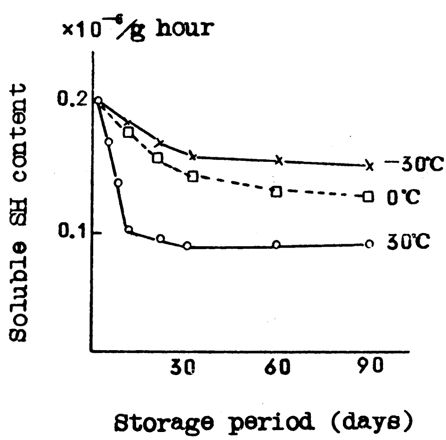


Fig. 3. Decrease of soluble SH content in flour stored at –30°, 0°, and 30°C. for various periods of time.

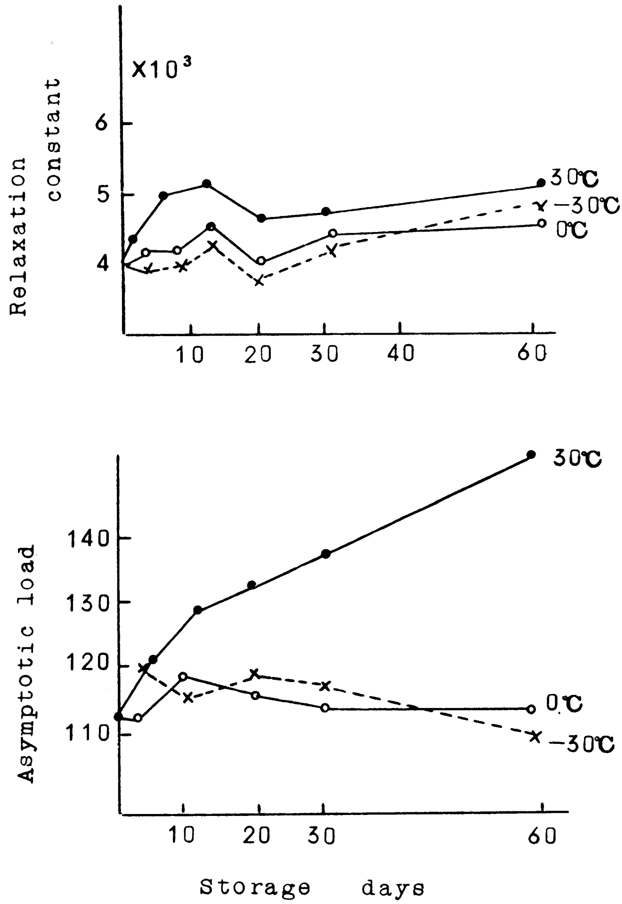


Fig. 4. Change of relaxation constant and asymptotic load at −30°, 0°, and 30°C. with storage time.

Structural Relaxation

Figure 4 shows how storage temperature affects structural relaxation properties. The effect of temperature in the range investigated on the relaxation constant is negligible. A more clear-cut effect is shown by the asymptotic load, which increases rapidly with storage time at 30°C. but remains essentially constant for samples stored at −30° and 0°C.

Viscoelastic Properties of Dough from Flour Stored at −30°, 0°, and 30°C.

Influence of the storage temperature of flour on rheological properties of the dough was further investigated with a Schwedoff-type coaxial rotational

TABLE I. INFLUENCE OF STORAGE TEMPERATURE OF FLOUR ON VISCOELASTIC PARAMETERS OF DOUGH

Storage Temperature °C.	Storage Period days	η_3 poises	γ_1 dynes/cm.^{2}	γ_2 dynes/cm.^{2}	η_2 poises	τ_k sec.
	0	1.8×10^7	1.2×10^4	1.3×10^4	1.2×10^6	92
	7	3.2	2.7	2.6	2.5	96
30	14	4.3	2.9	3.5	3.7	105
	21	5.5	3.3	4.1	4.6	112
	28	6.2	3.3	4.3	5.0	116
	7	1.8	1.5	1.3	1.4	108
	14	1.9	1.4	1.3	1.5	116
0	21	2.2	1.7	1.5	1.4	107
	28	2.1	1.5	1.8	1.7	95
	7	1.8	1.3	1.2	1.3	108
	14	1.6	1.1	1.1	1.5	136
−30	21	1.9	1.1	1.3	1.5	115
	28	1.8	1.3	1.3	1.7	131

viscometer. The values for the fundamental parameters are given in Table I. As noted above for structural relaxation, the modulus of elasticity and coefficient of viscosity also did not change during 4 weeks of storage below 0°C., but tended to increase with storage at 30°C. This is in line with the observations indicated above. Retardation time of the Voigt element did not show any definite trend.

Baking Results

As shown in Table II, specific volume decreased slightly when flour was stored at 30°C. for 30 to 60 days. According to the organoleptic evaluation of dough maturity, the dough appears mature from flour stored for about 1 week at 30°C., whereas storage for more than a month is required at −30°C. Changes in stickiness and elasticity of the dough with maturing can be discerned organoleptically by an experienced baker.

TABLE II. BAKING DATA SHOWING SPECIFIC VOLUMES AND DEGREE OF MATURITY[a]

Storage Period	Storage Temperature		
	−30°C.	0°C.	30°C.
days	cc./g.	cc./g.	cc./g.
0	1.00 (−)	1.00 (−)	1.00 (−)
6	1.00 (−)	1.0 (−)	1.03 (+)
12	1.00 (−)	1.01 (+)	1.01 (+)
20	1.00 (−)	1.01 (+)	0.98 (+)
30	1.00 (−)	1.00 (+)	0.98 (++)
60	1.00 (+)	1.00 (+)	0.92 (++)

[a]Minus sign indicates immature; plus, mature; double plus, overmature.

CONCLUSIONS

Disappearance of soluble SH in flour is much greater at 30° than at −30° or 0°C. Parallel changes occur in the rheological properties. Natural maturing of flour is directly dependent on the storage temperature, and this must be taken into consideration in commercial flour milling.

Acknowledgment

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