Rheological Studies of Dough with the Hoeppler Consistometer

J. PŘÍHODA[1], J. HAMPL, and S. KARLOVÁ, The Chemical and Technological University, Prague, Czechoslovakia

ABSTRACT

Some rheological properties of dough were investigated with the Hoeppler consistometer. The data obtained with this instrument can be used to plot flow curves which show the relation between velocity of falling ball and stress. These flow curves were affected by differences in flour quality, and to a lesser degree by mixing time; fermentation time had essentially no effect. At constant stress, the velocity of ball vs. time of mixing plots can be used to obtain information on the viscous and elastic components of the rheological properties of dough. Each flour showed a characteristic mixing time when the apparent viscosity and elasticity were maximum. The maxima in viscosity and elasticity did not occur at the same mixing time. During fermentation the dough showed maximum elasticity after 1.5 hr., whereas viscosity decreased steadily up to 3 hr.

Studies of the rheological properties of doughs have provided useful fundamental and practical information on the behavior of doughs at various stages of the breadmaking process. The highly empirical nature of the practical rheological instruments such as the alveograph, extensigraph, and the farinograph has precluded the correlation of fundamental physical properties such as the coefficient of viscosity and the modulus of elasticity with parameters measured by these instruments. The main difficulty arises from the fact that data obtained on different instruments are normally not comparable.

In the present study, the Hoeppler falling-ball principle of viscosity measurement was applied to doughs. Despite the empirical character of such measurements for non-Newtonian substances, the results are of more general physical meaning than results obtained with other empirical instruments. Owing to variations of shear stress and shear rate over the ball surface, and because of complex deformation, it is not possible to determine the actual values for the shear stress and shear rate over the total surface of the ball. Then the relation of the stress to shear rate was expressed in terms of acting force vs. velocity. The curves are generally called flow curves and are related only to the viscous properties of the material examined.

The Hoeppler consistometer can also be used to study elastic properties of materials such as dough. In the arrangement used (Fig. 1, A), elastic recovery was measured as follows: The counter-balanced ball was allowed to fall to a predetermined distance of 10 mm. under the influence of a weight placed on top of the rod leading to the ball. The weight was then removed and the recovery at zero force was measured in the usual manner.

Reversible deformation of viscoelastic materials depends on elasticity and viscosity. However, the contribution of viscosity to the magnitude of the recovery is negligible, if the recovery is measured after a sufficient time. The exact calculation of the relationship between these properties and reversible deformation

[1]Postdoctoral Fellow, Department of Plant Science, University of Manitoba, Winnipeg, Canada (1969–70).

is very complex (1). It is generally accepted that for heterogeneous materials such as dough, the elastic component of the deformation can be expressed in terms of the reversible deformation and the viscous component in terms of the irreversible deformation. Accordingly, in the present study, the magnitude of the recovery was used as the measure of elasticity.

This paper deals with the effects of flour quality and dough-processing conditions on the rheological properties of the dough as measured on the Hoeppler consistometer.

MATERIALS AND METHODS

Flours and Doughs

Three types of flours were used: very strong, medium, and weak. All were commercially milled (Type 650 by CSSR standards) with no chemical treatments. Pertinent characteristics of the flours are given in Table I.

The doughs were mixed in air at 30°C. with the Brabender farinograph mixer. The mixing speed was increased to 75 r.p.m. (slower blade).

To study the effect of mixing time, simple flour-water doughs were used. To study the effect of fermentation time, the following dough formula was used: flour, 250 g.; yeast, 7.5 g.; salt, 3.75 g.; and water, as required. The amount of water was adjusted to obtain a dough with a consistency of 500 B.U.

Hoeppler Consistometer

The Hoeppler consistometer is commercially manufactured by VEB Pruefgeraetewerk, Medingen, Dresden, Germany (2). This instrument can measure firmness, plasticity, elasticity, and viscosity by penetrating the test piece with a ball, or a flat or pointed plunger. The test sample is held in a container held within a thermostatically controlled chamber. The penetrating element can be attached to a head on which various weights can be placed to give the desired velocity. Movement of the penetrating element is read off a scale and timed with a stopwatch. In the present work, a steel ball of 1.6 cm. diameter was used as a penetrating element.

To measure reversible recovery, the weight of the ball is balanced by an equal counterweight.

In the present study, flow curves for each dough sample were determined for different ball velocities, obtained with six to eight different weights. The stress was calculated by dividing the applied force by the cross section area (2 cm.^{2}) of the ball. A fresh dough was used for each measurement.

