Model Studies of Cake Baking. IV. Foam Drainage in Cake Batter

M. MIZUKOSHI, Tokyo Research Laboratories, Kao Corporation, 1-3, Bunka 2-Chome, Sumida-ku, Tokyo 131, Japan

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ABSTRACT

Effects of temperature, viscosity, and silicone on foam drainage in cake batter were measured. A foam drainage test is described. The rate of drainage was proportional to the volume of undrained liquid in the foam. Drainage increased with increasing temperature up to 60° C, then decreased at 65° C. At temperatures from 40 to 55° C, the rate of drainage was in good agreement with the Arrhenius equation. Drainage rate was influenced by cake batter viscosity. A good relationship was observed between drainage rate in cake batter and formation of a gummy layer in cakes.

Colloidal and interfacial scientific investigations of food systems are active areas of research. By studying dairy systems, Sherman (1969, 1980) was a pioneer in these fields. Mulder and Walstra (1974) applied colloidal science to milk products. Friberg (1976) demonstrated the role of surfactants in food emulsions. Graham and Phillips (1979, 1980), Tornberg (1979), and Mita et al (1977, 1978) reported the importance of food protein conformation at liquid interfaces and the role of protein stabilizing emulsions and foam in model systems.

Few studies about the techniques of colloidal and interfacial science as applied to cake batter systems have been published. Handleman et al (1961) used the Laplace equation to help describe bubble-to-bubble gas diffusion and bubble movement in cake batter during baking. Wootton et al (1967) found that the ability to enhance air incorporation in cake batter systems was related to the interfacial behavior of surfactants, which adsorbed at the oil-to-water interface.

Miller et al (1967) reported that rubbery, gummy layers may appear at the bottom, top, or middle of cakes. Sometimes the gummy layer is discontinuous and appears as spots throughout the cake, but most frequently it occurs at the bottom. They discussed how a gummy layer forms, given the movement of water.

We previously reported the relation between cake quality and the foam stability of batter containing silicone during baking of actual or model cakes (Mizukoshi 1983). To relate colloidal and interfacial properties of cake batter to cake structure, foam stability during baking must be studied. In this paper, we describe a foam drainage test for cake batter. The test measures the effects of temperature, viscosity, and silicone on foam drainage, and relates foam drainage in cake batter to the formation of gummy layers in cakes.

MATERIALS AND METHODS

Cake ingredients, formulation, preparation, and baking methods were described previously (Mizukoshi et al 1979). Six cake batters containing 0, 0.5, 1, 2, 5, and 10 ppm silicone were prepared.

Foam Drainage and Viscosity Measurements

Cake batter (8.1 g) with a density of 0.50 g/cm^3 was placed in a 26-ml graduated cylinder (1.4 cm i.d.), which was placed in a water bath maintained at 40, 45, 50, 60, or 65 ± 0.02° C. Drainage volume was measured at half-minute intervals. Temperature of the batter was continuously recorded (ER-180, Yokogawa Electric Works, Ltd.). Apparent viscosity of cake batter was measured with a viscometer (type B, Tokyo Precision Instrument Co., Ltd.) using a no. 4 rotor at 6 rpm. Each treatment was duplicated.

RESULTS AND DISCUSSION

Equations for Foam Drainage

Liquid from many foams drains at a rate according to the following equations:

$$V = V_o (1 - e^{-kt}) \tag{1}$$

$$\frac{dV}{dt} = k V_o e^{-kt} = k (V_o - V) \tag{2}$$

$$- \ln (V_o - V) = kt + \text{constant} \tag{3}$$

where V = volume of liquid drained from the column of foam, V_o = original liquid volume in foam, t = time, and k = rate of drainage.

According to equation 3, the rate of drainage, k, is proportional to the volume of undrained liquid in the foam, $V_o - V$, such that drainage is as a first-order reaction (Bikerman 1973, Ross 1943).

