Grasas y Aceites
Vol. 49. Fasc. 3-4 (1998), 282-295

Industrial Frying Process

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SUMMARY

Industrial Frying Process

This paper is concerned with the industrial frying process and in particular the role of the frying oil and the influence this has on the food. Attention is drawn to various factors that can adversely affect the quality of the frying oil.

In this paper the term «frying oil» is used. Other publications may refere to frying fat or frying shortening. As these are all used well above their melting points, and are fully liquid, the term oil is preferred by the present author, there being no quality difference between the products so named.

The quality of oil or fat used for frying is of paramount importance with regard to the quality of the fried food. The amount of oil absorbed in different fried foods varies; battered fish or chicken absorb about 15% frying oil, while breaded fish or chicken absorb up to 20% frying oil. The amount of oil absorbed by doughnuts varies from 15-20% of their final weight. This is, of course, in addition to the shortening used in preparation of the dough, giving a final oil/fat content of up to 30%. Standard or traditional potato crisps absorb the highest quantity of oil, and up to 35 or 40% of the final food may be frying oil. Recently, modern technology has been introduced to produce low-fat crisps, but these still have about 20% absorbed oil. It should therefore be remembered that the fat used for frying becomes part of the food we eat.

The most important aspect of industrial frying is therefore the frying oil, and in surveying factors that affect frying oil quality, this paper reviews (a) oil properties and composition; b) transport, packaging and storage of oil; c) the nature of the food fried and its interaction with the frying oil; d) the frying equipment and the process of frying; and e) the evaluation of the quality of the frying oil during use. Each of these factors is important in its own way, and it is of no advantage to concentrate on one or two, or even three, of these aspects without appreciating that there may be additional influences on the quality of the frying oil, and thus the fried food.

KEY-WORDS: Oil evaluation during use – Oil properties – Oil storage – Oil transport.

Frying Oils

This paper relates to industrial frying and the quality of the final fried food. It is maintained that the largest single influence on this is the quality of the frying oil, and the paper therefore surveys the various aspects of industrial frying that can affect oil, and thus food quality. In this paper, the term «frying oil» is preferred to the alternative descriptions frying fat or shortening, as the oils are used well above their melting points.

The quality of oil, fat or shortening used for frying is of paramount importance with regard to the quality of the fried food. Table I illustrates this by listing the amount of oil absorbed in different fried foods, where it can be seen that battered food, such as fish or chicken, absorbs about 15% frying oil, while breaded fish or chicken absorbs up to 20% frying oil. The amount of oil absorbed by doughnuts varies from 15-20% of their final weight. This is, of course, in addition to the shortening used in preparation of the dough, giving a final oil/fat content of up to 30%. Standard or traditional potato crisps absorb the highest quantity of oil, and up to 35 or 40% of the final food may be frying oil. Recently, low-fat crisps have been introduced, but these still contain about 20% fat. It should therefore be remembered that the fat used for frying becomes part of the food we eat.

The most important aspect of industrial frying is therefore the frying oil, and, in surveying factors that affect frying oil quality, this paper reviews (a) oil properties and composition; b) transport, packaging and storage of oil; c) the nature of the food fried and its interaction with the frying oil; d) the frying equipment and the process of frying; and e) the evaluation of the quality of the frying oil during use. Each of these factors is important in its own way, and it is of no advantage to concentrate on one or two, or even three, of these aspects without appreciating that there may be additional influences on the quality of the frying oil and thus the fried food.

