Quality Control in the Use of Deep Frying Oils

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ABSTRACT

The chemical and physical changes that occur in frying fats during use and their significance to fat life and to finished product quality are reviewed. The more commonly used quality control tests for monitoring these changes are examined as is their applicability to food service institutions and food processors. The advantages and disadvantages of these tests and possible modifications to improve their ease for on-the-spot testing are discussed. Chemical tests such as free fatty acids (FFA), thiobarbituric acid (TBA) tests and peroxide value (PV) are available to those operations with laboratory facilities, whereas sensory and physical tests, including foam height, color, smoking, viscosity, odor and product flavor, are generally relied on by most food service facilities for on-the-spot assessment. The reliability of these tests, however, depends on the source and type of frying fat, the food being fried, and, in the case of the sensory and physical tests, on the skill and experience of the operator. Studies completed recently in this laboratory found a high correlation between polar compounds or FFA and length of frying time which suggests that either could predict oil abuse accurately. Recent adaptations which could facilitate on-the-spot testing by semi-skilled personnel (including a spot test for FFA and an instrument capable of monitoring the change in dielectric properties of an oil during frying) will be examined. Regardless of the quality control test used, the question remains of specifying reliable cutoff levels which can be related to the health and sensory constraints. This problem is also discussed.

INTRODUCTION

Deep-fried foods are one of the major items of the North American diet. Recent figures for the USA indicate that a major portion of the edible fats and oils consumed yearly are used in deep-fried foods. Over 200 million lb of fats and oils are used yearly for doughnut production and over 500 million lb for potato chip production (1). Canadian statistics show similar trends with a 54% increase in per capita consumption of fats and oils from 28 lbs/capita in 1950 to 43 lbs/capita in 1975 (2). These increases were due primarily to significant increases in the use of salad oils, shortenings and shortening oils and have been attributed not only to an increase in the use of fats and oils for cooking in the home, but also to the increase in fast food consumption. The latter is indicated by increases in total franchised food service outlet sales of 87% from 1971 to 1973 alone. In addition, total restaurant receipts increased by 64% from 1966 to 1974. Tonnages of snack foods, excluding potato chips, showed an increase of 26% from 1973 to 1974 and potato chip tonnage increased by 38.1% from 1972 to 1974 (2).

The popularity of deep-fried products is due in part to the basic structure imposed on them by the way in which they are cooked. In deep frying, the food is totally immersed in the hot fat with the fat acting as the medium of heat transfer. Cooking in this way is more efficient than the dry heat of an oven (3) and more rapid than boiling in water since the higher temperatures possible with deep frying result in more rapid penetration of heat into the product being cooked.

The result of deep frying is a food with a distinctive structure. The outer zone consists of the surface area which contributes to the initial visual impact. This surface is generally an even, golden brown color resulting from a browning or Maillard reaction which occurs when the sugars and proteins present in the product react in the presence of heat (5). The degree of browning depends largely on the time and temperature of frying in combination with the chemical composition of the food being fried rather than on the fat or type of fat used in the fryer.

The second part of the outer zone is the crust or crisp exterior skin formed on the food by dehydration during frying. The heat of the frying fat reduces the moisture content of this layer to 3% or less and it is the water driven off from this portion which is responsible for most of the steam released during frying. The void created by this loss of moisture is filled largely by absorption of the frying fat. This absorbed fat exerts a tenderizing effect on the crust as well as a 'wetting' effect on the fried food and thus contributes the second and third reasons for the popularity of deep fried foods, namely, their flavor, crispness and pleasant eating characteristics. The amount of frying medium absorbed by the food varies with the product being cooked and has been shown to vary basically with the ratio of crust to core (4). Thus, food products such as potato chips which have a larger surface area and very little core absorb ca. 30-40% fat whereas french-fried potatoes which have a smaller surface and crust area in relation to core area absorb 7-10% of the frying fat.

The inner zone or core is a cooked, moist interior composed solely of whatever food is being fried. The cooking of this zone is due to heat penetration and flavor or texture changes effected here are due to the effect of heat on the foodstuff rather than to fat absorption. The major exception to this occurs in foods whose physical shape results in the inner zone being fried out of the food leaving essentially one continuous crust. These foods include such products as potato and corn chips and fried noodles.

