Properties of Frying Fat. I. The Relationship of Viscosity to the Concentration of Non-Urea Adducting Fatty Acids[1]

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Abstract

The extent of the thermal oxidative change in commercial frying fats as measured by the amount of non-urea adducting fatty acids formed in the fat and the viscosity of the fat was compared. A direct and highly significant relationship was found. The relationship was found to be dependent upon the source and processing of the fat as well as the conditions of use.

Introduction

FOR SEVERAL YEARS NOW the question of heat damage to fats in the cooking process, particularly frying has received a good deal of attention. Today it is generally agreed that the extent of this damage, at least, in commercial deep fat frying operations is not nutritionally significant. It has been found that the conditions of heating and the rate at which the fat is used up and replaced with fresh unheated fat in commercial deep fat frying operations does not permit the accumulation of these heat damage products (1–3,12–14). Nevertheless, the processor and baker has sought some means of measuring the extent of heat damage or the concentration of these products so that the condition of the fat could be controlled in a formal manner.

It was found that the important heat damage products could be isolated by an urea adduction technique and it was hoped that this would be the basis for a control method (9,10). However, the method is complex and time-consuming and efforts to simplify it have not been successful. Its use even as a test to be performed in a control laboratory is unlikely while the ideal test would be one capable of giving significant results even when carried out by nontechnical personnel on the processing floor.

On the other hand, it has been noted by many observers that other properties of the fat change in a somewhat regular manner with the extent of heating and it was thought possible that one of these might correlate with the values given by the urea adducting technique and at the same time be simple enough to use as part of a control procedure. The viscosity of the fat at elevated temperature, which has long been used by our laboratories as a measure of its performance qualities, appeared to have a direction and rate of increase closely paralleling the build-up of non-urea-adducting acids (NAF) in frying fat while refractive index, iodine value, free acidity and other properties did not. We set about, therefore, to determine how well these two properties were correlated.

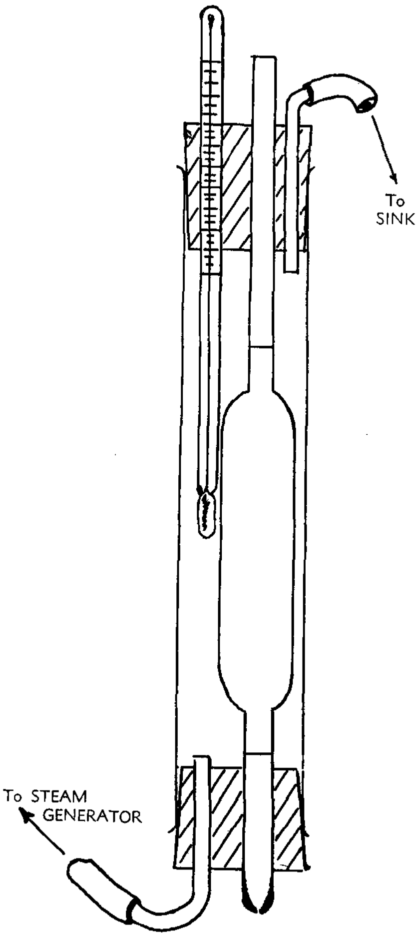

FIG. 1. The relationship of viscosity to the concentration of non-urea-adducting fatty acids.

Experimental Procedure and Data

It was realized that to be meaningful, comparison had to be made with fats that differed in source, processing, and condition of use. Accordingly, samples were drawn from 29 different commercial frying operations, including bakeries, fish processors, and restaurant operations. Information about the composition and condition of use were obtained whenever possible. These samples represent all commonly used frying fats, including animal, vegetable, animal-vegetable blends, hydrogenated fats and blends of hydrogenated with unhydrogenated fats. Differences in conditions of use include different fryer types, cleaning and fat handling procedures and most important, turnover rates ranging from the uncommon 1% to well over 10% per hour of heating.