Oil Properties and Composition

The compositions of some oils are indicated in Tables II and III. Some of these oils are used in frying applications while others are not. The lauric-acid-rich oils, palm kernel (PKO) and coconut (CNO) for instance, are generally unsatisfactory as industrial frying oils since they contain large proportions of lauric and other fatty acids with fewer than 14 carbon atoms. These acids are quite volatile. If palm kernel or coconut oil is used in a frying application, the moisture in the fried food causes hydrolysis of the glycerides and liberation of the short-chain fatty acids. These volatilise at frying temperatures, causing excessive smoke development. Fatty acids are, of course, liberated in the same way if palm oil or some other non-lauric oil is used for frying, but in this case the liberated fatty acids are of higher molecular weight, reflecting the constituents of the parent oil, and are therefore not so volatile. There is therefore less hazard of smoke formation. Coconut oil, however, is sometimes used as a frying medium where there is a local preference, e.g. in the Philippines, or if the particular flavour attributes of coconut oil are desirable, and a smoke problem can be tolerated; thus it is often used in the Pacific Islands to fry banana slices or nuts, which are then used in western foods such as muesli. These operations do not normally, however, corresponds to industrial frying as carried out in Europe. Lauric oils also are more expensive in Europe than alternative frying media and in general, therefore, PKO and CNO are not normally used in European frying applications.

Palm oil (PO) has no such problem of short-chain acids giving a smoke problem, but it contains a large quantity of saturated acids. The sample illustrated in Table II has 51% saturated acid, which some people may see as a disadvantage from a nutritional point of view.

Palm oil is also a solid fat in temperate climates, and this too can cause problems if the oil-storage facility in a frying plant is located out of doors. Bulk fats held in storage tanks seldom solidify, but solidification may take place in pipes or valves leading from an outside storage facility to the indoor frying installation. In locations where these aspects are not a problem, palm oil is an excellent frying oil. It has a low iodine value and a low level of polyunsaturated fatty acids. This is important, as the polyunsaturated fatty acids are, in general, responsible for oxidation and off-flavour development.

TABLE I
Oil absorption in fried foods

	% Absorption[a]
Frozen chips	5
Fresh chips	10
Battered food (fish/chicken)	15
Low-fat crisps	20
Breaded food (fish/chicken)	15-20
Traditional potato crisps	35-40
Doughnuts[b]	15-20

Notes:

[a] As a percentage of the finished food.

[b] Doughnuts also contain about 10% fat used in preparation of the dough.

TABLE II
Compositions of some oils

	Oils*							
Fatty acid	**PKO**	**CNO**	**PO**	**Olive**	**SBO**	**RSO**	**Tallow**	**Fish**
Sat ≤ C14	71	81	1	trace	–	–	4	7-12
Sat ≥ C16	11	11	50	14	15	7	50	10-25
C18:1	16	6.5	39	76	21	58	40	9-16
C18:2	2	0.5	10	8	54	21	3	5-18
C18:3				1	10	10	1	0-3
Unsat (≥ C20:X)				–		2	1	20-45
I.V.	18	9	52	82	120-140	110-126	45-55	120-200

*PKO=palm kernel oil
SBO=soya-bean oil
IV=iodine value
PO=palm oil
RSO=rapeseed oil
CNO=coconut oil

Olive oil is a premium frying oil. It has a low level of saturated fatty acids, so is not criticised on nutritional grounds; in fact it is said to be nutritionally advantageous and is extolled as part of the Mediterranean diet. Its good frying performance is linked to its relatively low melting point, which means that it is easily stored in cold climates. It also drains from the fried food readily, there being no danger of solidification of the frying oil leading to excess fat on the fried food. It has low concentrations of linoleic

(C18:2) and linolenic (C18:3) acids, giving the oil a low iodine value (IV) of about 80, which renders it resistant to oxidation. Its long shelf-life and high resistance to oxidation are also, in part, related to the advantageous combination of various phenolic antioxidants present in olive oil. Olive oil is available in several grades, extra virgin olive oil being the best and usually the most expensive. This high-grade olive oil is seldom used for industrial frying, although some high-class restaurateurs may justify the expense. For industrial frying, the cheaper refined olive oil grades are usually satisfactory.

Soya-bean oil and rapeseed oil are similar to one another in that they have high iodine values and low levels of saturated fatty acids, and are fully fluid even at low ambient temperatures. The main difficulty with soya-bean and rapeseed oils is the 8-10% or so of linolenic (C18:3) acid present, as this makes these two oils prone to oxidation and off-flavour development. In this respect, it must be remembered that, with industrial frying, it is not only oxidation during the frying process that must be considered but in many cases also oxidation of the oil during subsequent storage of the fried food. Crisps are a particular problem in this respect as they contain a high level of absorbed oil, are often stored in transparent bags and expose the oil on a large surface area to the surrounding atmosphere. However, rapeseed oil and soya-bean oil are cheap and are widely used in many frying operations, especially in the fast-food area, where storage of the fried product is not necessary.