CHANGES IN FATS DURING FRYING

The necessity of using a good quality frying medium and of maintaining it in that state as long as possible becomes obvious when one considers that some of the fat is absorbed by every piece of food fried in it. Before considering a number of options available for maintaining and protecting fat quality, it is necessary to examine some of the major changes which occur in frying fats during their use. Figure 1 shows the changes which occur during deep fat frying. During deep frying, the fat is exposed continuously or repeatedly to elevated temperatures in the presence of air and moisture. A number of chemical reactions, including oxidation and hydrolysis, occur during this time as do changes due to thermal decomposition. As these reactions proceed, the functional, sensory and nutritional quality of the fat changes and may eventually reach a point where it is no longer possible to prepare high quality fried products and the frying fat will have to be discarded. The rate of formation of decomposition products, and indeed the products themselves, vary with the food being fried, the fat being used, the choice of the fryer design and the nature of the operating conditions. It is this sensitivity to variations which makes it very difficult to recommend one particular method as ideal for quality control monitoring in all deep frying operations. In addition, these variations make it difficult for the researcher to determine exactly what is occurring during the deep frying procedure. To complicate matters further, a number of researchers (1,7) have reported that the chemical reactions taking place during deep fat frying differ from those which occur when the fat is heated continuously, thus reactions occurring in studies conducted with oils heated under air, with or without agitation, may not be representative of those of the same oils used under normal frying conditions.

In general, the decomposition products formed during frying can be divided into two broad classes: volatile and nonvolatile decomposition products.

Volatile Decomposition Products

Most of the volatile decomposition products (VDP) are removed from the frying medium by the steam generated during frying (3,5). However, they are of interest from a number of points of view. First, the mechanism of formation of these products may help to elucidate those which lead to the formation of the nonvolatiles since both types are produced simultaneously (1). Another more practical reason for concern with VDPs is the fact that not only have some of these products been shown to be retained in the fried food (1) but they are also inhaled by the deep frying operator and could thus have an effect on the health of these individuals. A third reason is that the VDPs have been reported to contribute to the flavor of deep-fried foods, hence knowledge of their chemical composition could facilitate the manufacture of a synthetic flavor for enhancing that of deep-fried foods or for manufacturing foods with a deep-fried flavor which do not have to be fried (1).

Although the VDPs are of interest to many researchers as indicated by the number of articles in the literature devoted to their study, they will not be considered further in this paper since they are not compounds which can be monitored easily under the normal constraints of quality control in a deep frying operation.

Nonvolatile Decomposition Products

Nonvolatile decomposition products (NVDP) make up the second class of products formed during deep frying. Their formation is due largely to thermal oxidation and polymerization of the unsaturated fatty acids present in the frying medium and is of concern since these products not only remain in the frying fat to promote further degradation but are also absorbed by the fried food and hence eaten by the consumer. Paradis and Nawar (8) report that the higher molecular weight compounds are more reliable indicators of fat abuse as their accumulation is steady and they have low volatility. The formation and accumulation of NVDPs are responsible for physical changes in the frying fat such as increases in viscosity, color and foaming as well as chemical changes such as increases in free fatty acids (FFA), carbonyl value, hydroxyl content and saponification value and decreases in unsaturation, with resulting increases in the formation of high molecular weight products (9).

As seen in Figure 1, a number of different types of reactions is responsible for these changes in frying fat quality. The color of the frying medium and the nature of the composition of the fat may be altered by the solubilization of colored compounds and lipid materials present in the food being fried.

Oxidation, which is accelerated at the higher temperatures used in deep frying, also occurs. Free fatty acids are formed during oxidation as a result of cleavage and oxidation of double bonds (9). Oxidation also results in the formation of hydroperoxides which may then undergo further degradation of three major types: fission to form alcohols, aldehydes, acids and hydrocarbons thereby also contributing to the darkening of the frying fat and flavor changes; dehydration to form ketones; or free radical formation of dimers, trimers, epoxides, alcohols and hydrocarbons, all of which contribute to the increases in viscosity and the nonurea aduct-forming (NUAF) fraction (10).

The rate of oxidation is reported to be roughly proportional to the degree of unsaturation of the fatty acids present, thus linolenic acid with three double bonds is much more susceptible than oleic with only one double bond. This explains in part why oils such as soybean and canola, which tend to be high in linolenic acid, are not considered to be as satisfactory for deep frying as oils such as corn which are low in linolenic. Partial hydrogenation of high linolenic oils to reduce the linolenic acid content results in a soybean or canola oil which then does not exhibit this problem (7).

