

Effect of a Modified Deep-Fat Fryer on Chemical and Physical Characteristics of Frying Oil

Hironori Negishi^{a,*}, Minoru Nishida^a, Yasushi Endo^b, and Kenshiro Fujimoto^b

^aFood R&D Center, The Nisshin OilIIO, Ltd., Yokosuka 239-0832, Japan, and

^bGraduate School of Agricultural Science, Tohoku University, Sendai 981-8555, Japan

ABSTRACT: We designed a modified deep-fat fryer (MDF) to have a smaller oil area (A) relative to depth or height (H) such that $H/\sqrt{A} = 0.93$. The modification was intended to retard the thermal degradation of the frying oil and the production of waste oil. Frozen croquettes were fried in vegetable oil using the MDF ($H/\sqrt{A} = 0.93$) and three conventional deep-fat fryers (CDF1, $H/\sqrt{A} = 0.25$; CDF2, $H/\sqrt{A} = 0.20$; CDF3, $H/\sqrt{A} = 0.30$) at 180°C for 72 h at 8 h/d. Frying oils were periodically collected, and their chemical and physical characteristics were examined. The acid value (AV) of frying oils used for 72 h in the MDF was lower than that for oils used in the CDF, although the AV was similar in all fryers until 32 h. The oil deep-fried with MDF had a higher degree of color than that with CDF until 48 h. Polymerized materials and the carbonyl value of frying oil after heating 72 h with MDF were lower than those with CDF. The residual tocopherol content of frying oil with MDF was 83% of the content in fresh oil, whereas with CDF the tocopherol contents were less than 63%. The oil consumption by MDF was less than that by CDF, although the turnover rate was higher in MDF than in CDF. These results suggest that during deep-fat frying the MDF may retard the thermal deterioration of vegetable oils and generate less waste oil.

Paper no. J10229 in *JAACS* 80, 163–166 (February 2003).

KEY WORDS: Acid value, carbonyl value, color degree, deep-fat fryer, polar compounds, polymerized materials, tocopherol, turnover.

During deep-fat frying, fats and oils are susceptible to thermal oxidative deterioration because of elevated temperatures above 170°C, although deep-fat frying is an excellent cooking method. Thermally abused fats and oils are usually discarded, because accumulation of oxidation products from fats and oils will not only reduce the sensory quality of fried foods but may also diminish their nutritional value. In general, 30% of used fats and oils with batch processes are discarded per week in a commercial frying operation. It is very important to minimize the waste oils generated during deep-fat frying, from the point of the cost for disposal of the waste oil and effective utilization of fats and oils.

The vacuum deep-fat fryer was developed to reduce the thermal oxidation of fats and oils (1). In this system, frying is performed at 100°C under pressure of 10–100 Torr. Thermal oxi-

dation of frying oil can be remarkably retarded by low temperature and low oxygen concentration. However, because it needs a vacuum pump, condenser, and cooler, the vacuum deep-fat fryer is too large for supermarkets and convenience stores.

Fujisaki *et al.* (2) designed a deep-fat fryer with low oxygen atmosphere (2% O₂) using N₂, and then fried frozen chicken with vegetable oils. They reported that the increase in acid values (AV) and carbonyl values (CV), the production of polymerized materials (PM), and the decrease in tocopherols were retarded during frying. However, an N₂ bomb is necessary for this system.

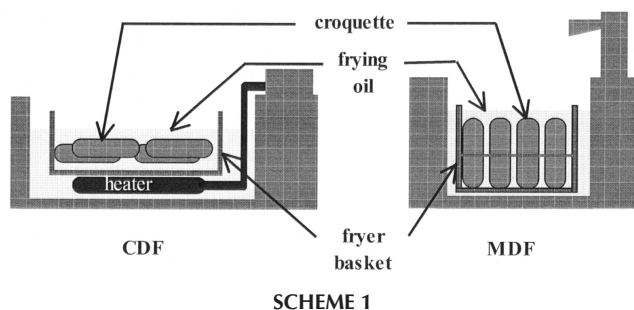
Kitamura (3) measured the refractive index of oil heated at 180°C to find the effect of surface area and weight of oils on thermal oxidation. He reported that in addition to temperature and time, the ratio of the surface area to the weight of oils was an important factor for thermal oxidation. We also observed that the surface area of oil and the turnover could affect the thermal degradation of oils and fats during deep-frying.