To these we added samples taken from the fryers of our quality control laboratory and other samples that were heated without frying under experimental conditions designed to explore the nature of frying fat deterioration. This provided us with 39 samples of a wide range of treatments. Each sample was analyzed for non-urea-adducting acids by the method of Firestone et al. (4) and for viscosity by timing the flow of a fixed volume of fat from a steam jacketed pipet (212F) that had been calibrated with viscosity standards obtained from the National Bureau of Standards. The viscometer is shown in Figure 1. The viscometer tube is a 25 ml volumetric pipet that has been altered as follows, the tapered tip is re-

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TABLE I

Data from All Sources

Sample No.	User	Type of fat	Fat supplier[a]	Turnover %/hr of heating	Viscosity at 212F (cs)	NAF (%)
1	Fish fryer	Oil	..	..	7.50	3.6
2	Doughnut fryer-bakery	Hydro lard	G	8	8.10	0.6
3	Doughnut fryer-bakery	Hydro A&V	C	10	8.15	0.4
4	Laboratory fryer	Hydro lard	A	10	8.35	0.2
5	Restaurant fryer	Hydro A&V	B	..	8.35	1.5
6	Doughnut fryer-bakery	Hydro veg.	C	..	8.45	0.5
7	Doughnut fryer-bakery	Hydro A&V	A	15	8.50	1.7
8	Restaurant fryer	....	..	..	8.65	0.2
9	Doughnut fryer-bakery	Hydro lard	H	..	8.70	1.1
10	Doughnut fryer-bakery	Hydro lard	A	10	8.75	0.8
11	Doughnut fryer-bakery	Hydro lard	A	10	8.75	1.0
12	Doughnut fryer-bakery	Hydro lard	G	6	8.75	2.3
13	Doughnut fryer-bakery	Hydro A&V	A	..	8.80	2.6
14	Restaurant fryer	....	..	9	8.80	3.4
15	Doughnut fryer-bakery	....	..	..	8.85	2.2
16	Doughnut fryer-bakery	Hydro A&V	C	6	9.00	3.4
17	Restaurant fryer	Hydro A&V	I	..	9.00	3.4
18	Experimental	Hydro A&V	E	..	9.10	1.3
19	Doughnut fryer-bakery	Hydro veg.	C	7	9.20	1.9
20	Fish fryer	....	..	..	9.20	3.8
21	Fish fryer	Hydro veg.	F	..	9.25	4.1
22	Doughnut fryer-bakery	Hydro lard	A	5	9.30	3.5
23	Doughnut fryer-bakery	Hydro lard	A	..	9.45	4.3
24	Doughnut fryer-bakery	Hydro A&V	J	..	9.70	2.9
25	Doughnut fryer-bakery	Hydro lard	A	5	9.75	4.0
26	Doughnut fryer-bakery	Hydro A&V	C	..	10.0	5.2
27	Restaurant fryer	Hydro veg.	C	2	10.1	5.9
28	Laboratory fryer	Hydro lard	A	4	10.4	4.6
29	Experimental	Hydro lard	D	0	10.4	4.9
30	Doughnut fryer-bakery	Hydro veg.	F	2	10.5	4.9
31	Doughnut fryer-bakery	Hydro A&V	B	..	10.7	6.5
32	Experimental	Hydro lard	A	0	11.0	5.4
33	Restaurant fryer	Hydro veg.	C	1	11.1	7.2
34	Experimental	Hydro lard	A	0	11.6	5.5
35	Experimental	Hydro lard	A	0	11.9	7.9
36	Experimental	Hydro lard	A	0	12.0	7.4
37	Experimental	Hydro veg.	A	0	12.1	8.9
38	Experimental	Hydro veg.	D	0	12.3	11.2
39	Restaurant fryer	Hydro veg.	C	..	12.6	6.9

$r = +0.86$

$\%\ \text{NAF} = 1.64 \times \text{viscosity (cs at 212F)} - 12.06 \pm 2.75$ at $P = 0.05$

[a] Each letter donates a different manufacturer.

moved and discarded, the cut end of the pipet is then fire polished until an orifice of approximately $\frac{1}{6}$ in. remains, this orifice may be reduced further if the flow rate of the fat at 212F is greater than 25 ml in 20 sec. A mark is scored into the glass tube midway between the new orifice and the bottom of the bulb of the pipet. This mark and the original 25 ml graduation mark above the bulb serve as the timing points. The pipet is jacketed as shown in Figure 1. The jacket is filled with water and steam from the steam generator is supplied at a rate sufficient to maintain a temperature of 212F at a point immediately adjacent to the bulb of the pipet. The sample is liquefied, filtered through coarse paper, and heated to 210–212F on a hot plate. The orifice of the pipet is covered with the rubber bulb of a dropper and the sample is filled into the viscometer to an inch above the top mark. After 10 min the dropper bulb is removed and the time of flow between the 2 marks on the viscometer pipet is determined to the nearest 0.1 sec. The viscometer is rinsed with the sample prior to the actual test of that sample and rinsed 3 times with CCl_4 if the viscometer is not to be used again for more than an hour. The time of flow is related to kinematic viscosity in centistokes by calibrating the pipet with three viscosity standards from the NBS. Viscometer calibrating liquids L, M, and N, permit the construction of a graph covering the entire range of viscosities encountered in the foregoing work without extrapolation.