TABLE I. PERTINENT CHARACTERISTICS OF FLOURS USED

Flour[a]	Strength	Moisture %	Ash (dry basis) %	Wet Gluten (dry basis) %	Farinograph Absorption %
F_1	Very strong	14.3	0.74	41.1	60.8
F_2	Very weak	14.3	0.72	21.1	54.6
F_3	Medium	13.4	0.74	32.0	57.1

[a]F_1 was milled from Canadian hard red spring wheat and the other flours were milled from Czechoslovakian wheats.

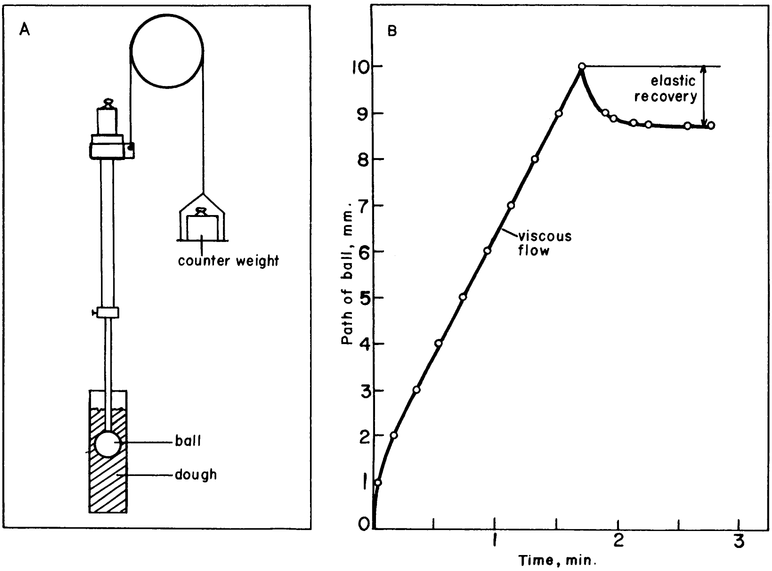

Fig. 1. A, Schematic representation of the Hoeppler consistometer; B, a typical graph of the falling and recovery paths vs. time.

Figure 1, A gives a schematic diagram of the apparatus used and Fig. 1, B shows a typical distance-time curve obtained with this apparatus.

RESULTS AND DISCUSSION

Reproducibility of Measurements

Figure 1, B shows a typical graphical representation of the falling and recovery paths of the ball. The shape of the curve is the same as the deformation curve for dough obtained with a rotating viscometer (3). This might be surprising in view of the empirical nature of the instrument used in the present study. The nonlinear first part of the curve reflects changes in both elastic and viscous properties. The subsequent linear part of the curve can be used to evaluate the coefficient of viscosity, whereas the magnitude of reversibility gives a measure of the elasticity.

Standard deviation (s') and variability coefficient (CV) were calculated to check the reproducibility of results obtained (4). Standard deviation was calculated from the following formula:

$$s' = k \cdot R$$

where R is maximum difference of replicate results and k is an empirical coefficient used in the statistical treatment of a small number of measurements. For five replicate measurements in the present study, the value of k was 0.430.

For calculation of the variability coefficient (CV), the following formula was used:

$$CV = \frac{s'}{X} \cdot 100$$

where X is the arithmetic mean of the five consistency values. The statistical data are summarized in Tables II and III. These data show that higher accuracy can be achieved with a stronger flour and higher falling-ball velocities.

TABLE II. THE STANDARD DEVIATION AND COEFFICIENT OF VARIABILITY VALUES FOR MEASUREMENTS OF VELOCITY OF BALL

Flour	Stress $g.cm.^{-2}$	Velocity of Ball $mm.sec.^{-1}$	Standard Deviation $mm.sec.^{-1}$	Coefficient of Variability %
F_1	250	0.0401	0.00250	6.20
	275	0.0560	0.00240	4.30
	300	0.0786	0.00400	5.10
	325	0.1084	0.00457	4.22
	350	0.1196	0.00419	3.51
	375	0.1429	0.00457	3.20
F_3	175	0.0438	0.00329	7.5
	200	0.0587	0.00475	8.1
	225	0.0851	0.00630	7.4
	250	0.1168	0.00730	6.2
	275	0.2055	0.01050	5.1
	300	0.2323	0.01090	4.7