The presence of moisture in the foods being fried also causes some hydrolysis which results in the formation of free fatty acids, mono and di-glycerides and glycerine. As can be seen from Figure 1, the presence of this moisture has a positive effect as well in that it creates a steam blanket effect over the fryer, thereby reducing contact with air as well as helping to volatilize and remove peroxides, flavors and odors which would otherwise accumulate in the frying fat (7).

The final type of change in frying fat quality takes place due to the presence of heat which accelerates the formation of dimers and cyclic compounds through polymerization. Although the mechanisms are very complex and not completely understood, the compounds which result from this process are large molecules formed by carbon-to-carbon and/or carbon-to-oxygen-to-carbon bridges among several fatty acids (7). Marked increases in these compounds contribute to increases in fat viscosity, foaming, 'gum' accumulation and color darkening (11).

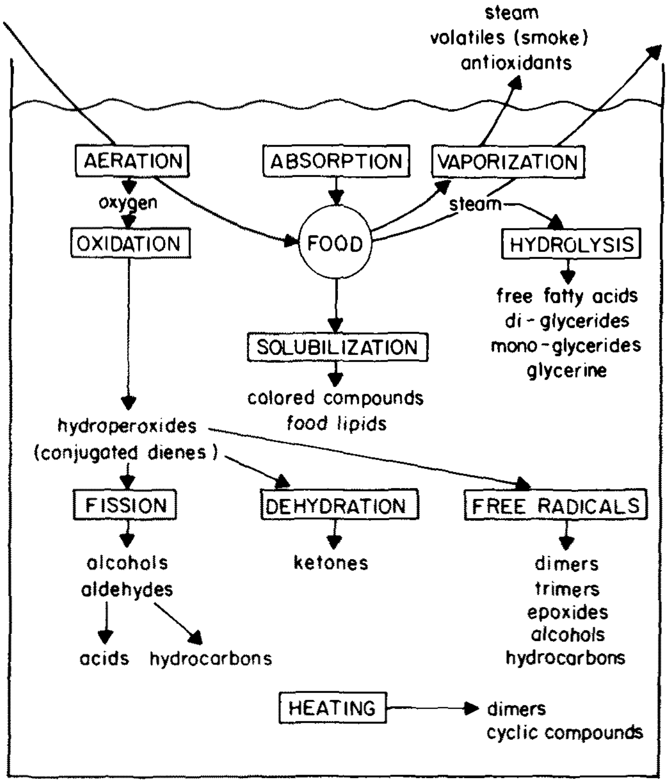

FIG. 1. Changes occurring during deep fat frying (6).

Controls

The changes occurring in fat during frying, therefore, affect both the quality of the frying fat and the quality of the finished product. Chemical and physical changes result in darkening of the fat, smoking, foaming and increases in viscosity. In addition, these changes impart poor flavor and odor to the food fried in the deteriorated fat as well as resulting in a dark, greasy product.

There are a number of changes a fryer operator can make to reduce or control fat breakdown. These may be considered under the broad headings of food, fryer and fat.

Food

The kind of food being fried affects fat quality. Frying foods which contain high levels of egg solids can contribute to early foaming due to leaching of lecithin into the frying fat (3). The frying fat may also become contaminated with fats from foods such as meat or chicken which diffuse into the fat during the frying process (3,7). This contamination can also come from the fats in foods such as frozen french fried potatoes which have been partially fried during processing (12). Foods which are breaded or battered may contribute particles of the surface coating to the fat, resulting in burning and off-flavors. Strongly flavored foods such as fish and onions can also contribute to off-flavors in the frying medium. Moisture from the food, although it has been shown to make a positive contribution, as mentioned earlier, can also increase the rate of fat breakdown if it is present in large quantities.

To reduce fat breakdown caused by the food during frying, the operator should ensure that the pieces being cooked are of uniform size and as free as possible from excess surface water, crumbs or breading material. In addition, make sure that any breading or coating material used is properly applied to reduce loss during frying (5).

Fryer

The second area in which the fryer operator can attempt to control the rate and degree of deterioration of his frying medium is in the selection and maintenance of the fryer. Factors to be considered in this case include capacity, kettle design, material of fabrication and ease of cleaning.