Effect of Temperature on Foam Drainage Rate

To investigate the effect of batter temperature on the rate of drainage, cake batter containing 10 ppm of silicone was placed in glass cylinders that were kept at 40, 45, 50, 55, 60, and 65° C. The logarithm of the volume of liquid in the foam plotted against time is shown in Fig. 1. Except at the early stage of heating, each line gave a linear logarithmic relationship between drainage and time. This relationship shows that equation 3 is applicable to the drainage of cake batter. The influence of batter temperature on the logarithmic rate of drainage, calculated from the slopes in Fig. 1, was plotted against the reciprocal of absolute temperature (Fig. 2). Between 40 and 55° C, increasing temperature linearly accelerated foam drainage. After a maximum rate of drainage at 60° C, further increase in temperature abruptly decreased the rate of drainage. Below 55° C, the linear logarithmic relationship between the rate of drainage and the reciprocal of absolute temperature agreed with the following Arrhenius equations:

$$k = A\, e^{-\frac{Ea}{RT}} \tag{4}$$

$$\ln k = -\frac{Ea}{R}\frac{1}{T} + \ln A \tag{5}$$

where k = rate constant, A = frequency factor, Ea = activation energy, R = ideal gas constant, and T = absolute temperature. From the slopes in Fig. 2, we calculated that the activation energy of batter drainage for this cake formula is 2.06 kcal.

Effect of Batter Viscosity on Foam Drainage Rate

To explain the drainage profile as affected by temperature, the apparent viscosity, η_{app}, of each batter was measured (Fig. 2). The plot of log η_{app} vs 1/T is linear between 40 and 55° C, ie, the apparent viscosity of batter linearly decreased with increasing temperature. This phenomenon agreed with the following equations proposed by Andrade (1930):

$$\eta = A\, e^{\frac{b}{T}} \tag{6}$$

$$\ln \eta = \frac{b}{T} + \ln A \tag{7}$$

where η = viscosity, A = constant, b = constant, and T = absolute temperature.

The apparent viscosity of the batters reached a minimum at 60° C, and further increases in batter temperature caused an increase of apparent viscosity. Between 40 and 55° C, foam drainage increased linearly with decreasing apparent viscosity (Fig. 3). These data show that rate of drainage is closely related to apparent viscosity between 40 and 55° C. The increase in apparent

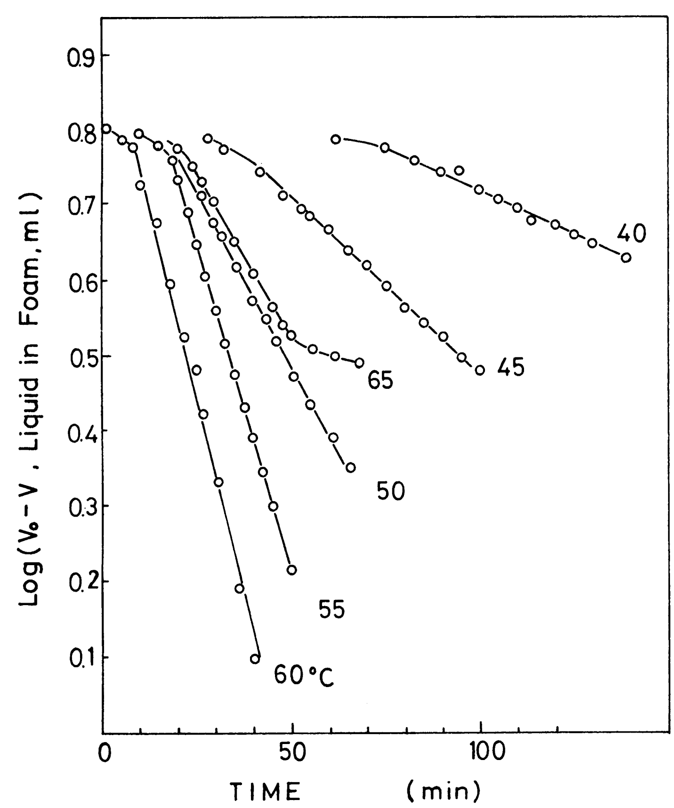

Fig. 1. Drainage profile of cake batters. Liquid volumes in foam, $V_o - V$, containing 10 ppm of silicone measured against time when batter temperatures were maintained at 40, 45, 50, 55, 60, and 65° C.

