Model Studies of Cake Baking. II. Expansion and Heat Set of Cake Batter During Baking

M. MIZUKOSHI, H. MAEDA, and H. AMANO, Tokyo Research Laboratories, Kao Soap Co., 2-1-3, Bunka, Sumida-ku, Tokyo 131, Japan

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ABSTRACT

Batter volume, bubble expansion, starch gelatinization, and protein coagulation were measured in sponge cake batters during baking. Gas release, protein coagulation, and cessation of both batter expansion and starch gelatinization took place at the same temperature, which was raised by the addition of sugar. A proposed ideal equation for bubble expansion in the cake batter during baking suggests a close relationship among bubble volume, saturated vapor pressure, and this temperature. These data are useful for a better understanding of the structural formation of cakes during baking.

The viscous fluid and aerated emulsion of cake batter is converted to an expanded, porous soft gel during baking. This spongelike character is the most important property of cake structure, causing its characteristic softness, mouthfeel, digestibility, etc. The leavening action of cake batter during baking is especially important in determining the spongelike structure of cakes (Handleman et al 1961).

Dunn and White (1939) investigated the leavening action of air in the cake batter. They found that half the increase in volume of a lean pound cake containing no chemical leavening agents was from the thermal expansion of air in the batter. Cake batters from which air was completely removed did not rise at all when baked. Handleman et al (1961) discussed bubble to bubble air diffusion and bubble movement in connection with bubble size. Mattil (1964) demonstrated that thermal expansion of air is a minor factor in the leavening process and that most expansion of the batter in the oven is due to increased vapor pressure of water in the air bubbles at high temperature. Miller et al (1964, 1967) measured the height of a cake during baking. Bell et al (1975) measured the diameter of gas bubbles using cinemicroscopy and television microscopy during baking. Shepherd and Yoell (1976) analyzed the bubble size distribution during the heating of cake batter.

None of these studies, however, has described in detail the relationship between expansion and heat set of cake batter during baking. Mizukoshi et al (1979) reported continuous starch gelatinization and protein coagulation during model baking. In the present report, a mechanism of bubble expansion and its relation to starch gelatinization and protein coagulation were investigated. Such knowledge should be useful in better understanding the structural development of cakes during baking.

MATERIALS AND METHODS

Ingredients and preparation of cake batters, model baking equipment, and measurement of light transmission were as described in the previous report (Mizukoshi et al 1979). Eight cake batters containing different sugar levels were prepared to investigate the effects of sugar on light transmission, batter volume, and gas release.

Measurement of Batter Volume and Gas Release Temperature

Cake batters with density of 0.50 g/cm^3 and containing 4.9 cm^3 of air (Table I) were placed in a 20-ml graduated cylinder inverted in a 100-ml stoppered graduated cylinder modified as shown (Fig. 1) and filled with a degassed liquid paraffin. This apparatus for measurement of batter volume and gas release temperature was kept in the bath for viscosity measurements in the model baking equipment (Mizukoshi et al 1979). Batter volumes and temperature changes were continuously measured. The temperature at which a bubble first appeared at the interface between the cake batter and liquid paraffin in the 20-ml graduated cylinder was measured and termed the gas release temperature. Measurement of batter volume and gas release temperature were duplicated for each sample.

RESULTS AND DISCUSSION

Light Transmission

Typical light transmissions of three sugar concentrations, 0, 60, and 120%, are shown in Fig. 2, in which light transmission is plotted against temperature. Previously, Mizukoshi et al (1979) showed that the increase in light transmission was caused by starch gelatinization and the subsequent decrease in light transmission by protein coagulation. From the light transmission curves, the initial temperature of starch gelatinization (t_1), ie, the intersection resulting from extrapolation of the portions of the curve representing light transmission before and after gelatinization, and the temperature of maximum light transmission (t_2) were determined. Temperature t_2 was interpreted as that at which starch gelatinization almost ceased and proteins began to coagulate abruptly. Temperatures t_1 and t_2 are plotted against sugar concentrations in Fig. 3. Both t_1 and t_2 increased with increasing sugar concentration. For instance, the addition of 120% sugar to the sugarless formulation increased t_1 24°C and t_2 21°C.