The capacity of the fryer should be such that it allows for maximum production with a minimum amount of frying fat. Use of fryers with a fat capacity greater than that required for the throughput of the food being fried wastes fat. In the case of operations which have seasonal fluctuations in production requirements or for those anticipating future growth, it would be advisable to purchase two smaller capacity fryers or to operate one smaller fryer for a longer period each day, rather than to use a single fryer of larger capacity in which the fat would be idling for extended periods (11). Fats held at frying temperatures without being used for frying break down rapidly and then must be discarded. If fryers must be placed on standby, a temperature range of 95-120 C (200-200 F) is recommended to reduce deterioration (3).

Overloading or exceeding the fryer capacity is another common problem which can be avoided by the fryer operator. The fryer capacity is limited by the heat balance of the fryer, i.e., the relationship between the heat input and heat requirement. Heat balance is inherent in the fryer design and overloading results in a greater requirement for heat than can be met. The general tendency is to set the thermostat higher to compensate for overloading. This results in more rapid breakdown of the frying fat and a product which is overcooked on the surface but undercooked inside. If the temperature is reduced and the food cooked at a slower than normal rate, the product will be greasy due to excess fat absorption and soggy due to inadequate loss of moisture (3). From the point of view of fat stability, the lowest temperature possible, which will give a product of optimum quality, is desirable.

The design of the fryer will effect rate and degree of fat deterioration (13). The effect of air on the hot fat has been shown to be one of the greatest contributors to fat breakdown. Although some contact with air is unavoidable, it can be minimized by using fryers designed with small surface-to-volume ratios and by avoiding aeration of the fat. The latter may be accomplished by avoiding leaky pumps which can suck air into the fat stream at any point in a bulk handling system, by using subsurface entry of fat into continuous fryers or avoiding splashing and rapid pouring of liquid fats into batch-type fryers and by eliminating excessive mechanical agitation during the frying process (11).

The way in which the fryer is designed to distribute the heat to the frying fat should also be considered as it too will affect the quality of the fat in the fryer. The larger the area of the heating surface, the faster and more even will be the heating of the fat. Avoidance of hot spots which could scorch the fat is also very important to maintain fat quality (4).

Cleanliness of the fryer is another factor to be considered in controlling fat breakdown. Although the ease with which this can be accomplished is a factor of equipment design, the actual physical cleaning is the domain of the operator and hence provides another way in which he may help maintain fat quality. Polymerized fat deposited on the fryer tends to catalyze the formation of more 'gum' and contributes to foaming, color darkening and further deterioration of the frying fat. Regular cleaning of the frying equipment, with special attention being paid to proper rinsing, will contribute to longer fat life. It is especially important to ensure that all traces of soaps or detergents are removed during rinsing since even minute amounts of these substances can catalyze fat breakdown when frying is resumed (3,11,14).

The material from which the fryer is made has been shown to affect fat life. The recommended metal for fryer construction is stainless steel. In a study reported by Robertson (4), nickel and aluminum were also found to contribute little to fat damage, however, the price of nickel and the reactivity of aluminum with the detergents necessary for fryer cleaning make these metals impractical choices. Copper exerts a marked catalytic effect in oxidative fat breakdown and thus should be avoided in utensils, petcocks, filter screens, piping or heating ducts or for brazing of broken equipment. Bronze and brass, both alloys of copper should also not be used in contact with the frying fat (3,11,14).

Probably the most important factor in maintaining fat quality is the 'turnover rate. which is described as the ratio of the total amount of fat in the fryer to the rate at which fresh fat is added to the kettle (4). A recommended daily turnover is 15-25% of the fryer capacity (3). The higher the rate of turnover, the better the condition of the frying fat will be. Proper turnover rate will keep the level of FFA low and will replace silicones lost due to adherence to the fried product. A sufficiently high turnover rate would make the use of antifoaming agents such as silicones unnecessary since it would also ensure that the levels of polymers accumulating remain below that which causes foaming (3). In large-scale commercial operations where frying is continuous, this turnover period can be as low as 12 hr and fat degradation is minimal. In restaurant or food service institutions, however, the turnover period becomes much longer due to fluctuations in demand for fried foods. In this case, some of the fat in the fryer will have to be discarded to allow sufficient fresh fat to be added in order to maintain fat quality (3,4).

Fat

A wide variety of fats is suitable for use in deep fat frying, depending on the product being fried. Among considerations for fat selection are cost, rate of fat turnover and temperature at which the fried product is to be consumed, as well as whether the cooked product is to be stored rather than eaten on-the-spot.