TABLE III. THE STANDARD DEVIATION AND COEFFICIENT OF VARIABILITY VALUES FOR MEASUREMENTS OF ELASTIC RECOVERY

Flour	Stress $g.cm.^{-2}$	Elastic Recovery mm.	Standard Deviation mm.	Coefficient of Variability %
F_1	250	0.73	0.0172	2.36
	275	0.78	0.0172	2.20
	300	0.85	0.0215	2.54
	325	0.96	0.0172	1.79
	350	1.08	0.0215	1.99
	375	1.12	0.0086	0.77
F_3	175	0.42	0.0172	4.10
	200	0.46	0.0172	3.73
	225	0.49	0.0129	2.62
	250	0.51	0.0086	1.68
	275	0.56	0.0129	2.30
	300	0.61	0.0129	2.10

Effect of Flour Quality and Dough Processing

The rheological properties of dough measured by the Hoeppler consistometer appear to be related to flour quality (Figs. 2 and 3). For Fig. 2, the doughs were mixed to optimum consistency. Figure 3 shows flow curves for doughs mixed for 10 min. Both sets of curves show that at constant velocity of deformation, the stress increases, or at constant stress, the velocity decreases with increasing flour strength.

Figure 4 shows the flow curves for three mixing times (1.5, 3, and 5 min.) for flour F_3. The effect of mixing time is considerably less than the effect of flour quality.

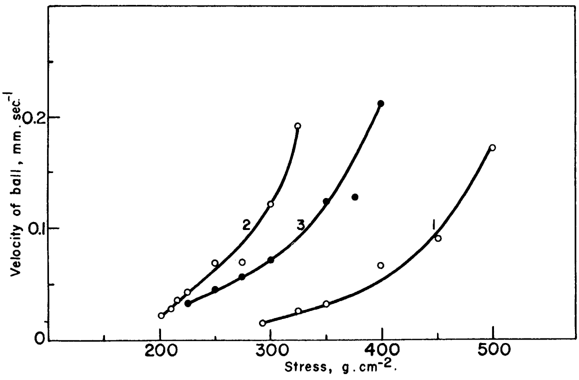

Fig. 2. Flow curves for doughs from flours of different quality mixed to maximum consistency in the farinograph.

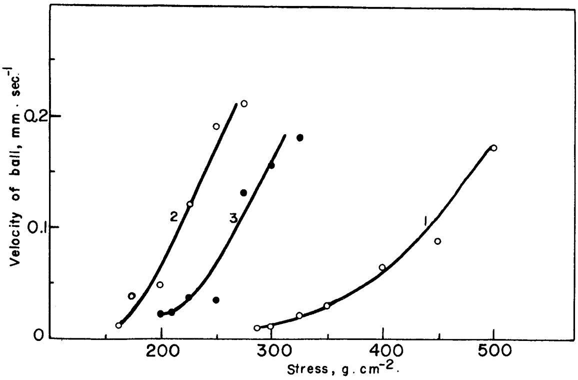

Fig. 3. Flow curves for doughs from flours of different quality mixed for 10 min. in the farinograph.

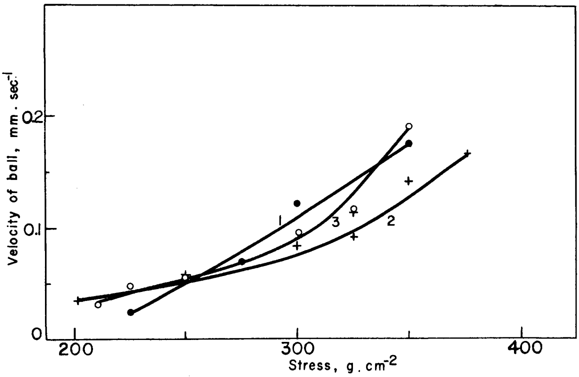

Fig. 4. Flow curves of doughs from flour F_3 mixed for different times: curve 1, 1.5 min.; 2, 3 min.; and 3, 5 min.

An objective evaluation of the flow curves for different mixing times is complex because they are not directly comparable. Better results were obtained when the linear velocity of the ball or the magnitude of reversibility was plotted against the mixing time. Curves for a number of stresses are shown in Figs. 5 to 9. Figures 5 to 7 show the velocity vs. mixing time curves for flours F_1 to F_3, respectively. Figures 8 and 9 show the elastic recovery vs. mixing time for flours F_1 and F_3.

With increasing stress, the velocity curves showed a distinct "velocity minimum" which is a characteristic value for each flour. This corresponds to maximum apparent viscosity since the velocity of the ball and apparent viscosity are inversely related. The elastic recovery curves showed an "elasticity maximum" for all the stresses used. A comparison of the data of Figs. 5 to 7 and Figs. 8 and 9 showed that the time required to reach maximum viscosity was shorter than the time necessary to reach maximum elasticity.