Expansion of Cake Batter and Gas Release

Figure 4 shows expansion of cake batter containing 120% sugar. Bubble volume changes were calculated from the volume of cake batter during baking by using the equation:

$$\text{Bubble volume} = \text{batter volume} - \frac{\text{sampling weight of batter}}{\text{density of batter without bubble}}$$

Bubble volume of 4.9 cm^3 before baking increased with the temperature to 14.1 cm^3 at 88°C. From this point to the end point of baking, only a slight decrease in batter volume was observed. Final bubble volumes of samples containing different sugar concentrations are shown in Fig. 5. Each circle indicates the bubble volume and the temperature at which increase in bubble volume

TABLE I
Sampling Weight, Initial Volume, and Density of Cake Batters[a]

	Sugar Concentration (flour basis, %)							
	0	20	40	60	80	100	120	140
Sampling weight, g	4.65	4.50	4.35	4.30	4.15	4.05	3.95	3.91
Initial volume, cm^3	9.3	9.0	8.7	8.6	8.3	8.1	7.9	7.8
Density,[b] g/cm^3	1.05	1.09	1.14	1.17	1.22	1.26	1.30	1.34

[a]Averages of duplicate determinations.
[b]Density of batter without bubbles. (Density of the aerated cake batter was 0.50.)

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stopped. Increasing sugar concentration increased the temperature at which bubble expansion ceased and also increased the final batter volume. Expansion of cake batter ceased at the same time the bubble appeared at the interface between batter and liquid paraffin, ie, the temperature at which batter expansion ceased coincided with the gas release temperature (t_3). Temperature t_3, like t_1 and t_2, was also raised by increasing the sugar concentration (Fig. 6).

Protein Coagulation and Gas Release

Temperatures t_2 and t_3 give the linear relation shown in Fig. 7. A coefficient of correlation for t_2 and t_3 was calculated as 0.999, and a regression line was calculated as $t_3 = 4.99 + 0.949\, t_2$. Since $t_3 = t_2$ in the temperature range between 67° C and 88° C, we concluded that protein coagulation, starch gelatinization, cessation of bubble expansion, and gas release occurred at about the same temperature.

Ideal Bubble Expansion

To estimate the expansion process of bubbles in the cake batter during model baking, we calculated the ideal bubble expansion during baking, assuming the following ideal conditions: 1) bubbles are trapped in water; 2) composition of the bubble is air, saturated with water; 3) total pressure in the bubble is 760 mmHg; 4) Dalton's law of partial pressure applies; 5) no bubbles escape from batter during baking; and 6) surface tension at the bubble surface is negligible.

From Dalton's law of partial pressure,

$$(p_a + p_w)\, v = (n_a + n_w)\, RT \qquad (1)$$

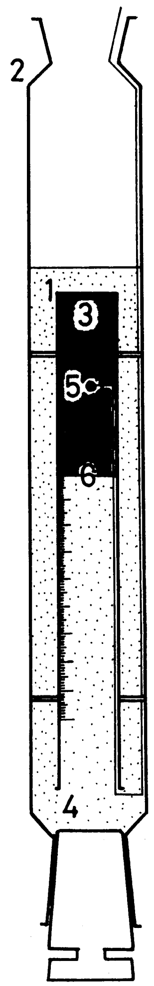

Fig. 1. Apparatus for measuring cake batter volume and gas release temperature. **1,** 20-ml graduated cylinder; **2,** 200-ml stoppered graduated cylinder; **3,** cake batter; **4,** liquid paraffin; **5,** thermistor; **6,** cake batter-liquid paraffin interface.

$$n_a = \frac{p_a v_b}{RT} \qquad (2)$$

at 20° C,

$$n_a^{20} = \frac{p_a^{20}/p^{20}}{RT}\, v_b^{20} = \frac{(760 - 18)/760}{R(293)}\, v_b^{20} \qquad (3)$$

at t ° C,

$$n_a^{t} = \frac{p_a^{t}/p^{t}}{RT}\, v_b^{t} = \frac{(760 - p_w^{t})/760}{R\,(273 + t)}\, v_b^{t} \qquad (4)$$

at (3) = (4),

$$v_b^{t} = 2.53 \left(\frac{273 + t}{760 - p_w^{t}}\right) v_b^{20} \qquad (5)$$

where,

p_a = partial pressure of air (mm Hg)
p_w = partial pressure of water vapor (mm Hg)
v = volume of bubble (cm^3)
n_a = amount of air (mole)
n_w = amount of water vapor (mole)
R = gas constant (8.31×10^7 erg $mole^{-1}$ K^{-1})
T = temperature (° K)
t = temperature (° C)
v_b = volume of bubble (cm^3)
n_a^{20} = amount of air at 20° C (mole)
p_a^{20} = pressure of air at 20° C (mm•Hg)
p^{20} = total pressure at 20° C (mm Hg)