Frying fats available run the gamut from unhydrogenated vegetable and salad oils through various levels of hydrogenation to the 'heavy duty' fats which are hydrogenated to a degree which makes them fairly resistant to oxidative changes during the frying operation. In addition, they may be of animal or vegetable origin or blends of both.

Unhydrogenated vegetable oils are high in polyunsaturated and unsaturated fatty acids and are therefore susceptible to oxidative changes during frying. They also have a tendency to become rancid rapidly at room temperature which makes them unsuitable for slow turnover operations and for products that require extended shelf life. Partial hydrogenation of these oils results in a pourable product with improved resistance to rancidity and oxidative changes which produces fried foods suitable for operations with slower turnover rates and where the shelf life of the product must be considered. Products fried in vegetable oils exhibit an oily surface and have good mouthfeel (11).

Hydrogenation of oils, sufficient to render them solid at room tempterature, results in frying fats which are resistant to oxidative changes during frying and which produce foods with good shelf life. They are well suited to low turnover operations. Products fried in oils of this type have a less oily surface than those fried in unhydrogenated oil. Mouthfeel will depend on the degree of hydrogenation of the frying oil. Lower melting point oils generally impart better mouthfeel since they melt faster at body temperature (5). In the case of hydrogenated oils, the melting point varies directly with the degree of hydrogenation. For this reason, operations such as snack food industries, whose products are consumed at room temperature rather than hot, tend to prefer fats with a slightly lower degree of hydrogenation.

Animal based fats, such as lard, contain fewer unsaturated fatty acids than vegetable oils and thus have less tendency to form gums during the frying operation. These products have good resistance to oxidative changes and impart fair to good shelf life stability depending on their degree of hydrogenation. In many areas, they are preferred over vegetable oils for the flavor they impart to the fried product. Tallow, on the other hand, has a higher melting point than lard and a less desirable mouthfeel (11).

Blended fats and oils of animal and vegetable origin are often used as economical substitutes for all-vegetable or all-animal based products. Their properties vary depending on the proportions of the various fats used, however, they tend to be resistant to oxidation, suited to high or low turnover rates and provide good shelf life stability (11).

Regardless of end use, one of the factors which contributes significantly to used frying fat quality is the quality of the fat at point of purchase. Quality specifications should be appropriate for the type of fat being used and will vary with the product to be fried. In general, though, the parameters shown in Table I are the most common ones included in quality specifications.

The FFA content is probably the most important specification in that it indicates whether the fat has been properly refined whereas the peroxide value is useful as an indication of product freshness. Specifying a smoke point of 200 C or greater ensures that the fat will not smoke excessively when first used, and specifying a moisture content of less than 0.10% helps to reduce the likelihood of splattering. Fats and oils which are light in color, bland in flavor and odor and of low melting point will enhance the eating quality of the foods fried in them (3,11).

The final sphere in which the fryer operator can exert some control on the rate and degree of fat breakdown is in proper maintenance of the frying medium. This involves filtering the fat daily or on a continuous basis depending on fryer design. There are numerous types of filters and filter aids available to the operator which will not only remove burnt particles of food and breading from the fat but will also reduce the FFA content and the color of the frying medium. Care must be taken in selecting these products, as some of them have been reported to reduce the potential stability of the frying fat (14). Caution must also be used to avoid excessive aeration of the frying fat during the course of the filtering procedure.

TABLE I

Common Analytical Specifications for Deep Frying Fats and Oils[a]

Parameter	Level in unused fat/oil
Free fatty acid (FFA)	0.05-0.08%
Peroxide value	1.0 me/kg
Iodine value	Varies with type of fat
Active oxygen method (AOM)	60 hr or greater if extended shelf life required
Smoke point	200 C
Moisture	0.10%
Color	Light
Melting point	Varies with product being fried
Flavor and odor	Bland

[a]Refs. 3,11.

QUALITY CONTROL TESTS

As can be seen from the discussion thus far, the changes occurring in fat during deep frying are complex and variable, producing numerous types of decomposition products and altering the functional, sensory and nutritional quality of the frying fats. There are a number of controls at the fryer operator's disposal to keep the rate of fat decomposition to a minimum, and a number of good frying practices which can reduce the buildup of breakdown products, thereby extending the life of the frying fat, however, the major problem which still confronts the operator is knowing when to discard the fat in his frying kettle.