The oil surfaces are designed to be large to enhance the production capacity in conventional fryers. However, the large oil surface increases the likelihood of thermal oxidation and the loss of thermal energy from the oil surface. As a result, conventional fryers usually need excessive oil to control the temperature of the bath. When we measured the surface area (A) and height (H) of the oil bath of the commercial deep-fat fryers, the H/\sqrt{A} ratio was below 0.6 (4). If the surface area and volume of frying oil in the fryer were smaller, the turnover rate would increase and thermal degradation of oil might be retarded during deep-frying. We designed a modified deep-fat fryer (MDF) to have a smaller surface area relative to height. In this study, we chose an MDF with the ratio H/\sqrt{A} at 0.93, which was constant enough to maintain a high turnover rate and frying capacity compared with conventional fryers. We deep-fried frozen croquettes using the MDF and conventional deep-fat fryers (CDF), and then measured chemical and physical characteristics of the frying oil.

MATERIALS AND METHODS

Deep-fat fryers. Scheme 1 shows the CDF and the MDF. The MDF was an electric stainless-steel fryer in which the heater did not directly contact the frying oil. The MDF was made in cooperation with the Nisshin Plant Engineering Co. Ltd. (Yokohama, Japan) and the Eishin Electronic Co. Ltd. (Yokohama, Japan) (4). The CDF were commercial electric stainless-

*To whom correspondence should be addressed at Food R&D Center, The Nisshin OilIIO Ltd., 1 Shinmei-cho, Yokosuka, 239-0832 Japan. E-mail: h-negishi@nisshin.oilligroup.com



SCHEME 1

steel fryers, and the heaters directly contacted the frying oil. All fryers were regulated at 180°C during deep-frying.

Test frying oil and its quantity. Refined, bleached, and deodorized rapeseed oil and palm olein were provided by the Nisshin Oil Co., Ltd. (Yokohama, Japan). A mixture of rapeseed oil (70%) and palm olein (30%), to which 2 ppm silicon oil was added, was used for deep-fat frying tests.

When 1.5 kg of mixed oil was put into MDF the H/\sqrt{A} was initially 0.93. When 3.0 kg of mixed oil was put in CDF1 and CDF2, and 5.0 kg of oil was put in CDF3, the H/\sqrt{A} were 0.25, 0.20, and 0.30, respectively (Table 1). The FA composition of mixed oil was 16:0 (15.4), 18:0 (2.7), 18:1 (54.4), 18:2 (18.4), and 18:3 (6.7%).

Materials. Commercially nonfried and frozen croquettes were purchased for deep-frying at a food wholesale dealer.

Frying conditions. Four pieces of frozen potato croquettes (4 × 75 g) were deep-fried as a batch for 6 min once each 30 min. Deep-frying of croquettes was continued for 9 d at 8 h/d. The total quantity fried for all four fryers was 576 pieces (43.2 kg) for 72 h. Total frying time was 20% of total heating time.

During deep-frying, each fryer was replenished with fresh oil four times per day, because the frying oil was absorbed by foods. Residual frying oil was weighed every day. Forty grams of frying oil was collected every day after the heating had ended and was filtered through with a paper towel, except for the first day when 25 g of frying oil was collected.