Animal tallows are also used for frying, beef tallow being popular in Yorkshire and eastern England, while lard is popular in Lancashire. Although animal fats have high levels of saturated fatty acid and are solid at room temperature, fresh fats have pleasant distinctive flavours, which are imparted to the fried food. There is a low tendency to oxidation of the fresh fat as the level of polyunsaturated fatty acid is quite low. Unlike vegetable oils, however, animal fats contain no natural tocopherol antioxidants. Some fast-food chains have used beef tallow in their frying operation, usually blended with a small amount of liquid vegetable oil.

Fish oils are seldom used for frying, as they have a tendency to cause excessive foaming. Fish oils have extremely high iodine values, reflecting the high levels of polyunsaturated fatty acids with 20 or more carbon atoms. These long-chain polyunsaturated acids render fish oils extremely prone to oxidation and in general fish oil is unsuited for frying operations. Producers of fried fatty fish therefore ensure that their normal frying oil does not become accidentally contaminated with fish oil.

Table III includes the compositions of some oils manufactured for industrial frying, as well as those of oils used for batch frying.

Groundnut oil was at one time a premium frying oil. It is sufficiently fluid at ambient temperature to cause few problems of pipe blockage due to solidification, although it might solidify in pipes or drums exposed to very cold winter weather. Its main attraction is its low iodine value, and low level of polyunsaturated fatty acids. Its most unsaturated component is linoleic acid (C18:2), which ranges from 15-40% depending on the origin of the oil. The oil should contain less than 0.1% linolenic acid. However, some manufactured products may contain trace contamination with other oils, and slightly higher levels of linolenic acid, up to 0.3%, might at times be experienced. In terms of frying performances, the low iodine value and the near zero level of linolenic acid make it an admirable oil. Unfortunately, groundnut oil has declined in popularity, owing in part to its cost but also to production problems related to the aflatoxin problem with groundnuts, and to public worries about the peanut allergy to which some people are sensitive.

Table III
Industrial frying oils

Oils	Iodine Value	% Unsaturated fatty acids	Polyunsats: sats ratio	Most unsaturated component (% level)
GNO	85-105	85	1.3	C18:2 (15-40)
P. Oleine	56-60	53	0.3	C18:2 (10-12)
RSO	116-119	88	4.6	C18:3 (8-10)
HRSO	88-96	84	0.9	C18:3 (1-2)
SBO	130-135	84	3.5	C18:3 (7-9)
HSBO	100-115	80	3.5	C18:3 (1-3)
HWSBO	105-110	85	2.4	C18:3 (1.5-2.5)
HSun	95-105	80	3.3	C18:2 (37-43)

GNO=groundnut oil P. Oleine=palm oleine RSO=rapeseed oil
HRSO=hydrogenated rapeseed oil SBO=soya-bean oil
HSBO=hydrogenated soya-bean oil
HWSBO=hydrogenated winterised soya-bean oil
HSun=hydrogenated sunflowerseed oil

Palm oleine is similarly of low iodine value (55-65 units), and has an even lower content of polyunsaturated fatty acids. Its most unsaturated component is linoleic acid, which occurs at concentrations of around 10%. Palm oleine has a relatively high level of saturated fatty acids, and may thus be frowned on from a dietary point of view. However, it is more fluid than palm oil and should seldom cause problems of pipe blockage or lack of pourability due to solidification unless, as with groundnut oil, oil pipes or drums are exposed to very cold wintry weather. In batch installations, palm oleine may partly solidify in drum storage, and it is usually recommended that unopened drums should be warmed before use, e.g. by being placed alongside the frying kettle. One disadvantage with palm oleine is that the oil tends to darken during frying, causing kitchen staff to presume that the oil is deteriorating in quality. In fact, this has been shown by the Palm Oil Research Institute of Malaysia (PORIM) to be due to the presence of low levels of polar compounds such as parahydroxybenzoic acid and vanillin[1]. The darkening of palm products during frying is therefore in no way a reflection of any inferior performance. The uses of palm oil and oleine in frying have been reviewed by Berger[1,2].