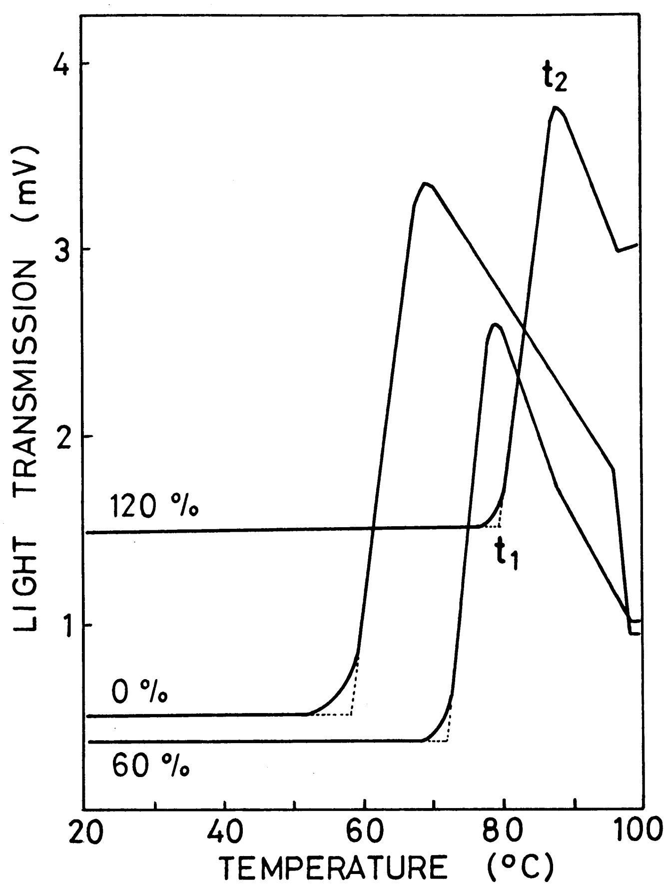

Fig. 2. Changes in light transmissions during baking of cake batters containing 0, 60, and 120% sugar. t_1 = Starch gelatinization temperature (C°), t_2 = maximum light transmission temperature (C°).

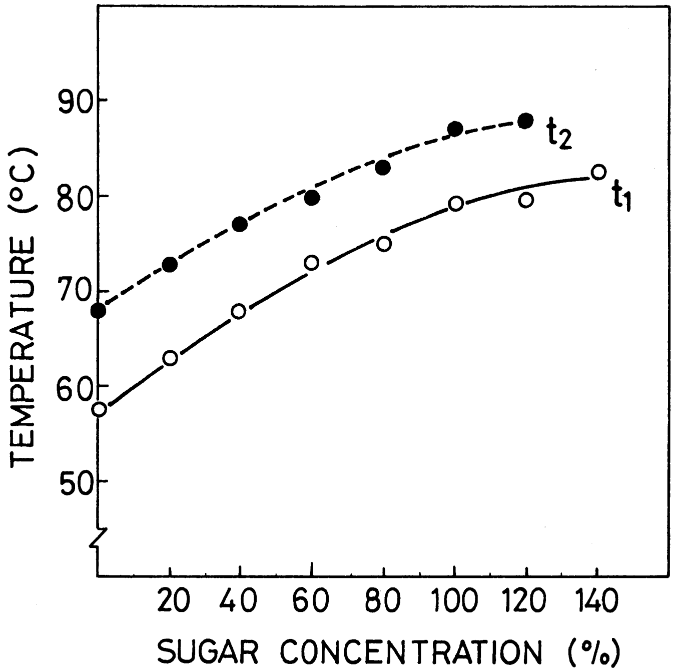

Fig. 3. Relations between t_1 or t_2 and sugar concentration. t_1 = Starch gelatinization temperature (°C), t_2 = maximum light transmission temperature (°C).