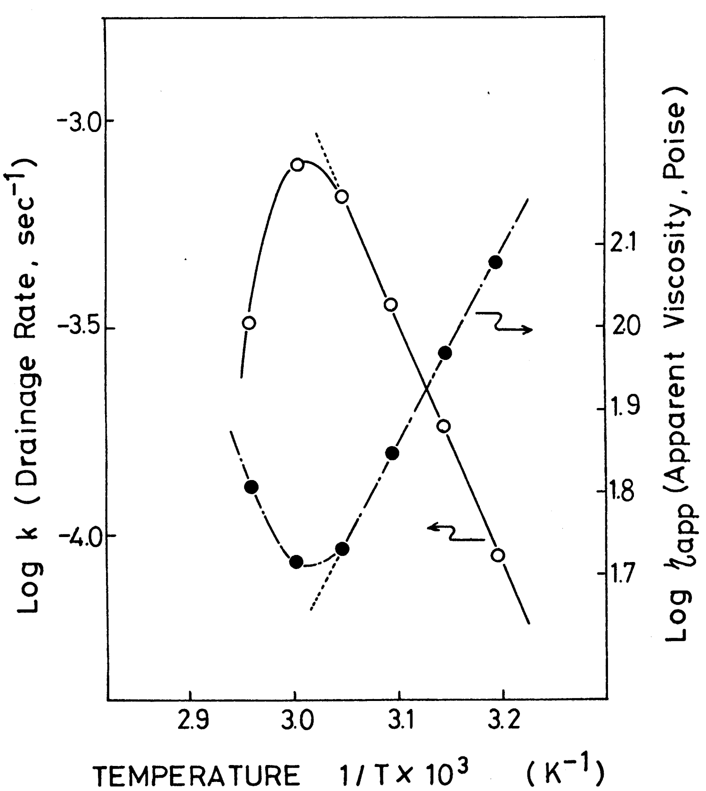

Fig. 2. Relationship between the rate of drainage, k, and apparent viscosity, η_{app}, vs temperature, T. Logarithm of the rate of drainage (—) and logarithm of apparent viscosity (---) were measured when the cake batter temperature increased from 40 to 65° C.

viscosity above 60° C may be caused by some starch swelling below the temperature of initial gelatinization, which may have caused a decrease in foam drainage.

Silicone and Foam Drainage

To study the effects of foam drainage on cake crumb, drainage measurements at 60° C were made on six cake batters containing 0, 0.5, 1, 2, 5, and 10 ppm of silicone (Fig. 4). Cake batters without silicone did not show drainage up to 40 min; however, only 0.5 ppm of silicone caused drainage and further increases of silicone-accelerated drainage. The relation between log $(V_o - V)$ vs t (time) is presented in Fig. 5. Each silicone-containing batter showed a good relationship between foam drainage and time, which was predicted by equation (3). The rate of drainage, calculated from the slopes in Fig. 5, is listed in Table I, as well as observations of gummy layer formation in cakes baked from these batters. These data indicate that the measurement of foam drainage predicts the formation of a gummy layer in cakes. Moreover, the rate of drainage was a good indicator of the degree of gummy layer formation, ie, cake batter having a large value of k had a thicker, more distinct gummy layer.

In principle, foam stability and foam drainage are independent of each other, but in reality, there is considerable interplay between them. Foam stability is influenced by one or more of the following factors: rate of drainage; diffusion of air across liquid lamellae; surface viscosity; surface rigidity; Marangoni effect; and mutual repulsion of overlapping double layers. Foam drainage is the settling of surplus water to the bottom of the foam column, under the influence of gravity and the pressure in the Plateau border. Foam drainage has been shown to be influenced by viscosity, temperature, and composition (Bikerman 1973, Davis and Rideal 1963). In this study, foam drainage was influenced by viscosity, temperature, and silicone.