Rapeseed oil and soya-bean oil are illustrated in Tables II and III, and it has already been mentioned that a problem with these two oils is the high level of linolenic acid. Some of the newer varieties of rapeseed oil recently introduced into the UK do in fact have even higher linolenic acid contents[3,4]. Rapeseed oil and soya-bean oil can, therefore, be slightly hydrogenated during manufacture of oils for industrial frying, in order to reduce the linolenic acid content. This procedure can also be applied to sunflowerseed oil, as illustrated in Table III. These hydrogenated oils, therefore, have reduced levels of polyunsaturated fatty acids. In the case of hydrogenated rapeseed and hydrogenated soya-bean oils, the level of linolenic acid is reduced to below 3%, the corresponding iodine values being around 100 units, similar to that of some varieties of unhydrogenated groundnut oil. Sunflowerseed oil has no linolenic acid, and the linoleic acid content can be reduced to about 40%. Hydrogenated sunflowerseed oil may be attractive where a high polyunsaturated to saturated (P/S) ratio is needed for dietary purposes, together with a good shelf-life. However, hydrogenated sunflowerseed oil will be more expensive than alternatives based on other vegetable oils, and attention should be paid to the *trans* acid content of the hydrogenated oil, an aspect currently causing concern in nutritional debates[5]. In fact, the use of hydrogenated sunflowerseed oil may not be seen as an attractive option, since the main dietary attraction of sunflowerseed oil is its high linoleic acid content, but hydrogenation destroys this.

These hydrogenated oils do, of course, have higher melting points, and in some cases a somewhat harder frying fat is an advantage. In doughnut production for instance, such a fat will solidify quickly, giving better adhesion to the sugar dusting. Palm oil is therefore attractive here. In cases where cold weather fluidity is important, the hydrogenated oils can be fractionally crystallised and filtered to remove high-melting components, as in the production of palm oleine. This is illustrated in the case of soya-bean oil in Tables IV and V[6]. Soya-bean oil with an initial iodine value (IV) of 131 can be selectively hydrogenated at either of two temperatures, of 170 °C and 130 °C, to IVs of 106.6 and 104.0, respectively. In both cases, the residual linolenic acid content will be close to the target level of 2%. However, there is an appreciable *trans* isomer content in both oils, and a danger of solid-phase formation during storage. The oils are therefore slowly cooled to approximately 5 °C and then held at this temperature overnight to allow complete crystallisation. Several methods may be employed to separate solid crystals and liquid oil, a rotating drum filter being the cheapest to install, but other types of flat-band filter and membrane/diaphragm units are also used. A more sophisticated procedure is to mix the oil with aqueous detergent solution, which preferentially wets the solid phase, enabling centrifugal separation. This is the so-called Lipofrac system. Winterised oils of the type illustrated in Table V may be obtained. These have good fluidity and resistance to oxidation and off-flavour development.

The production of frying oils from soya and rape is reviewed in Leatherhead Food RA Symposium Proceedings No 31[7], and by Hastert[6].

TABLE IV

Production of partially hydrogenated soya-bean oil[6]

	Feedstock oil	**Hydrogenation at 170 °C**	**Hydrogenation at 130 °C**
IV	103.9	106.6	104.0
	Fatty acid composition (%)		
C16:0	11.0	11.1	10.9
C18:0	4.0	4.4	5.3
C18:1	23.9	45.4	46.7
C18:2	52.6	36.1	34.3
C18:3	7.6	2.2	1.9
C20:0	0.4	0.5	0.5
Others	0.5	0.3	0.4
Trans isomers (%)	0.5	21.9	19.7