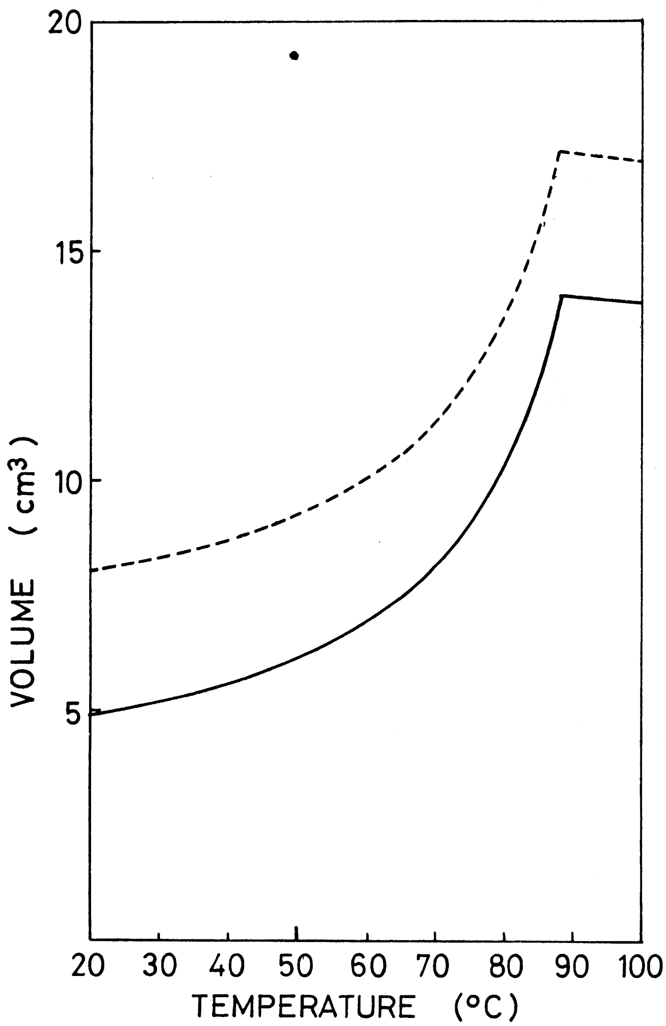

Fig. 4. Batter volume and bubble volume changes during baking of batter containing 120% sugar. ——— = Observed changes in batter volume, ——— = calculated changes in bubble volume.

v_b^{20} = volume of bubble at 20°C (cm^3)
n_a^t = amount of air at t°C (mole)
p_a^t = pressure of air at t°C (mm Hg)
p^t = total pressure at t°C (mm Hg)
v_b^t = volume of bubble at t°C (cm^3)
p_w^t = pressure of water vapor at t°C (mm Hg)
p_w^{20} = pressure of water vapor at 20°C (mm Hg)

By using equation 5, the ideal volume change of bubble expansion in the cake batter during baking was calculated and is shown in Fig. 5. The pressure of water vapor, p_w^t, was obtained from tables (Perry 1950). Although a slight difference exists between ideal expansion and actual expansion of batter, equation 5 gives a good approximation of bubble expansion in cake batter during model baking. The ideal expansion curve agrees very closely with the actual expansion curve in the range from 20°C to 70°C. However, larger values were calculated for ideal expansion than for actual expansion in the range from 70°C to 88°C. The following factors account for this difference from the ideal batter: 1) gas in the bubble was not an ideal gas; 2) vapor pressure of water in the bubble did not reach saturation; and 3) surface tension existed at the bubble surface.

Model Scheme for Cake Structural Formation

From the results of the light transmission and batter expansion measurement, we propose the following model scheme for cake structural formation during model baking. In the early stage of baking, as temperature increases, batter volume is increased by expansion of bubbles from the increase in vapor pressures of water and air in the bubbles. Further increase in temperature causes starch swelling, which is observed as increased light transmission in the model system. At the temperature of maximum light

