A Fryer Design with Constant Specific Surface Area

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ABSTRACT: The specific surface area (surface area/volume) of a traditional frying vessel with a rectangular profile increases as the oil level decreases. In order to maintain a constant specific surface area of frying oil regardless of oil consumption, a special fryer was designed and constructed. The specific surface area of a frying vessel having a linear-inclined profile (Valentine batch fryer) deviated from a constant value by a maximum of 7.5%. The specific surface area of a frying vessel with an exponentially curved profile maintained a constant specific surface area even though the oil level varied.

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KEY WORDS: Exponentially curved profile, fryer, frying oil, specific surface area.

Many researchers have studied the effects of the frying process on the properties of frying oils (1–3). It has been difficult to achieve consistent and highly reproducible experimental results because the frying process is complex, involving numerous factors. One factor is the shape of the fryer itself, and little is known about the effects of the shape of the fryer on the frying process.

Specific surface area is defined as the ratio of the interfacial area between air and frying oil and the volume of the frying oil, as follows:

$$\text{specific surface area} = A/V \qquad [1]$$

where A = interfacial area between air and frying oil and V = volume of frying oil. Specific surface area is an important factor in frying experiments because it affects the deterioration of frying oil. As the specific surface area increases, the frying oil is exposed to more air per unit volume of oil. In the case of a common batch fryer having a frying vessel with circular or rectangular sides, the specific surface area increases during the frying process because the oil level decreases from oil absorption into fried foods or by sampling. In order to exclude the effects of specific-surface-area changes on the oxidation of frying oil, it is necessary to develop a new shape of fryer having constant specific surface area during frying. The Valentine batch fryer with linearly inclined sidewalls has been developed and used as a small-scale batch fryer for experimental purposes to minimize the increase in specific surface area (4,5). However, constant specific surface area cannot be achieved by using linearly inclined sidewalls. This article is aimed at describing a new design concept for a fryer having exponentially curved sidewalls to achieve constant specific surface area.

EXPERIMENTAL PROCEDURES

A fryer was made of a stainless steel body with a stainless steel removable frying vessel of 15 L capacity. Heat was supplied *via* a stainless steel heating element (3 kW) controlled by a thermostat. The accuracy of the temperature control was ±1°C.

RESULTS AND DISCUSSION

A specially designed fryer with a removable frying vessel having two exponentially curved sidewalls was constructed. Figure 1 shows the design for achieving constant specific

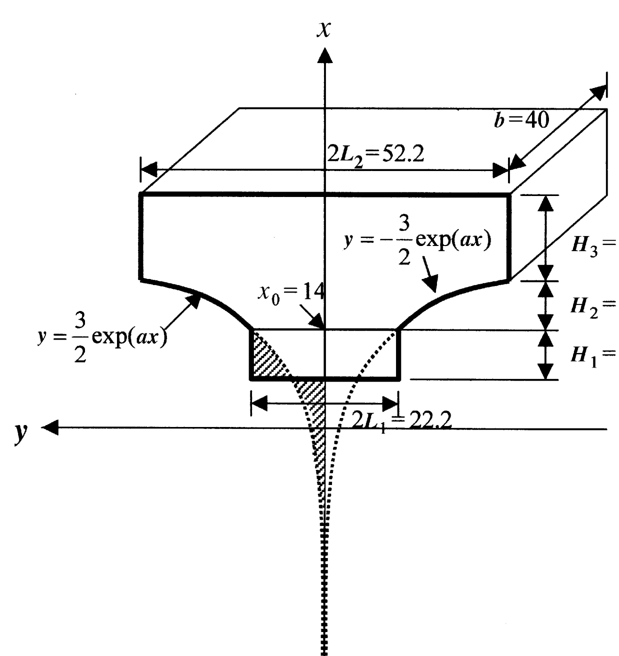

FIG. 1. Design of a frying vessel with exponentially curved sidewalls.

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surface area. If a frying vessel that has a shape described by two curves of $y = (3/2)\exp(ax)$ and $y = -(3/2)\exp(ax)$ in x-y surface has a width of b in z-x surface, and if the level of the interfacial surface is x_1, then the interfacial area is $(3/2)\exp(ax_1)2b$. The volume below the interfacial area, which is the volume of the frying oil, can be calculated by an integral equation as:

$$V = \int_{-\infty}^{x_1} \frac{3}{2}\exp(ax)2b\,dx = \left[\frac{3}{2a}\exp(ax)2b\right]_{-\infty}^{x_1} = \frac{3}{2a}\exp(ax_1)2b \qquad [2]$$

The specific surface area, that is, the ratio of the interfacial area to the volume of the frying oil, is:

$$\frac{A}{V} = \frac{(3/2)\exp(ax_1)2b}{(3/2a)\exp(ax_1)2b} = a \qquad [3]$$

Therefore, the specific surface area is constant (i.e., a) even though the level of the frying oil (i.e., x_1) varies. The a can be any value for the design of a frying vessel having constant specific area.

