

COMMUNICATION TO THE EDITOR

The Rate of Diffusion between Gas Cells in Batters or Doughs

DEAR SIR:

In a recent paper, "Bubble mechanics in thick foams and their effects on cake quality" (Cereal Chem. **38**: 294-305; 1961), Handleman, Conn, and Lyons calculate the rate at which a large gas cell expands at the expense of a smaller one by means of diffusion of dissolved gas through the batter between the two cells. The present author proposes two corrections to their considerations (paragraphs 1 and 2 herein). Moreover, he prefers an alternative choice for one detail of them (paragraph 3). Finally, by slightly extending the argument, he obtained an interesting conclusion about a change in rate of the diffusion process as leavening proceeds (paragraph 4).

1. In equation 9, dV'/dt (the original V is replaced by V') denotes the flow of an amount of dissolved gas that may be expressed as a volume of (gaseous) gas passing per unit time. Then this volume V' must be based on an arbitrary but constant pressure, say atmospheric pressure P_a . Consequently dV' is not the real volume change dV of a gas cell with an internal pressure P different from P_a ; this real volume change is $dV = (P_a/P)dV'$.

2. The quantity $2\gamma/r$ is not the gas pressure in a cell but the excess over atmospheric pressure. The gas pressure is $P = P_a + 2\gamma/r$. Although equation 12 should be corrected accordingly, this correction does not affect equation 13. It affects, however, the ratio dV/dV' .

3. The present author prefers to substitute $\pi r_1 r_2$ for A as an average value for the cross-section of the diffusion path between cells 1 and 2, instead of πr_1^2 or πr_2^2 ; in this treatment variations of the cross-section of the diffusion path with place are inconsistent with the conservation of matter. In the original treatment as well as in the proposed modification, contributions of longer, curved diffusion paths are neglected; therefore, the final result is a low estimate of the rate of diffusion.

The changes proposed thus far result in:

$$\frac{dV_2}{dt} = \frac{\pi DP_a r_2 (r_2 - r_1)}{KX \left(1 + \frac{P_a r_2}{2\gamma}\right)}$$

According to the photomicrographs, radii of the gas bubbles vary from 10^{-4} to 10^{-3} cm.; further, $P_a \cong 10^6$ g.cm. $^{-1}$ sec. $^{-2}$, and $\gamma \cong 50$

g.sec.⁻². Consequently, for the smaller bubbles, the effect of variations in the surface tension is smaller than predicted by the original equation 14.

4. If the gas cells contain identical mixtures of gases with various diffusion coefficients D_i and Henry coefficients K_i , and each contributing a fraction a_i to the total pressure ($\sum_i a_i = 1$), then the above equation should be rewritten as:

$$\frac{dV_2}{dt} = \frac{\pi P_a r_2 (r_2 - r_1)}{X \left(1 + \frac{P_a r_2}{2 \gamma} \right)} \cdot \sum_i \frac{a_i D_i}{K_i}$$

As a consequence of its much higher solubility (low K_i), carbon dioxide contributes relatively more to the diffusion process than does nitrogen or oxygen. At 30°C. and in water ($D_i/K_i \times 10^{13}$ is 3.2, 6.8, and 169 g.⁻¹ cm.³ sec. for nitrogen, oxygen, and carbon dioxide, respectively (data from J.H. Perry, ed., *Chemical Engineers' Handbook*, 3rd ed., pp. 374, 540, and 674 ff., McGraw-Hill, New York, 1950). In a batter or dough the ratios between these quantities are the same as in water. The factor $\sum_i a_i D_i/K_i$ is 35 times higher for a mixture of 80%

of carbon dioxide and 20% of air than for air alone. In batters as well as in bread doughs, the carbon dioxide production is usually amply sufficient to permit such a change in composition. Therefore, a considerable increase in the rate of the diffusion process considered is generally to be expected during leavening or fermentation of batters and doughs.

As a matter of course, these considerations do not enable us to decide whether diffusion of gas or rupture of dough membranes is the principal cause of a decrease of the number of gas cells during fermentation.

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