Various criteria may be used to assess this point (Table II). In a restaurant or food service institution, the decision to discard the frying fat is generally based on physical changes measured subjectively. Color, foam height,

TABLE II

Quality Control Tests Available to Deep Frying Operation without Laboratory Facilities (e.g., Restaurants, Food Service Institutions)

Test	References
Color	7,11,15
Foaming	1,7
Smoking	7,11
Odor of frying fat	7,11
Length of fat use	15
Sensory evaluation of cooked product for flavor, odor and texture	11,15

smoking and odor of the frying medium as well as flavor, odor and greasiness of the cooked product are the criteria generally used in these cases (7,16). In a survey done by the Department of Foods and Nutrition at the University of Manitoba of 18 food service operations, color was used by the majority (15/18) as the major indicator for fat dumping (15). Only four of the 15 operations, however, used color standards for this test, the rest relied on the experience of the operator. Other criteria mentioned in this survey were length of fat use, smoking and foaming. Only one of the facilities surveyed used taste panels as a routine tool for monitoring product acceptability.

The reliability of these types of tests as a mechanism for quality control depends heavily on the skill and experience of the fryer operator. In addition, the source and type of frying fat and the food being fried have a direct bearing on the suitability of these tests as criteria for discarding fat. For example, Chang et al. (1) report that in the cases of foaming, decomposition products sufficient to cause adverse effects to safety, flavor, color and texture of the fried product may be present before the operator considers the degree of foaming sufficient to indicate that the fat should be discarded. This could become even more of a problem in the case of fats which have dimethylpolysiloxane added to suppress foaming.

A number of standard methods exist for measuring some of these criteria used by food service operations. The AOCS Official and Tentative Methods Manual lists three methods for color (17-19) and one for smoke point (20). A number of methods are listed in the literature for determination of viscosity (14,21) as are descriptions of apparati for measuring foam height (22,23). In most cases, however, these methods require more time, trained personnel and/or equipment than would normally be available for on-the-spot use in a food service operation.

Operations such as those of food processors, who have access to laboratory facilities, have a broader range of chemical, as well as physical, tests at their command for quality control monitoring (Table III). These include the physical tests available to the food service institutions but which, in the case of an operation with laboratory facilities, may be conducted in a more objective manner since the measurements may be made instrumentally rather than being based simply on the experience of the operator. In addition, there are large numbers of chemical tests requiring varying degrees of technical expertise and equipment.

The most commonly used of the physical tests (Table III) are color determinations and smoke points. The latter, though a standard procedure, still relies heavily on the ability of the technician to determine the point at which the fat actually begins to smoke. In addition, values for smoke point vary directly with the temperature of the testing room. In a collaborative test among 17 laboratories using three different fats, Arens et al. (24) reported ranges of up to 26 C in smoke point temperatures for a single fat. Recently, a more objective method using a closed system fitted with photocells and a recorder was described by Seher and Bregulla (25). Use of this method is reported to reduce the deviation in results from 20 C to less than 4 C. It is also faster than the traditional Cleveland cup method since the determinations are done automatically.

Table III also shows a myriad of chemical tests which may be used by operations with access to laboratory facilities to monitor the quality of their frying fats during use. The suitability of these tests as routine quality control measures varies with the time available for testing, level of expertise of the technical personnel and the type of frying operation. Tests such as determining total polars and petroleum ether insoluble oxidized fatty acids are complex, require highly skilled personnel and are very time consuming. Although these tests provide the most reliable measures of the extent of fat deterioration, they are more suited to use in regulatory agencies where precision is important and a high throughput of samples is not critical (6). Other methods which tend to be time consuming and hence are of more use to researchers interested in following changes taking place during frying rather than to food processing operations include tests for dienes, carbonyls, AOM and NUAF.

TABLE III

Quality Control Tests Available to Deep Frying Operations

Physical tests	References
Without laboratory facilities[a]:	
Color	7,11,15
Foaming	1,7
Smoking	7,11
Odor of frying fat	7,11
Length of fat use	15
Sensory evaluation of cooked product for flavor, odor and and texture	11,15
With laboratory facilities[b]:	
Smoke point	3,20,23,25
Foam height	16,22,23
Viscosity	13,14,21,23
Color	3,14,17-19
Refractive index	21,27
Sensory evaluation of cooked product for flavor, odor and texture	2,14
Chemical tests	**References**
With laboratory facilities[b]:	
FFA	3,23,31
TBA	14.29
Peroxide value	2,30
Iodine number	14.21
AOM	3,14
Dienes	16,28
Carbonyls	6,28
Anisidine value	6,26
NUAF	14,21,27
Petroleum ether insolubles	6,30
Total polars	8,16,23,30

[a] Restaurants, food service institutions.
[b] Food processors.