TABLE V

Properties of hydrogenated winterised soya-bean oil[6]

	170 °C Hydrogenation		**130 °C Hydrogenation**	
Fraction	**Solid**	**Liquid**	**Solid**	**Liquid**
Yield	24.3	75.7	23.1	76.9
IV	96.3	108.9	93.0	105.3
	Fatty acid composition (%)			
C16:0	13.9	10.3	14.2	10.3
C18:0	6.1	3.7	8.0	4.4
C18:1	45.6	45.7	45.6	46.9
C18:2	31.4	37.3	29.3	35.8
C18:3	1.9	2.3	1.7	1.9
Others	1.1	0.7	1.2	0.7
Trans isomers (%)	24.4	21.6	22.0	19.5

Another aspect of quality influenced by the composition of the oil is the nature of the flavours that eventually develop during storage of the fried food. Although these may all be described as off-flavours, some are more acceptable than others. Thus coconut oil develops an initial coconut flavour, but, in the presence of moisture, a strong soapy off-flavour can be produced[8], these soapy off-flavours also being a problem with palm kernel oil. Soya-bean and rapeseed oils develop painty, fishy, or beany off-flavours, while those in corn (maize) are slightly burnt or corny, and those in cottonseed or peanut are often nutty. The off-flavours that may develop in hydrogenated oils are more varied, as there is a wider variety of unsaturated fatty acid isomers in the oil. In some cases, they are not detected when the food is eaten, but lingering cardboardy notes can develop on the palate some time after the food has been consumed. Fortunately, however, this is a rare occurrence, and is probably encountered only with oils hydrogenated under poorly controlled conditions. Blumenthal, Trout & Chang[9] found that the flavours developing in hydrogenated soya-bean oil were less attractive than those developing in hydrogenated corn, cottonseed or peanut oils.

The criteria that should be taken into account in selecting a frying oil are therefore price, fluidity, a low tendency to foam or smoke formation, oxidative stability of the oil with products that are eaten after a period of storage, and good flavour stability of the fried product. Where slight off-flavours do develop, they should be acceptable in terms of the food fried. When dietary requirements play a role, the ratio of polyunsaturated to saturated fatty acids (P/S) must be taken into consideration.

Although COMA[10] discounted dietary cholesterol as a major factor in heart disease, some consumers nevertheless prefer frying oils with low cholesterol contents. The concentrations of cholesterol in some foods are therefore listed in Table VI, olive oil having the lowest level of all. It is ironic that some consumers may ask for fish portions battered with a composition containing egg yolk, or a chicken piece, to be fried in oil substantially free of cholesterol, when the base food contains much more cholesterol than the cooking oil.

In many cases the above requirements are conflicting, and a balance or compromise must be made in selecting an oil for industrial frying.

The frying oil must also, of course, be fresh and subject to normal quality control criteria, as illustrated in Table VII. The peroxide value should be less than 0.4 mEq/kg and the colour should be less than 2 Lovibond red units in a 5.25-inch cell. In many cases, the linolenic acid level should be below 3%. For freshly refined oils, the free fatty acid level should be below 0.05%, but with some natural oils, like olive oil, or unrefined animal fats (e.g. dripping), higher levels of free fatty acid may be tolerated. In fact, Matz[11] claims that a free fatty acid concentration of 0.4% is optimum for heat transfer to the fried food, as it reduces the interfacial tension between the hot oil and the film of surface moisture on most uncooked foods. The low concentrations of free fatty acid in most grades of olive oil are therefore a benefit in the frying process.

TABLE VI

Cholesterol contents
(range (mean) - mg/kg)

Safflower oil	6- 10(10)	Soya oil	20-35(28)
Sunflower oil	10- 40(17)	Fish oil	2,000-6,000
Maize oil	20-100(50)	Dairy butterfat	2,200-2,800
Groundnut oil	10- 40(30)	Beef tallow	1,000-1,200
Cotton oil	20-100(43)	Egg yolk	*ca* 12,600
Rapeseed oil	25- 80(50)	Fish	500-7,000
Olive oil	1-24(7)	Chicken, lamb chop	*ca* 1,000

Blumenthal & Stier[12] developed this concept further, and claim that one of the most important aspects of frying performance is the influence of surface-active agents in the oil breaking down interfacial tension between hot oil and wet food. Thus partly oxidised fatty acids, which form in the hot oil, act as surface-active agents and improve frying performance as an oil «matures». This is termed «breaking in» the oil.