The data for the 39 samples are presented in Table I.

Discussion

The correlation coefficient for this data was found to be 0.86 which indicates that the correlation of viscosity with % NAF is significant at the 99.9% level and the residual variance about the regression line for the data is ±2.75 at the 0.05 level.

It was believed that this relationship could be improved by taking into account the changes introduced by differences due to type of frying operation, source of the fat and the processing history of the fat since the amount of nonadducting acids present in the fat before use has been shown to be dependent at least on the last two variables (15).

By treating the data for bakery fats and for fats from a single source separately, the importance of these variables are demonstrated. The correlation coefficients are found to be 0.90 and 0.97 respectively, both significant at the 99.9% level and the two sigma limits about the best fit line for each improved to ±1.58 and ±1.40, respectively. These relationships are shown in Tables II and III.

It is our opinion that though this relationship is not micrometer sharp, it is adequate for in-plant control. Certainly, it can be used to signal departure from the normal operating range as long as the same type of fat is used consistently. It is not possible at this time to suggest a maximum value for viscosity beyond which the fat should be discarded in the interest of nutritional safety since there is not sufficient data to identify this point in terms of NAF concentration. However, it appears highly likely that the recommended maximum viscosity for product quality and manufacturing economics is well below what can be expected to be the maximum for health reasons. Although definite physiological effect was observed with fats containing 11% NAF in at least one reported work (8), most of the literature on the subject indicates that only fats containing in excess of 20% NAF may warrant concern (9–11). Our data indicates that a minimum increase of 4 centistokes or a value of about 12.5 centistokes would be required

TABLE II

Data for Bakeries

Sample No.	Viscosity at 212F (cs)	NAF (%)
2	8.10	0.6
3	8.15	0.4
6	8.45	0.5
7	8.50	1.7
9	8.70	1.1
10	8.75	0.8
11	8.75	1.0
12	8.75	2.3
13	8.80	2.6
15	8.85	2.2
16	9.00	3.4
19	9.20	1.9
22	9.30	3.5
23	9.45	4.3
24	9.70	2.9
25	9.75	4.0
26	10.0	5.2
30	10.5	4.9
31	10.7	6.5

r = +0.90

% NAF = 2.20 × viscosity (cs @ 212F) − 17.47 ± 1.58 at P = 0.05

TABLE III

Data for Hydrogenated Lards from the Same Manufacturer

Sample No.	Viscosity at 212F (cs)	NAF (%)
4	8.35	0.2
10	8.75	0.8
11	8.75	1.0
22	9.30	3.5
23	9.45	4.3
25	9.75	4.0
28	10.4	4.6
32	11.0	5.4
34	11.6	5.5
35	11.9	7.9
36	12.0	7.4

r = +0.97

% NAF = 1.93 × viscosity (cs at 212F) − 15.43 ± 1.40 at P = 0.05

before 11% of nonadducting acids would be formed. This value is derived from the regression equation for the data given in Table I using the maximum variance in favor of the lowest possible viscosity value. Such an increase in viscosity, however, would be accompanied by radical changes in the functional properties of the fat and it is unlikely that this level would be reached in commercial practice. For example, it was found that increases of approximately 1 centistoke increases the fat absorption of fried cakes by 10 to 15% (5,6) which is of appreciable economic significance in this industry. Changes in viscosity greater than 2.5 centistokes not only increases the fat absorption and the product cost proportionately, but introduces serious quality defects (5,7). This latter effect is probably the result of changes in the heat transfer properties of the fat. Fat, 3.0 centistokes higher than its viscosity when fresh, transfers at least 20% less energy to the product than fresh fat in the same time interval (7). In the case of fried cake this results in a misshapen fat spotted product that would be difficult to sell. In the case of potato chips the product does not develop the acceptable color or crispness. Although in the case of potatoes, frying longer or putting through less product can partially overcome this effect, the product economics would be seriously effected by these changes.

It appears, then, that viscosity, a property that is relatively simple to measure accurately can serve the frying industry as a control tool to monitor both the performance and the nutritional quality of the frying shortening.

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