The most commonly used chemical tests in a food processing operation include FFA, TBA and determination of peroxide values (11,14,16). Unfortunately, none of these tests is completely satisfactory for monitoring changes in fat quality. Since degradation products accumulated in the fat change over time, and since different food-fat combinations form different compounds at different rates, a test suitable for monitoring fat changes in one operation will not necessarily be useful for another operation (6). Furthermore, its usefulness will change within an operation if more than one kind of food is fried in the same fat.

Determination of FFA appears to be the method favored by many operations for quality control evaluation of the frying fats (11). There are, however, a number of factors which should be considered when using this method. The level of FFA found in the frying fat not only reflects those formed during the frying process but also the level of FFA initially present in the fat before heating (6,11). In addition, FFA are formed during frying both by oxidation and by hydrolysis. The rates of these processes vary according to a number of variables including the type of shortening being used and initial FFA level. The rates may also vary over time within the same operation. Although the products of hydrolysis have been shown to have little effect on the nutritional quality of the fried food and although changes of this type are generally small in a deep frying operation, the methods used for FFA determination do not permit differentiation between FFA formed by hydrolysis and those formed by oxidation (6,16). This being the case, use of FFA alone to indicate when frying fat should be dumped, can often result in 'acceptable' fat being discarded and in some cases, spent fat being retained for frying.

Although the TBA test has been reported to be one of the more commonly used methods for determining the extent of lipid oxidation, it too is subject to certain reservations. This test may be applied directly to the food product followed by extraction of the colored pigment, or to a portion of a steam distillate from the food. Gray (28) reports that meaningful results from the TBA test can be obtained only by comparison with those of samples of a single material at different stages of oxidation. Work in the Department of Foods and Nutrition at the University of Manitoba also showed poor correlation of TBA results with length of deep frying time (29). In addition, attempts to correlate TBA values with flavor scores have had variable success.

According to Fritsch et al. (16), peroxide values are not generally used to measure frying fat deterioration. This is because peroxides are very unstable at frying temperatures. They are useful as indicators of oxidation at the initial stages but, if observed over the entire frying time, will be seen to peak and then decrease (28). Another problem with using peroxide values is that they may increase after a sample is taken from the fryer (6). Despite these drawbacks, good correlations have been reported between peroxide values and sensory scores for a number of commercial fats (28).

Because the more complicated, time-consuming tests tend to monitor quality changes more accurately, a number of researchers have attempted to study the correlation of these test results with those of the simpler physical and chemical tests. Viscosity results have been reported to correlate well with NUAF results (14) and foam index with polymer levels (23). Studies conducted in the Department of Foods and Nutrition at the University of Manitoba have shown good correlation between both FFA and polar determinations with length of frying time for both solid and liquid canola and soybean-based fats in which frozen french fries were cooked (29). These two tests also showed good correlation with each other. Determination of total polar compounds also correlates well with the accumulation of petroleum ether insoluble oxidized fatty acids with 1% of the latter corresponding to ca. 27% total polars (6,30). Although the method for polar determination is still time consuming, it is, nonetheless, faster than that for petroleum ether insolubles and considerable work is being done to streamline the polar method further (8,30).

Studies examining the relationships between various tests have led also to the development of a number of method modifications resulting in the production of tests or instruments which can be used to monitor quality changes on-the-spot. Robern and Gray (31) report the development of a colorimetric spot test for heated oils. This test, based on the determination of FFA content by monitoring pH changes in the frying fat, is rapid and can be used without any specialized knowledge. The test consists of coating a clean glass slide with a suspension of silica gel and bromocresol-green indicator in a methanol/water (1:1) solution adjusted to pH 7.3 with 0.1N sodium hydroxide. The coated slide is dried under controlled conditions and then a drop of the frying medium to be tested is placed on the slide. If the spot remains blue, the FFA level is negligible. Green indicates a moderate level of FFA and yellow, a high concentration. The color development also parallels the development of polar compounds. Although this type of test does not assess the level of FFA with a great deal of accuracy, and although the slides can be affected by exposure to air over several days and hence must be stored in a closed container, this method provides a rapid, on-site assessment of the quality of the frying fat which can be confirmed if necessary by further laboratory testing. For a food service institution, it provides a less subjective assessment than smoking or foaming, is fast, safe to use and requires no special technical training.