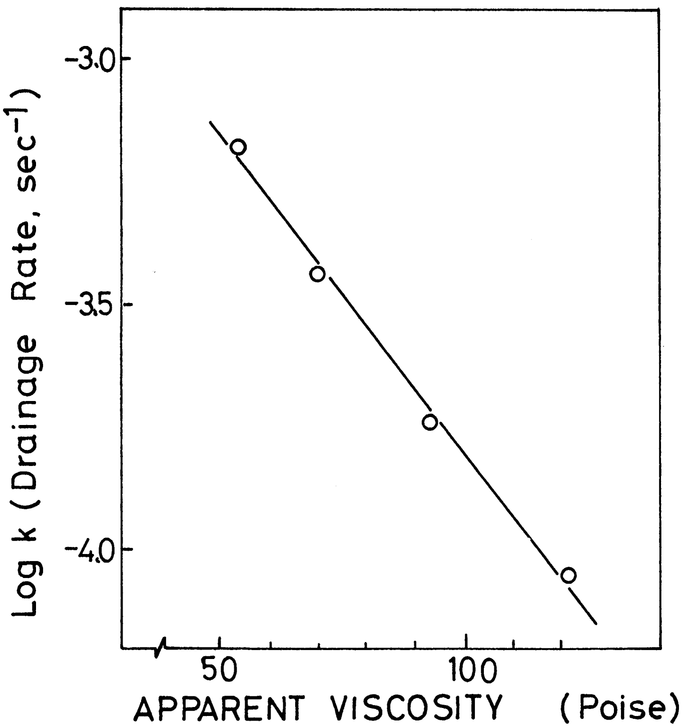

Fig. 3. Relationship between the rate of drainage, k, and apparent viscosity, η_{app}.

TABLE I
Silicone Concentration, Rate of Foam Drainage, and Extent of Gummy-Layer Formation in Sponge Cakes

Silicone Concentration[a] (ppm)	k Rate of Drainage (sec^{-1})	Gummy Layer[b]
0	≃0	−
0.5	3.19×10^{-4}	±
1	3.64×10^{-4}	+
2	4.40×10^{-4}	+
5	4.77×10^{-4}	++
10	7.85×10^{-4}	+++

[a] Dimethylpolysiloxane, as ppm (flour weight basis).
[b] Symbols represent: −, not present; ±, barely present; +, present; ++, clearly present; and +++, prominently present.

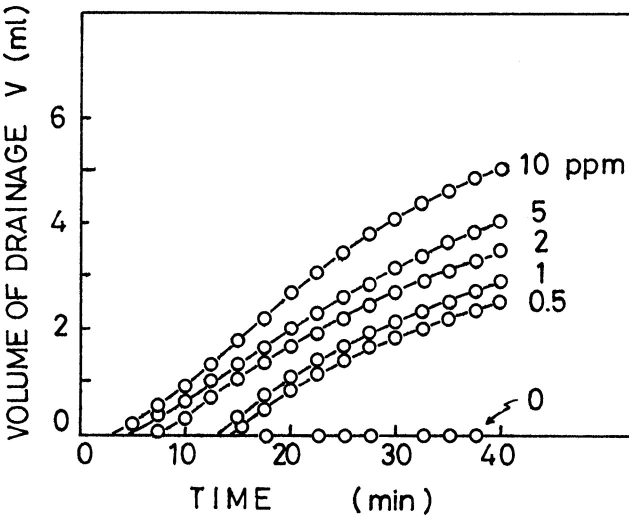

Fig. 4. Foam drainage of cake batters containing 0, 0.5, 1, 2, 5, and 10 ppm of silicone were measured at 60° C.