Analyses of heated oils. The FA composition was measured by GC using a Supelco SP-2340 capillary column (i.d. 0.32 mm × 0.2 μm × 30 m; Bellefonte, PA) after methylation (5). AV was determined by alkali titration according to the standard methods of the Japan Oil Chemists' Society (6). CV was determined by the 2,4-dinitrophenylhydrazine method with triphenylphosphine pretreatment (7). PM was measured by a high-performance liquid chromatograph equipped with a

refractive index detector by the method of Wolff *et al.* (8). The column was PLgel (7.5 × 300 mm, 5 μm; Polymer Laboratories Ltd., Shropshire, United Kingdom). THF was used as mobile phase at a flow rate of 0.5 mL/min. PM was detected with an ERC-7515A refractive index detector (ERC Inc., Kawaguchi, Japan). Color of frying oils was assessed by Lovibond chromaticity (The Tintometer Ltd., Salisbury, United Kingdom) using the 1.27-cm cell after filtration with a paper filter (9). The tocopherol contents were measured by normal-phase HPLC with a fluorescence detector. The column was YMC-pack SIL A-012 (Milford, MA; 6.0 × 150 mm, 5 μm). The mobile phase was *n*-hexane/2-propanol (100:0.5, vol/vol) at a flow rate of 2 mL/min. Tocopherols were detected at an excitation wavelength of 298 nm and an emission wavelength of 325 nm using a Tosoh FS-8020 fluorescence detector (Tosoh Corp., Tokyo, Japan) (10).

Deep-frying was carried out in duplicate. Data were represented as mean + SD.

RESULTS AND DISCUSSION

Consumption of frying oils. The consumption of frying oil (after heating 72 h) is shown in Table 2. The weight of frying oil consumed during deep-frying with MDF was 7107 g, which was lower than that with CDF1 (9668 g), CDF2 (9652 g), or CDF3 (9424 g). The frying oil consumed during deep-frying with MDF corresponded to 73.5, 73.6, and 75.4% of consumption with CDF1, CDF2, and CDF3, respectively, but the frying performance of MDF was almost equal to that of CDF. The oil content in croquettes fried with MDF was 17.2%, which was lower than that with CDF. It was suggested that MDF may reduce the absorption of oil in foods. The turnover ratio of MDF was 6.9%/h, which was higher than that of CDF1 (4.6), CDF2 (4.6), and CDF3 (2.7%/h).

AV and CV. The changes in AV of frying oil during heating with MDF and CDF are shown in Figure 1. AV of frying oil heated with MDF was almost the same as that with CDF until 32 h, whereas frying oil with MDF showed lower AV than that with CDF after 40 h. AV of frying oil heated with MDF for 72 h was 1.6 mg/g, whereas that with CDF1, CDF2, and CDF3 was 2.0, 2.1, and 3.6 mg/g, respectively. Frying oil in MDF seemed to be more susceptible to hydrolysis by moisture from foods because the oil capacity of MDF was less than half that for CDF. However, the increase in AV during heating with MDF was lower than that with CDF. The high

TABLE 1
Oil Bath Structures, Height (H) of Oil Bath, Surface Area (A), and H/\sqrt{A} Ratio of Deep-Fat Fryers (CDF1, 2, 3) and Modified Deep-Fat Fryer (MDF)^a

Variable	CDF1	CDF2	CDF3	MDF
Initial oil	3000 g	3000 g	5000 g	1500 g
Height (H) of oil bath	5.8 cm	5.0 cm	7.9 cm	11.2 cm
Surface area (A)	552.0 cm ²	640.0 cm ²	675.0 cm ²	144.0 cm ²
H/\sqrt{A}	0.25	0.20	0.30	0.93
Electric power of heater	1300 W	1300 W	1500 W	1600 W
Voltage	100 V	100 V	100 V	100 V

TABLE 2
Consumption of Frying Oil in CDF1, 2, 3 and MDF^a

Variable	CDF1	CDF2	CDF3	MDF
Initial oil (g) (a)	3000	3000	5000	1500
Sampling (g) (b)	305	305	305	305
Replenished oil (g) (c)	9973 ± 20	9957 ± 124	9729 ± 61	7412 ± 42
Frying oil consumption (g) (d) = (c) - (b)	9668 ± 20	9652 ± 124	9424 ± 61	7107 ± 42
Total frying time (h) (e)	72	72	72	72
Turnover rate (%/h) (g) = 100 × (c)/(a)/(e)	4.6 ± 0.0	4.6 ± 0.0	2.7 ± 0.0	6.9 ± 0.0

^aMean ± SD. For abbreviations see Table 1.

turnover of oil that resulted from the small volume of MDF probably suppressed the increase of AV during deep-frying.