Another possible advantage in allowing an oil to mature is that some of the fried food flavours can arise as a result of interactions between aldehydes in used cooking oils and proteins in the food. Such flavours may be absent in foods fried in very fresh refined oils[13,14].

However, assessment of an oil intake at a bulk frying installation must require the flavour to be bland, as any development of cooked, fried or partially oxidised flavour before the oil is used must denote some deterioration or premature breakdown of the oil, and indicates poor quality. In addition, the flash and smoke points should be above 315 °C and 200 °C, respectively, although olive oil, because it is unrefined, will have flash and smoke points at lower temperatures - of about 285 °C and 169 °C, respectively. This will also be the case with unrefined animal fats. Oils with very low flash points can give rise to possible fire or explosion dangers.

TABLE VII

Quality limits for a frying oil

Peroxide value (mEq/kg)	0.4 max.
Linolenic acid (%)	3.0 max.
Colour (Lovibond Red units, 5.25 inch cell)	2.0 max.
Free fatty acid (%)	0.1% max. (but 0.4% is optimum according to Matz[11] to provide better heat transfer)
Flavour	Bland
Flash point	315 °C
Smoke point	200 °C
Moisture	0.05% max.

Minor Components

All oils contain minor components, some of which are beneficial to performance during frying, and others detrimental. Table VIII lists the minor components that may be considered to be beneficial. Tocopherols are natural, phenolic antioxidants, and are present in all vegetable oils[15]. Processing of the oil, and its subsequent storage and handling, should be arranged so that the natural tocopherols are preserved for as long as possible. However, high levels of tocopherols, e.g. over 1,000 mg/kg, can promote oxidation, so additional quantities should not normally be added in large amounts. Any tocopherol additions should therefore be adjusted to replace tocopherols unavoidably lost during processing, or to achieve some agreed optimum level bearing in mind the intended uses. Animal fats do not contain natural tocopherols, and, with these frying media, addition of moderate amounts of tocopherol can give significant improvement. Some sterols - for example, Δ^5 -avenasterol, also act as antioxidants[16,17,18]. Rice-bran oil contains more Δ^5 -avenasterol than most other liquid oils, and this may confer good frying performance on this oil. Low levels of phospholipids (lecithin) act synergistically with tocopherols in alleviating risk of oxidation[19]. Concentrations of lecithin should, however, be limited to a maximum of about 100 mg per kg as higher levels cause foaming. Carotenoids can also inhibit oxidation during frying and it is sometimes claimed that an oil lasts longer if small pieces of carrot are added to the frying bath during frying. Various additives can also be used to enhance or retain oil quality. Synthetic antioxidants such as BHT or BHA are permitted at concentrations of up to 200 parts per million. Although BHT and, to a lesser extent, BHA, are steam-volatile and are lost from the oil during the frying operation, some benefits are passed on to the fried food. Citric acid is also useful because it complexes transition metals such as iron and copper, thus limiting their catalytic pro-oxidant influence. Most suppliers of refined oil will add up to 100 mg/kg citric acid to the oil immediately after the deodorisation if requested.

TABLE VIII

Beneficial minor components

Natural:	Tocopherols - up to 1,000 ppm Sterols, e.g. Δ^5 avenasterol Pospholipids (lecithin) - up to 100 ppm Carotenoids
Additives:	BHA (BHT) up to 200 ppm Citric acid up to 100 ppm Silicon oil up to 2 ppm MirOil Life Powder

Silicon oil (polydimethyl siloxane) is useful in that it is claimed to form a film on the surface of the frying oil, limiting uptake of atmospheric oxygen, as shown in Table IX[20].