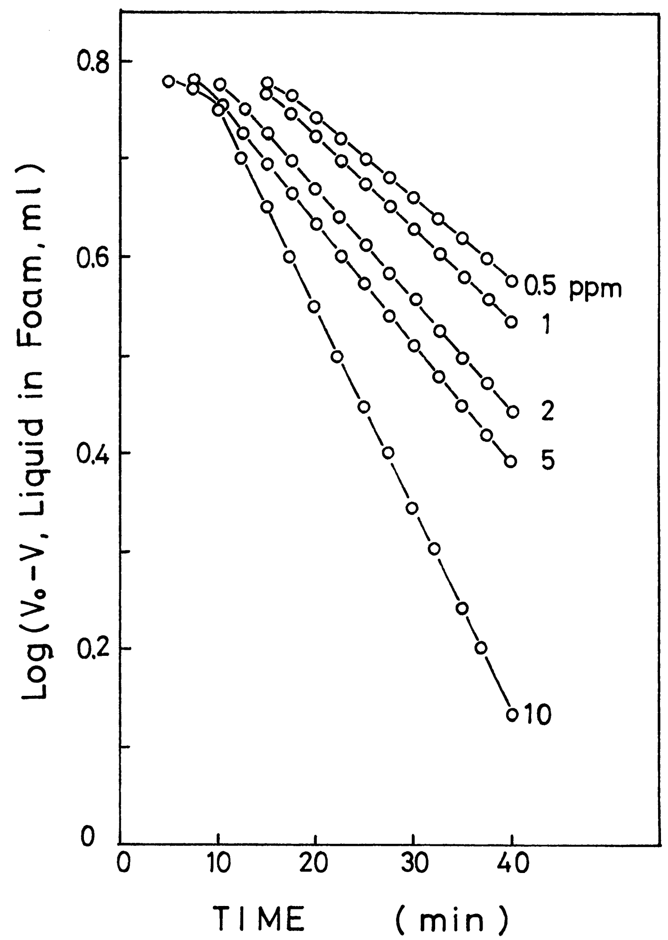

Fig. 5. Liquid volume in foam, $V_o - V$, of cake batter containing 0, 0.5, 1, 2, 5, and 10 ppm of silicone, measured against time at 60° C.

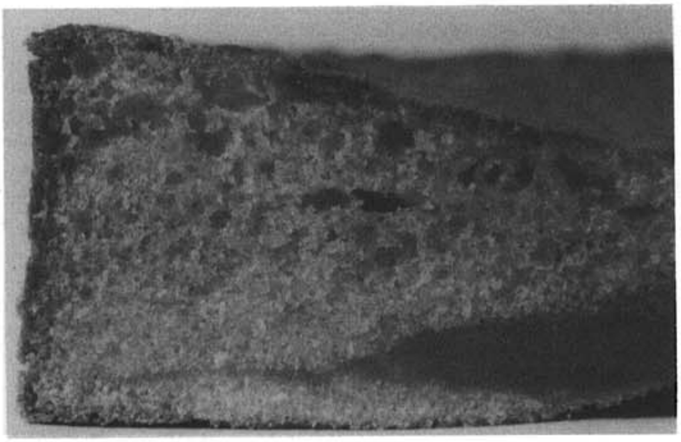

Fig. 6. Cross section of a gummy layer in a cake treated with 10 ppm silicone.

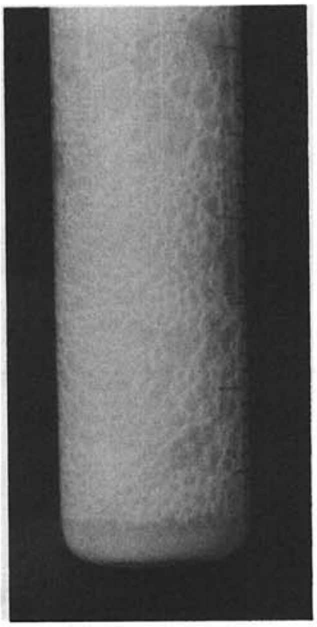

Fig. 7. Example of drained cake batter containing 10 ppm silicone.

Foam Drainage and Gummy Layer Formation

Photographs of gummy layers in cake and in the foam drainage stability test are shown in Figs. 6 and 7, respectively. Gummy layers and foam drainage layers had a greenish-yellow color and lacked visible bubbles. They appeared mostly at the bottom of cakes and glass cylinders of the foam drainage test. This observation led to the hypothesis that the gummy layer in cakes is caused by foam drainage, which is in turn caused by lack of foam stability.

Cake batter is a gaseous emulsion composed of bubbles as a discontinuous phase and of an egg-sugar-water mixture as the continuous phase, in which flour particles are dispersed. In the early stages of baking, batter viscosity decreases as temperature increases. In batters lacking foam stability, decreasing viscosity accelerates drainage from foam lammella of cake batter. This drainage flows downward and accumulates at the bottom of the cake. Further increasing temperature causes starch swelling and gelatinization in the continuous phase and increases batter viscosity. Further increases in temperature cause heat setting of the foam structure, after which drainage stops. The drainage layer at the bottom of the cake changes to the undesirable gummy layer.

It is emphasized that the colloidal and interfacial properties during the baking of cake batter play an important role in the formation of cake structure, especially foam stability and foam drainage. These properties are only two areas of colloidal and interfacial science. To investigate other aspects of cake structure (surface ring, bottom rise, coarse grain, mouthfeel, texture) more detailed colloidal and interfacial approaches are necessary.

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