CV of frying oil after 72 h heating with MDF and CDF are shown in Table 3. CV of frying oil heated with MDF was 12.7 meq/kg, which was lower than that with CDF1 (19.9 meq/kg), CDF2 (18.6 meq/kg), and CDF3 (20.8 meq/kg). This result shows that the thermal oxidation of oils was retarded during deep-frying with MDF.

PM. The changes in PM in frying oil during heating with MDF and CDF are shown in Figure 2. The level of PM in frying oil with MDF was lower than that with CDF during deep-fat frying. The level of PM in frying oil with MDF was constant at 2.0% after 32 h, whereas that with CDF1 and CDF2 reached 3.8 and 3.9%, respectively, after 40 h and then became constant. The production of PM in frying oil with CDF3 became constant at 4.8% after 56 h.

The thermal oxidation that produced PM during deep-frying with MDF could be retarded due to the small surface area of oil in contact with air and the high turnover. These results demonstrate that MDF was able to retard polymerization during deep-frying.

Color. Figure 3 shows the changes in color degree (Y+10R) of frying oil during heating with MDF and CDF. The degree of color of frying oil after 72 h heating with MDF was lower than that for CDF3 and similar to that of frying oils heated with CDF1 and CDF2. On the other hand, the frying oil heated with MDF had a higher degree of color than that with CDF until 48 h. Generally, small volumes of fats and oils

TABLE 3
Carbonyl Value in Frying Oils After 72 h Heating at 180°C with CDF and MDF^a

Frying oil	Carbonyl value (meq/kg)
Fresh oil	3.5 ± 0.0
CDF1	19.9 ± 2.5
CDF2	18.6 ± 0.9
CDF3	20.8 ± 0.6
MDF	12.7 ± 0.3 ^b

^aMean ± SD.^bData on MDF were significantly different from data on CDF1, 2, and 3 ($P < 0.05$). For abbreviations see Table 1.

are more susceptible to coloring during deep-fat frying. Therefore, deep-frying oil with MDF showed a higher color degree than that with CDF in the early stages. However, the color degree of the MDF oil was similar to or lower than that with CDF after 72 h, because coloring of the MDF oil was suppressed by the high turnover rate.

Tocopherols. Table 4 shows the level of tocopherols in frying oils after 72 h heating with MDF and CDF. The total tocopherol content of vegetable oil was 61.5 mg/100 g and was decreased to 62, 63, and 58% that of fresh oil in deep-frying oil with CDF1, CDF2, and CDF3, respectively. When frying oil was heated with MDF for 72 h, 83% of tocopherols were retained. Mainly γ -tocopherol decreased in deep-frying oil with MDF, whereas both α - and γ -tocopherols significantly decreased in deep-frying oil with CDF. The degradation of tocopherols and tocotrienols was retarded during deep-frying

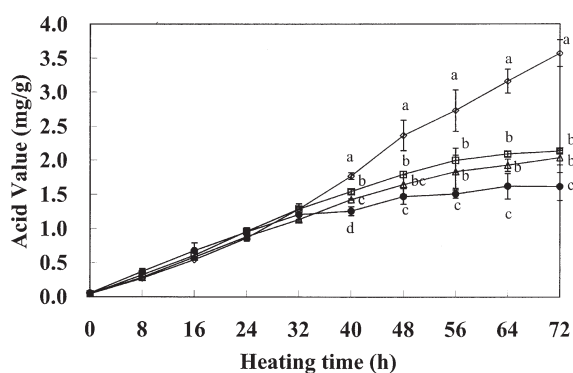
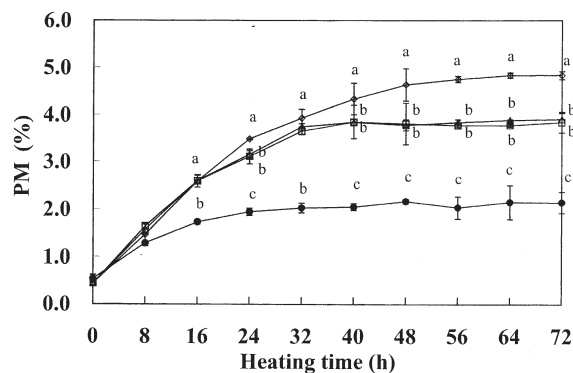
**FIG. 1.** Changes in acid value of frying oil during heating at 180°C with different deep-fat fryers. Mean ± SD; values in a vertical row with different superscript letters are significantly different ($P < 0.05$). —●—, MDF; —△—, CDF1; —□—, CDF2; —◇—, CDF3.**FIG. 2.** Changes in polymerized materials (PM) in frying oil during heating at 180°C with different deep-fat fryers. Mean ± SD; values in a vertical row with different superscript letters are significantly different ($P < 0.05$). —●—, MDF; —△—, CDF1; —□—, CDF2; —◇—, CDF3.