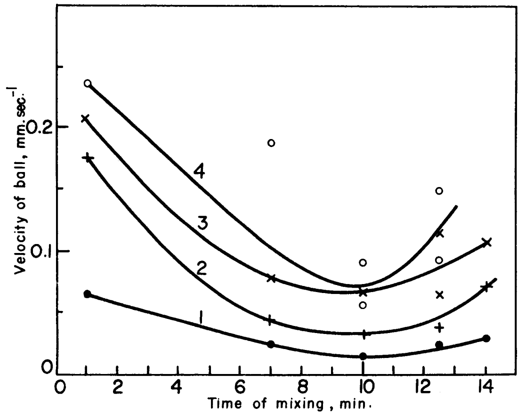

Fig. 5. Variation of ball velocity with mixing time for doughs from flour F_1 for four stresses: 1, 300 g.cm.$^{-2}$; 2, 350 g.cm.$^{-2}$; 3, 400 g. cm.$^{-2}$; and 4, 450 g.cm.$^{-2}$

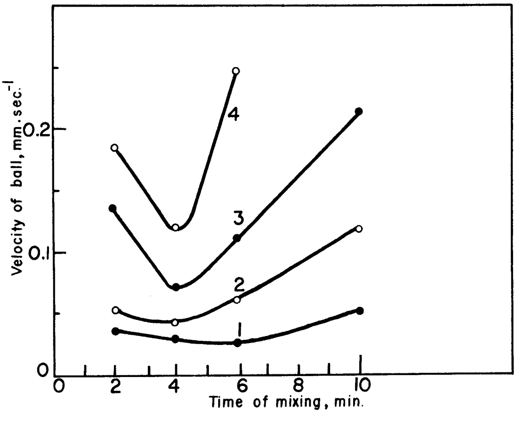

Fig. 6. Variation of ball velocity with mixing time for doughs from flour F_2 for four stresses: 1, 210 g. cm.$^{-2}$; 2, 225 g.cm.$^{-2}$; 3, 275 g.cm.$^{-2}$; and 4, 300 g.cm.$^{-2}$

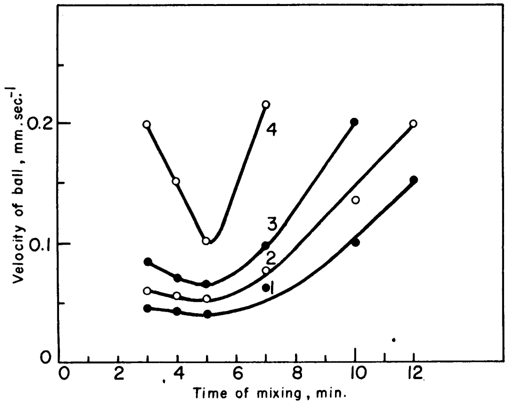

Fig. 7. Variation of ball velocity with mixing time for doughs from flour F_3 for four stresses: 1, 175 g.cm.$^{-2}$; 2, 200 g.cm.$^{-2}$; 3, 225 g.cm.$^{-2}$; and 4, 275 g.cm.$^{-2}$

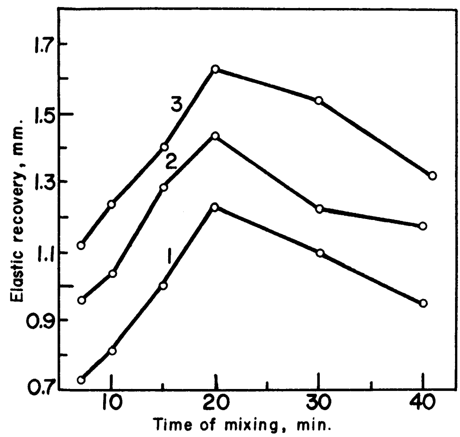

Fig. 8. Variation of elastic recovery with mixing time for doughs from flour F_1 at three different stresses: 1, 250 g.cm.$^{-2}$; 2, 325 g.cm.$^{-2}$; and 3, 375 g.cm.$^{-2}$

Effect of Fermentation Time

Changes in viscous and elastic properties of dough that occur during fermentation at 30°C. for flour F_3 are shown in Figs. 10 and 11, respectively. Apparent viscosity (expressed as ball velocity) decreased gradually throughout the fermentation period examined while elasticity showed a maximum value at 1.5 hr. of fermentation. Further work is necessary to determine the values of viscosity and elasticity that are optimum for optimum breadmaking quality.

