USE OF THE CHOPIN ALVEOGRAPHE AS A RHEOLOGICAL TOOL. I. DOUGH DEFORMATION MEASUREMENTS[1]

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ABSTRACT

An alveographe has been modified in order to inflate dough bubbles at various constant air-flow rates and to record pressures with a better accuracy. The chronophotographic recording of bubble expansion allows a quantitative evaluation of dough extension in the polar region and also in nonpolar regions located in the upper part of the bubble. The experimental results are compared with theoretical predictions proposed by Bloksma: the agreement is generally good, and would probably be better with the use of small volumes and moderate air-flow rates.

For 70 years, several apparatuses have been devised for the study of wheat-flour dough behavior in biaxial extension (1). The Chopin Alveographe is the only one which has gained a real success. A few attempts to interpret the Alveograms on a rheological basis have been made (2–4) but, until now, no unequivocal information on dough rheology has been obtained from them. The first step to interpret the Alveograms is to evaluate how the dough sheet is deformed during bubble inflation. Bloksma (5) has proposed a theoretical model describing dough bubble deformation; the aim of this work was to check the validity of this model.

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MATERIALS AND METHODS

Flours and Doughs

French baking flours are used. The doughs are prepared in the Chopin Alveographe kneader at 25° C and mixed 6 min; they contain 43.2% water and 0.83% NaCl (dough basis).

Chopin Alveographe

A modified apparatus (6) is used. Compared with the standard Alveographe, the two main improvements are: a) pressure measurements with a pressure gauge and a potentiometer, and b) inflation at a true-constant air-flow rate, using compressed air or N, pressure reducers, and a flow meter, with the adjustable air-flow rate between 0.5 and 50 $cm^3 \cdot sec^{-1}$.

Deformation Measurements

The deformation measurements are based on the chronophotographic recording of distances between dots placed on the dough before the test. The dots are created with vegetable black and a circular brass plate with many small holes (0.5 mm) used as a stencil; the stencil is 27.4 mm in radius, 0.5 mm in thickness, and the holes are located about every 1.5 mm on four equally spaced diameters. In order to avoid heating of the dough, the film must give good results with moderate artificial lighting at short exposure times (1/60 sec); we chose a Kodak plus X 125 film. The camera axis is settled in line with the center of the dough sample, the lens located 35 cm from the sample. After processing and enlargement, prints (18 cm × 25 cm) are obtained and used in the deformation measurements.

RESULTS AND DISCUSSION

Theoretical Basis

Bloksma has calculated dough thickness at any point of the bubble using the following assumptions (5): a) the dough is incompressible, b) the bubble has a spherical shape, and c) each dough particle is shifted normally to itself during inflation.

The radius R of the sphere (Fig. 1) can be calculated from the height h of the bubble:

$$R = \frac{a^2 + h^2}{2h} \tag{1}$$

The volume V of air entrapped below the bubble at the inflation time t is linked with air-flow rate Q and height h in the following, equation 2:

$$V = \frac{\Pi}{6} h(h^2 + 3a^2) = Q\,t \tag{2}$$

Points located on the same parallel at the surface of the sphere are characterized by a common value of the position parameter s (Fig. 1) and the thickness Δ of the dough on that parallel is given by equation 3 (5):

$$\Delta = \Delta_0 \left(\frac{a^4 + s^2h^2 \;{}^{2}}{a^2\,(a^2+h^2)} \right) \qquad (3)$$

In the vicinity of the pole ($s^2 << a^4/h^2$) equation 3 is reduced to:

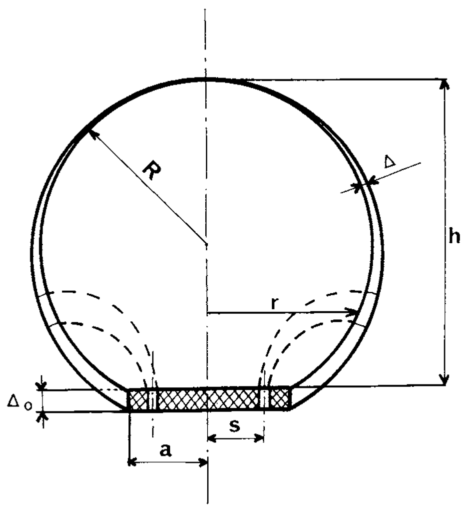
$$\Delta = \Delta_0 \,(1 + h^2/a^2)^{-2} \qquad (4)$$

At each time t the experimental check of equations 1 and 2 is based on the comparison of the calculated bubble radius R (R given by equation 1, h being obtained from equation 2) with the experimental one. Because a direct evaluation of dough thickness is not feasible, the diameter 2r of a parallel is measured during the course of inflation; the theoretical value can be easily obtained using equation 20 of reference 5:

$$2r = 2\,a^2 s \quad \frac{a^2 + h^2}{a^4 + s^2h^2} \qquad (5)$$

In the polar region, equation 5 is reduced to:

$$2r = 2s\left(1 + \frac{h^2}{a^2}\right) \qquad (6)$$



a = 2.74 cm
Δ_0 = 0.25 cm

Fig. 1. Geometrical characteristics of a dough bubble.