H_2 in Figure 1 is the working region where the specific surface area is constant and the level of the interface between air and frying oil should be positioned during frying. The bottom of the frying vessel is designed to have a rectangular profile for convenience by folding up the shaded parts as shown in Figure 1. The volume of the region H_1 was designed to be the same as the volume below x_0 (which is the lowest level of the oil during experiments) in the original exponentially curved shape, i.e.,

$$H_1\frac{3}{2}\exp(ax)2b = \int_{-\infty}^{x_0}\frac{3}{2}\exp(ax)2b\,dx \qquad [4]$$

The specific surface area of the actual design of the frying vessel in this paper was 1/7 cm^{-1}. This value was chosen arbitrarily and was similar to the specific surface area of the Valentine fryer that was made by Yoon *et al.* (4). The corresponding dimensions of the actual frying vessel were as follows: $H_1 = 7.0$ cm, $H_2 = 6.0$ cm, $H_3 = 10.0$ cm, $2L_1 = 22.2$ cm, $2L_2 = 52.2$ cm, $b = 40.0$ cm, and $x_0 = 14.0$ cm.

The actual volume (V_1) of the region H_1 was

$$V_1 = \left[\frac{3}{2a}\exp(ax)2b\right]_{-\infty}^{x_1} = \left[\frac{3}{2a}\exp(ax)2b\right]_{-\infty}^{14} = \frac{3\times 7}{2}\exp\left(\frac{1}{7}\times 14\right)\times 2\times 40 = 6{,}207 \text{ mL} \qquad [5]$$

The total volume (V_t) of the frying vessel (which was the summation of the two volumes in regions H_1 and H_2) was

$$V_t = \left[\frac{3}{2a}\exp(ax)2b\right]_{-\infty}^{20} = \frac{3\times 7}{2}\exp\left(\frac{1}{7}\times 20\right)\times 2\times 40 = 14{,}624 \text{ mL} \qquad [6]$$

Then, the volume (V_2) of the test section (region H_2) where the interfacial surface should remain was:

$$V_2 = V_t - V_1 = 14{,}624 \text{ mL} - 6207 \text{ mL} = 8{,}419 \text{ mL} \qquad [7]$$

The maximum volume of the frying oil was about 15 L, and the minimum volume was about 6.2 L. The region H_3 was added just for convenience in handling the fryer.

Three types of frying vessels were compared, as shown in Figure 2. The profile of the frying vessel in Figure 2A is rectangular. The frying vessel in Figure 2B has a linearly inclined profile in the region H_2. The frying vessel in Figure 2C has an exponentially curved profile in the region H_2. The specific surface areas of the three types of frying vessels are compared in Figure 3.

The specific surface area of the frying vessel with the exponentially curved profile was constant even though the oil level varied. The specific surface area of the frying vessel with the rectangular profile decreased as the oil level increased. The specific surface area of the frying vessel with the linearly inclined profile was 1/7 cm^{-1}, when the oil level remained at the bottom of the region H_2. It deviated from 1/7 cm^{-1} when the oil level increased over the bottom of the region H_2. For example, when the oil level remained 2 cm over the bottom of the region H_2, the specific surface area was 0.154 cm^{-1}, which was 7.5% more than the desired value, 1/7 (=0.1429) cm^{-1}. A frying vessel with a constant specific surface area during the frying process might exclude one cause of error in frying experiments.

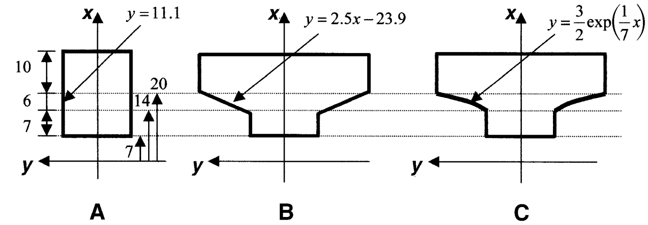

FIG. 2. Side views of frying vessels that have three different sidewall designs: (A) the rectangular profile, (B) the linear profile, and (C) the exponential profile.

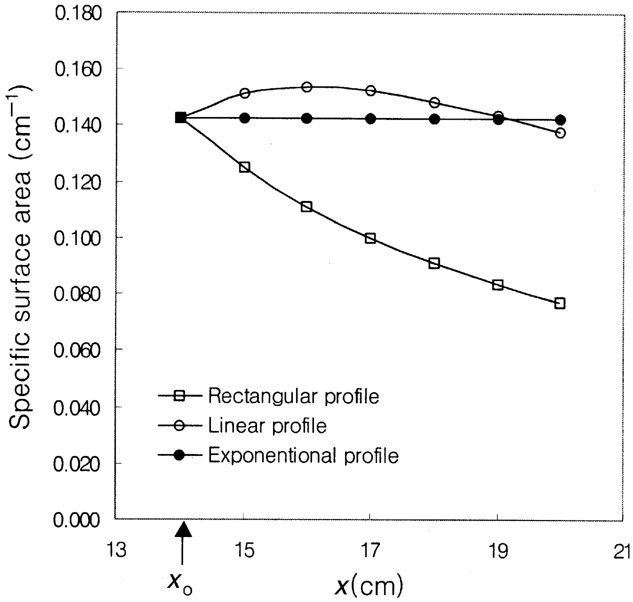

FIG. 3. Comparison of the specific surface areas of three frying vessels with three different profiles; (A) the rectangular profile ($y = 11.1$), (B) the linear profile ($y = 2.5x - 23.9$), and (C) the exponential profile [$y = (3/2)\exp(1/7)x$], respectively.

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