TABLE 4
Tocopherols (Toc) and Tocotrienols (T3) in Frying Oils After 72 h Heating at 180°C with CDF and MDF^a

Frying oil	Total Toc and T3 contents (mg/100 g)	Toc contents (mg/100 g)					
		α -Toc	γ -Toc	δ -Toc	α -T3	γ -T3	δ -T3
Fresh oil	61.5 \pm 1.0	20.2 \pm 1.2	33.3 \pm 1.0	1.2 \pm 0.1	2.3 \pm 0.3	3.6 \pm 0.4	0.9 \pm 0.2
CDF1	38.1 \pm 1.1	14.5 \pm 0.2	18.4 \pm 1.3	1.1 \pm 0.1	1.5 \pm 0.0	2.0 \pm 0.0	0.6 \pm 0.1
CDF2	38.7 \pm 2.5	14.7 \pm 0.3	18.8 \pm 2.2	1.0 \pm 0.1	1.6 \pm 0.0	2.1 \pm 0.1	0.6 \pm 0.1
CDF3	35.7 \pm 2.1	14.9 \pm 1.2	15.9 \pm 0.4	1.0 \pm 0.0	1.5 \pm 0.0	1.9 \pm 0.3	0.7 \pm 0.3
MDF	51.3 \pm 1.7 ^b	17.9 \pm 1.0 ^b	26.5 \pm 0.5 ^b	1.2 \pm 0.1	2.2 \pm 0.2 ^b	3.0 \pm 0.2 ^b	0.7 \pm 0.1

^aMean \pm SD.

^bData on MDF were significantly different from data on CDF1,2, and 3 ($P < 0.05$). For other abbreviations see Table 1.

with MDF because of the reduced thermal oxidation of oils.

In this study, we designed a desktop type of MDF in which the H/\sqrt{A} of the oil bath was 0.93 to minimize the generation of waste oil by reducing thermal oxidative deterioration of fats and oils. The structure of MDF (higher H/\sqrt{A}) contributed to the high oil turnover rate and the smaller oil surface. As a result, thermal oxidation of frying oils and fats could be suppressed by both factors. When frozen croquettes were deep-fried with vegetable oil using MDF, the turnover rate increased remarkably (Table 2). As a result, AV of frying oil could be controlled to less than 2.5 mg/g of the value regulated by the Japanese Ministry of Health and Welfare (11). The increase of PM and CV in frying oil was also smaller during heating with MDF compared with CDF. The production of PM in frying oil during deep-frying was especially inhibited in the early stages (within 16 h) (Fig. 2). The retarded thermal oxidation of frying oils with MDF may be due to the small surface area of oil in contact with air. The surface area of the MDF is about one-fourth the area of CDF.

PM produced during deep-frying is well known to impart an antinutritional property to fried foods (12). Moreover, Usuki and Kaneda (13) reported that the carbonyl compounds and lactones contained in frying oil contributed to undesirable flavor of fried foods. Deep-frying using MDF might be effective to control the quality of fried foods. In addition, maintaining a high tocopherol content in vegetable oils during deep-frying with MDF results in a higher vitamin E content in fried foods.