DISCUSSION

Since the Hoeppler consistometer is an empirical instrument, the viscous properties of dough measured with it were expressed in terms of the velocity of the ball which is inversely related to the apparent viscosity. Similarly, the elastic

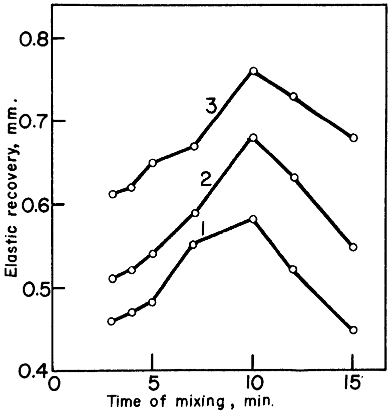

Fig. 9. Variation of elastic recovery with mixing time for doughs from flour F_3 at three different stresses: 1, 200 g.cm.$^{-2}$; 2, 250 g.cm.$^{-2}$; and 3, 300 g.cm.$^{-2}$

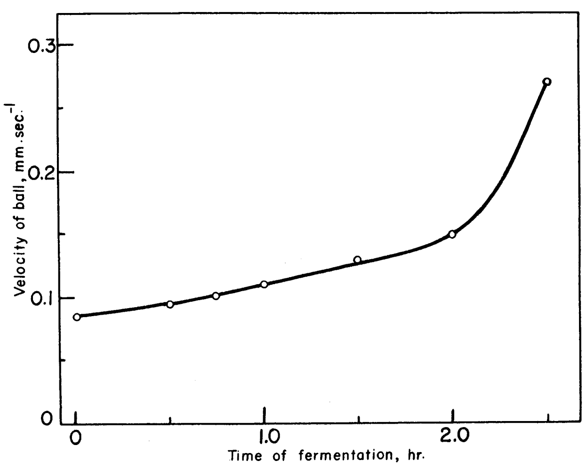

Fig. 10. Variation of ball velocity with fermentation time for doughs from flour F_3 at 300 g.cm.$^{-2}$ stress.

properties were expressed in terms of recovery. This parameter is directly related to elastic modulus.

The results presented emphasize the predominant effect of flour quality on the rheological properties of dough measured with the Hoeppler consistometer. Effects of mixing time and fermentation time were measurable; however, they were relatively smaller.

Increasing flour strength displaced the flow curves in the direction of higher stress. The relation of apparent viscosity with mixing time showed a maximum; the time at which this maximum occurred increased with increasing flour strength. During fermentation, apparent viscosity of dough examined decreased over the range of times investigated (up to 2.5 hr.). The elasticity of the doughs increased at

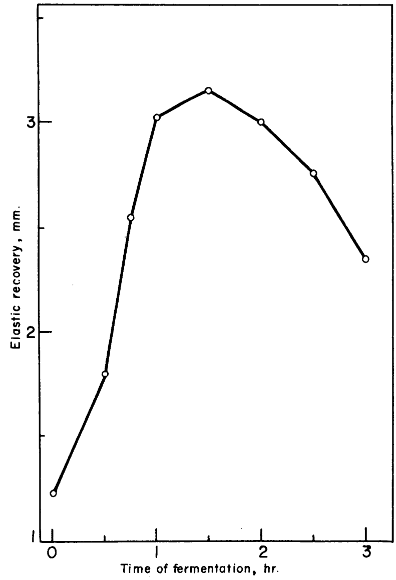

Fig. 11. Variation of elastic recovery with fermentation time for doughs from flour F_3 at 300 g.cm.$^{-2}$ stress.

first and then decreased with increasing mixing time; stronger flours required longer time to reach the maximum elasticity. All three doughs examined showed maximum elasticity after 1.5 hr. of fermentation. These observations indicate that it might be possible to use the Hoeppler consistometer to measure flour strength, and to determine optimum mixing requirements of different flours.

Acknowledgment

We are indebted to W. Bushuk of the University of Manitoba, Winnipeg, Canada, for assistance in the preparation of this manuscript.

Literature Cited

1. NADAI, A. Theory of flow and fracture of solids. McGraw-Hill: New York (1963).
2. VEB PRUEFGERAETEWERK. Beschreibung und Gebrauchsanleitung (in German). Manual for Hoeppler Konsistometer, Medingen, Dresden, Germany.
3. BLOKSMA, A. H. Rheologie von Brotteig bei Langsamen Deformationen. Brot Gebaeck 18: 173 (1964).
4. ECKSCHLAGER, K. Chyby chemických rozborů (Errors, measurement and results in chemical analysis (in Czech.)). SNTL, Prague (1961).

[Received January 22, 1970. Accepted July 30, 1970]