Experimental Results

The final enlargement obtained on the prints is calculated, taking into account the decreasing distance between the studied points and the lens; this enlargement varies between 1.55 and about 2.2. All the prints observed thus far show that the equatorial section of the bubble is almost perfectly circular: the major *vs.* minor axis ratio never exceeds 1.04. A typical example of calculated (equations 1 and 2) *vs.* mean experimental diameter 2R is shown in Fig. 2: the former is about 5% less than the latter, which means that the bubble shape remains quasispherical.

The diameter 2r in equations 5 or 6 is the distance between two diametrically opposite points located on the same parallel. Because of the pronounced effect of any slight dough heterogeneity on the sample center displacement during inflation, the measurements are made using two diametrical points which remain at about the same distance from the actual pole of the bubble. As the brass stencil is not precisely machined, the exact distances between holes (2r = 2s at t = 0) are measured on ten-fold enlarged prints. The results obtained with points close to the pole are shown in Fig. 3. The distances 2r calculated with the equations 2 and 6 are compared with the experimental values. The agreement is rather good; however, Fig. 3 and Table 1 indicate a tendency to get a systematic deviation when flow rates and/or volumes increase.

It is easier to study the extensions in the nonpolar zone if equation 5 is linearized by using the auxiliary parameter $Z = 1/(h^2s^2 + a^4)$:

$$2r = 2\,\frac{a^2}{s}\left[a^2(s^2 - a^2)\,Z + 1\right] \qquad (5')$$

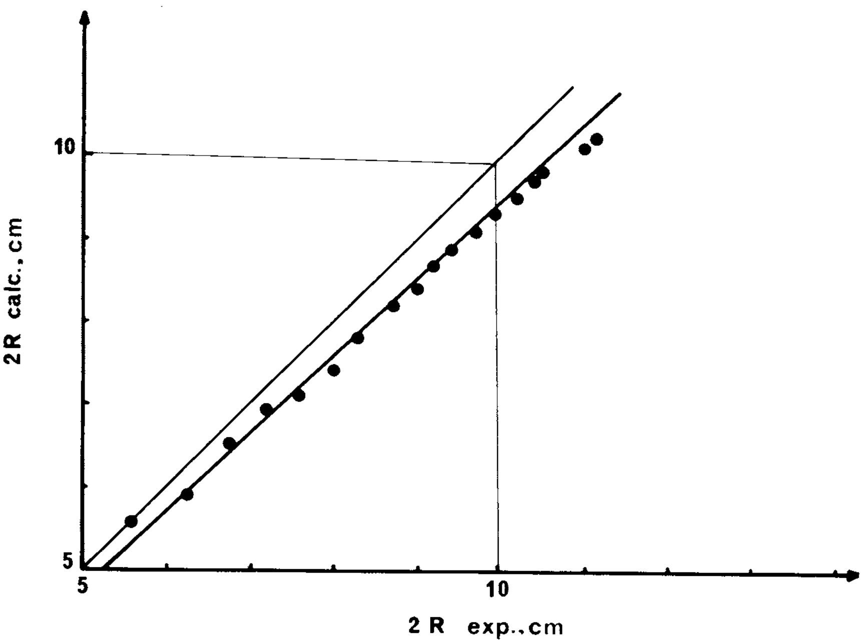


Fig. 2. Calculated *vs.* experimental diameter ($Q = 16.67\ cm^3 \cdot sec^{-1}$).

The selected couple of points have to remain in the upper part of the bubble until rupture occurs. In the nonpolar zone the agreement between the calculated distances 2r (equations 2 and 5′) and the experimental ones is quite satisfactory

TABLE I
Extent of the Relative Deviations (in %) between Calculated- and Experimental-Extension Values (Close to the Pole)

Volume cm^3	Flow Rate[a] 3.06	8.33	30
120	<5	<5	< 5
190	<5	<5	15
260	<5	>5	20
430			30

[a] $cm^3 \cdot sec^{-1}$.