Need for rapid test methods which require little technical expertise to operate and interpret and can be done on-the-spot has also resulted in development of portable equipment for monitoring quality changes in frying fats. One such instrument is the Foodoil-Sensor Oil Quality Analyzer (32). It measures the changes in the dielectric constant of the heated oil which result as the number of polar molecules accumulate during fat breakdown. Sample testing consists of zeroing the instrument with a standard or unused oil sample, then measuring the dielectric change between the standard and the used frying fat. The analysis takes 3-5 min to complete. Tests conducted with this instrument by a number of researchers showed that oxidation products were primarily responsible for the change in dielectric constant, and that total polar materials showed the highest correlation with instrument values (8,16,32). Work by Paradis and Nawar (8) indicates that instrument values actually represent the net balance between polar and nonpolar materials present in the frying fat. They reported that, in general, positive changes in the readings were produced by moisture, oxygenated dimeric material, polar volatiles and diglycerides, whereas negative changes resulted from FFA, hydrodimer acids and nonpolar volatile compounds. Although simple and rapid to operate, this instrument also has its limitations. Fresh fats differ in dielectric constants, hence the instrument must be standardized separately for each fat being tested. In addition, artifacts present in the frying fat such as water or fat extracted from the fried food can cause spurious instrumental readings (8). For this reason, samples should not be taken from the fryer while the food is being fried (16). The instrument also requires up to 4 hr warm up before readings can be taken and the operator must be careful not to overheat the fresh shortening samples when melting them before instrumental calibration (16). This instrument appears to be best suited to monitoring operations where frying time is the only variable. For proper assessment of fat quality, the exact history of the frying fat should be known (8).

Cut-Off Levels

The concern with the effects of frying fat breakdown products on the health of the consumer reaches back over the past 30 years. Although numerous conflicting reports exist as to the metabolic effects of these products, the general consensus is that the oxidative products formed in frying fats and oils heated over extended periods of time may be harmful to the consumer (1,31,33).

In the Federal Republic of Germany, recommendations exist for frying fat assessment. A used fat is considered to have deteriorated if: (a) its odor and flavor are definitely not acceptable, (b) the concentration of petroleum ether insoluble oxidized fatty acids is 0.7% or higher and the smoke point is lower than 170 C or (c) the concentration of petroleum ether insoluble oxidized fatty acids is 1% or higher (30). A level of 0.7% petroleum ether insoluble oxidized fatty acids has been shown by Billek et al. (30) to be equivalent to ca. 25% polar components.

In the Netherlands, frying fats can be rejected for consumption on the basis of sensory evaluation as well as when levels of polymeric and dimeric triglycerides exceed 10% or dimeric triglycerides exceed 6% (31).

Other than these specifications, few guidelines appear to exist for reliable cut-off levels for chemical tests to determine at what point a frying fat should be considered spent.

Although it is obvious from the findings reported in this paper that many different factors affect the rate and degree of fat breakdown, much work remains to be done, both in the areas of developing rapid, simple, safe methods which can be used to assess frying fats on-the-spot, and in developing reliable cut-off levels for these tests which can be related to health and safety constraints. There are a number of check sample services available through the AOCS, but these exist only to enable test laboratories to check the accuracy of their methods. There is a need for collaboration amongst researchers along similar lines to establish concrete cut-off levels for each of the chemical tests used routinely by processors for fat assessment. In addition, a concerted effort needs to be made by researchers to develop new tests or modify existing ones to the conditions which exist in food service institutions, namely lack of sophisticated testing equipment, untrained technical personnel and a need for fast results. In this way, the food services, too, may benefit from the developments at the laboratory level. Spot tests for FFA, equipment for measuring changes in dielectric constant and other similar innovations represent a positive step in this direction, however, the search cannot be abandoned at this point. The results of these methods are very susceptible to artifacts present in the fats which vary from operation to operation. It is only through cooperation between researchers and industry that these problems will be solved and that the test results will then be meaningful to the food operation relying on their accuracy to indicate when to discard their fat.

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