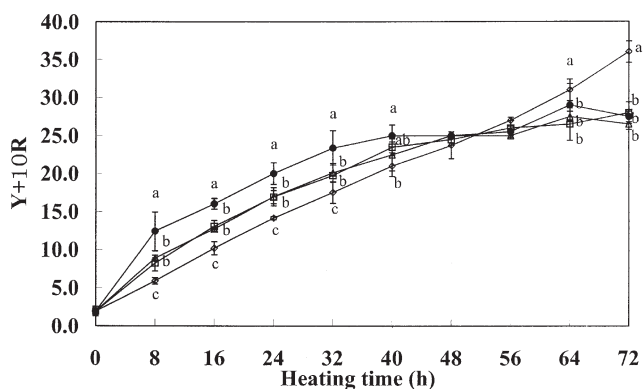


FIG. 3. Changes in degree of color of frying oils during heating at 180°C with different deep-fat fryers. Mean \pm SD; values in a vertical row with different superscript letters are significantly different ($P < 0.05$). —●—, MDF; —△—, CDF1; —□—, CDF2; —◇—, CDF3.

The MDF that we have developed could retard not only the degradation of oils and fats but also the generation of waste oil during deep-frying. MDF would be advantageous as a deep-fat fryer at supermarkets and convenience stores because it is a desktop type and needs no other specific equipment.

ACKNOWLEDGMENTS

We wish to thank the Nisshin Plant Engineering Co., Ltd. and Eishin Electric Co., Ltd. for providing the deep-fat fryers.

REFERENCES

- Kotani, A., Vacuum Deep-Fat Fryer as New Food Processing Technology, *Food Sci.* 26(6):38–40 (1984) (in Japanese).
- Fujisaki, M., M. Sato, Y. Endo, and K. Fujimoto, Frying Under Low Oxygen Atmosphere Retards the Oxidative Deterioration of Oils and Foods, *J. Oleo Sci.* 50:121–127 (2001).
- Kitamura, K., Examination of Deterioration Rate on Deep-Fat Frying Oils by Refractometer. Heat Deterioration Law of Oils in Deep-Fat Frying, *J. Jpn. Oil Chem. Soc.* 47:609–614 (1998) (in Japanese).
- Nishida, M., A. Okumura, and T. Intui, Method of Preparing Fried Food and Frying Cooker, PCT/JP01/10089 (2001).
- Standard Methods for the Analysis of Fats, Oils and Related Materials*, Japan Oil Chemists' Society, Tokyo, Japan, 1996, 2.4.2.1-1996.
- Ibid.*, 2.3.1-1996.
- Chiba, T., M. Takazawa, and K. Fujimoto, A Simple Method for Estimating Carbonyl Content in Peroxide-Containing Oils, *J. Am. Oil Chem. Soc.* 66:1588–1592 (1989).
- Wolff, J.P., F.X. Mordret, and A. Dieffenbacher, Determination of Polymerized Triglycerides in Oils and Fats by High-Performance Liquid Chromatography: Results of a Collaborative Study and Standardized Method, *Pure Appl. Chem.* 63:1163–1172 (1991).
- Standard Methods for the Analysis of Fats, Oils and Related Materials*, Japan Oil Chemists' Society, Tokyo, Japan, 1996, 2.2.1.1-1996.
- Abe, K., and G. Katsui, Application of High-Speed Liquid Chromatography for Determination of Tocopherols in Vegetable Oils, *J. Jpn. Soc. Nutr. Food Sci.* 28:453–455 (1975) (in Japanese).
- Code of Hygiene Practice on Lunch Box and Cooked Foods, No. 161, Japanese Ministry of Health and Welfare, 1979.
- Marquez-Ruiz, G., and M.C. Dobarganes, Nutritional and Physiological Effects of Used Frying Fats, in *Deep Frying*, edited by E.G. Perkins and M.D. Erickson, AOCS Press, Champaign, 1996, pp. 160–182.
- Usuki, R., and T. Kaneda, Recent Advances in the Research on Tastes and Odors of Fats and Oils, *J. Jpn. Oil Chem. Soc.* 25:717–723 (1979) (in Japanese).

[Received January 22, 2002; accepted November 20, 2002]