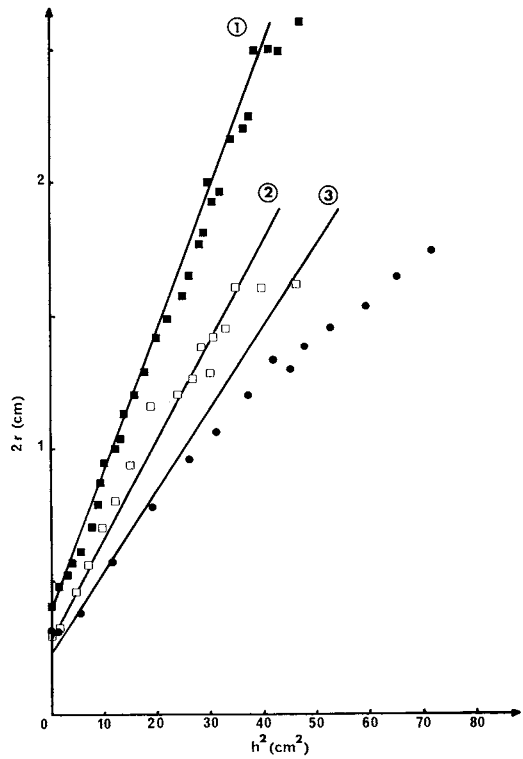


Fig. 3. Polar extensions: theoretical lines (eqn. 6) and experimental points: 1) $Q = 3.06\ cm^3 \cdot sec^{-1}$, $s = 0.20$ cm; 2) $Q = 8.33\ cm^3 \cdot sec^{-1}$, $s = 0.14$ cm; 3) $Q = 30.0\ cm^3 \cdot sec^{-1}$, $s = 0.12$ cm.

(Fig. 4) until rupture in the case of the low-inflation rate and until about V = 360 cm^3 for high-inflation rates. Nevertheless, in the latter case, a phenomenon similar to a temporary extension lag is apparent on Fig. 4.

CONCLUSION

Bloksma (5) has proposed an equation which quantitatively predicts how the dough bubble thickness decreases from the base to the pole: the results shown here largely confirm this equation; so, the underlying assumptions are verified, at least when the bubble volume is not too large. The degree of agreement has to be appreciated taking into account the limits of the experimental work: a) the distances between dots are evaluated at ±0.5 mm; b) the time measurements are given with a 0.1- or 0.2-sec accuracy, which corresponds to $\Delta V = \pm 6$ cm^3 at high flow rates ($\Delta h = \pm 1.6$ mm with V = 100 cm^3); and c) the time t = 0 is evaluated on the prints as the instant at which the distance between two polar dots just starts to increase. In addition to these limitations, it appears that any local dough inhomogeneity affects the deformation at this point and, in the extreme cases, the bubble may become asymmetrical. At high volumes, some flattening of the bubble is noticeable and could explain an increasing gap between theory and

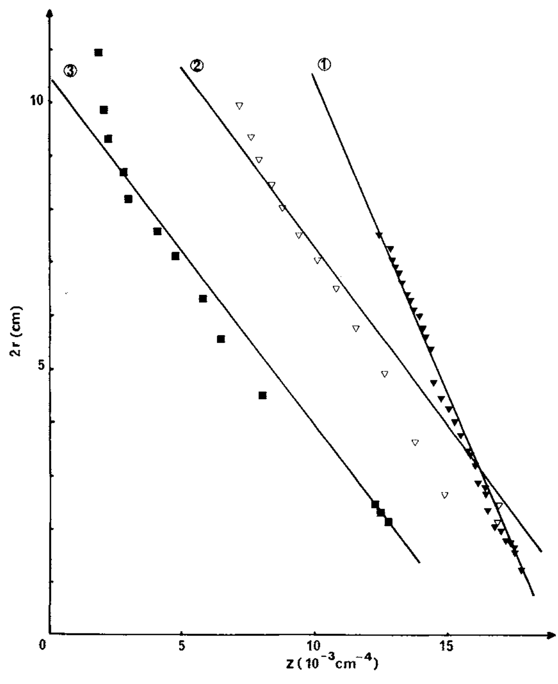


Fig. 4. Nonpolar extensions: theoretical lines (eqn. 5′) and experimental points: 1) Q = 3.06 $cm^3 \cdot sec^{-1}$, s = 0.68 cm; 2) Q = 30 $cm^3 \cdot sec^{-1}$, s = 1.07 cm; 3) Q = 31.94 $cm^3 \cdot sec^{-1}$, s = 1.09 cm, with the line and the points shifted by Z = 5 to the left.

experiment: side views of the bubble should confirm this point. Some flours having no baking value have, in the Alveographe, a characteristic behavior which may be due to a deformation mode different from the one described here.

Acknowledgment

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