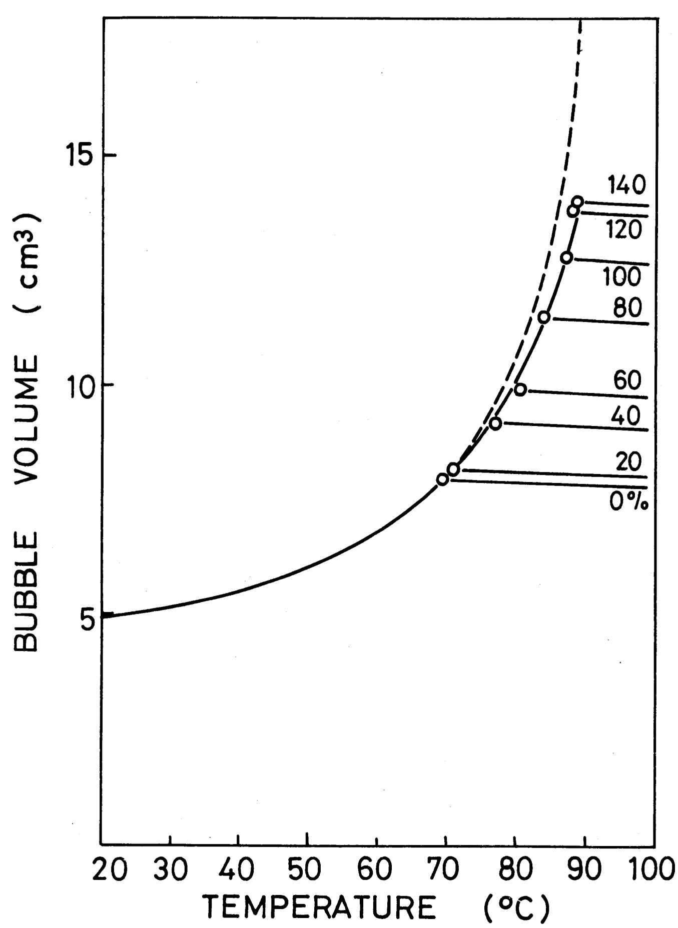

Fig. 5. Observed and ideal bubble expansions during model baking. ——— = Observed bubble volume changes of cake batters containing various sugar levels, ——— = ideal bubble volume calculated from equation.

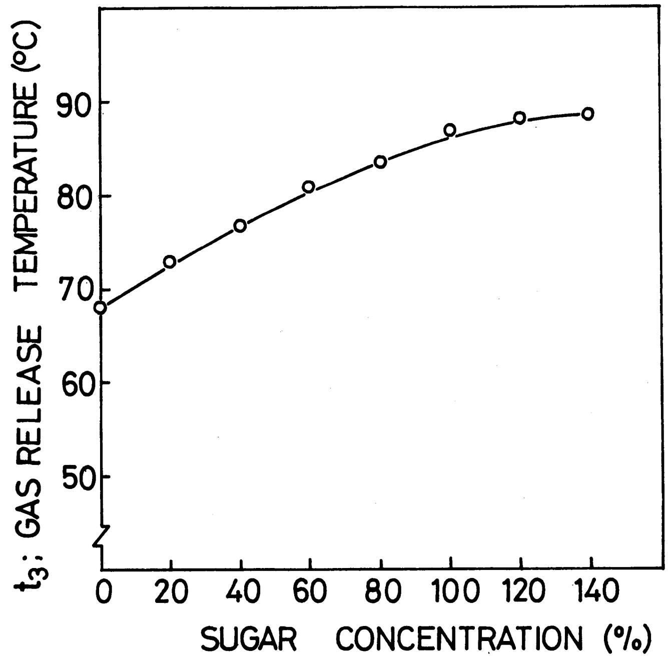

Fig. 6. Effect of sugar concentration on gas release temperature (t_3).

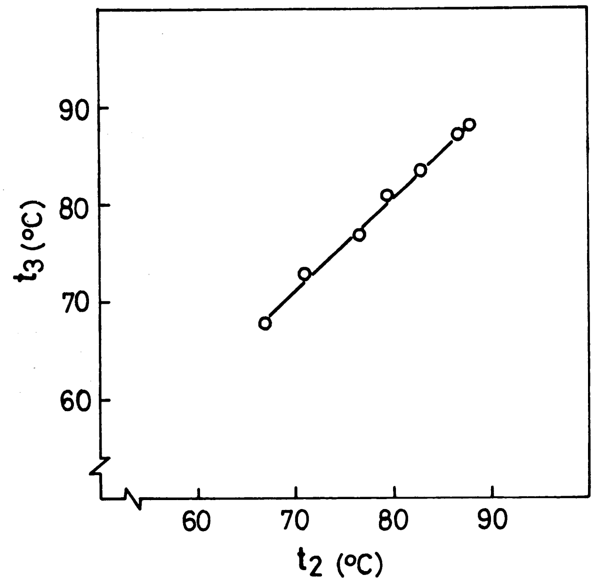

Fig. 7. Relation between maximum light transmission temperature (t_2) and gas release temperature (t_3).

transmission, the starch is almost gelatinized and protein coagulation is accelerated. Moreover, at the same time, the sol of cake batter begins to change to the gel-like structure of cake. Formation of a continuous gel phase depresses the expansion of bubbles, and further increased pressure in the bubbles causes the gas in the bubble to release. At this point, expansion of the cake batter is stopped. Continued heating causes further coagulation of egg and flour proteins, and strengthening of the cake structure continues until the end of the bake.

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