MirOil Life Powder is claimed to enhance the properties of the frying oil. It is a mixture of citric acid and moisture absorbed onto the surface of a food-grade volcanic ash. It is claimed that, when the powder is added to a used frying oil, the citric acid and moisture react with alkaline materials in the oil, such as soaps, precipitating these in a form in which they can then be removed along with the earth during filtration. Any residual iron or copper compounds are doubtless removed at the same time, and any suspended particulate matter is absorbed and removed by the earth during filtration. The filtration must be very thorough, however, to prevent carry-over of any powder into the frying bath, as this would contaminate the food with the powder, which, although it may be used as a processing aid, is not an approved food ingredient..

Schulz[21] claims, however, to have tested MirOil Life Powder in a large-scale industrial frying operation with no beneficial effect.

TABLE IX

Influence of polydimethyl siloxane (per cent non-oxidised triglyceride in sunflowerseed oil)

Heating time	Silcon anti-foam concentration (ppm)			
at 180°C	0	0.04	0.06	0.10
1(h)	78	77	80	81
2 (h)	70	77	77	82
4 (h)	63	66	69	75
6 (h)	50	54	56	72
8 (h)	40	44	51	64

From Freeman, Padley & Sheppard[20]

Table X illustrates minor harmful components that may be present in an oil. Lecithin and partial glycerides cause excessive foaming if they are present in moderate or high concentrations. Free fatty acid will cause smoke when present at levels of over 2%. This influence depends on the volatility of the free fatty acid, being more of a problem with the shorter-chain acids present in palm kernel or coconut oils, as discussed earlier. The most detrimental minor components are trace metals such as iron and copper. These promote oxidation if present at levels of over 0.1, or 0.01 mg/kg, respectively, and all efforts should be taken to minimise contamination of the oil with these transition metals, especially copper. Residual solvents will not normally be present; if they are, they will reduce the flash point and give potential explosion danger. Proteinaceous residues may be present in the oil when purchased. This is a more serious problem in unrefined cold-pressed oils such as groundnut oil or beef dripping. Residues of the food fried will also fall into this category, and should be removed by effective filtration or skimming. The hot oil should not continue to flow through a filter bed of hot debris, however, as this will negate the benefits of filtering it off. Filters should therefore be discharged on a regular basis.

When animal fats are used as frying media, these will of course contain much higher levels of cholesterol than vegetable oils, as shown in Table VI, and fried vegetable products will then acquire an increased cholesterol level. However, this is not regarded as a problem by nutritional experts[10].

Alkaline-reacting materials (ARM) such as sodium oleate are also reputed to cause deterioration of the frying oil[22], as illustrated in Table XI, where it can be seen that the concentration of alkaline-reacting material (as sodium oleate) increased during the use of frying oil in a restaurant. When the level of ARM had risen to 43 mg/kg (as sodium oleate) it became necessary to discard the oil[22].

Foaming can be a major problem in frying operations, and can cause a fire. Figure 1 shows the difference between foaming and bubbling oil. Foaming is when the oil surface becomes covered with a mass of thick bubbles that do not disperse during frying. This is dangerous because the foam can rise over the top of the fryer and cause a fire. Foaming should not be confused with the more open bubbles that appear when the food is first added to the oil and which should disperse. In the latter case, the bubbles are located only above the fried food, and do not cover the whole surface of the oil.

TABLE X

Minor harmful components

Lecithin - foaming if over 100 ppm
Partial glycerides - foaming
Free fatty acids - smoke if over 2.0%
Trace metals - oxidation. Cu < 0.01 ppm
Fe < 0.1ppm
Residual solvents - reduces flash point -fire, explosions
Alkaline materials - sodium oleate < 40 ppm
Proteinaceous residues - burnt flavours

TABLE XI

Alkaline-reacting material (ARM) in restaurant frying oil

Days of use at 180°C	ARM (as sodium oleate)
0 (fresh)	7 ppm
1	15 ppm
2	18 ppm
3	37 ppm
4 (discard)	43 ppm

From Blumenthal, Stockler & Summers[22]

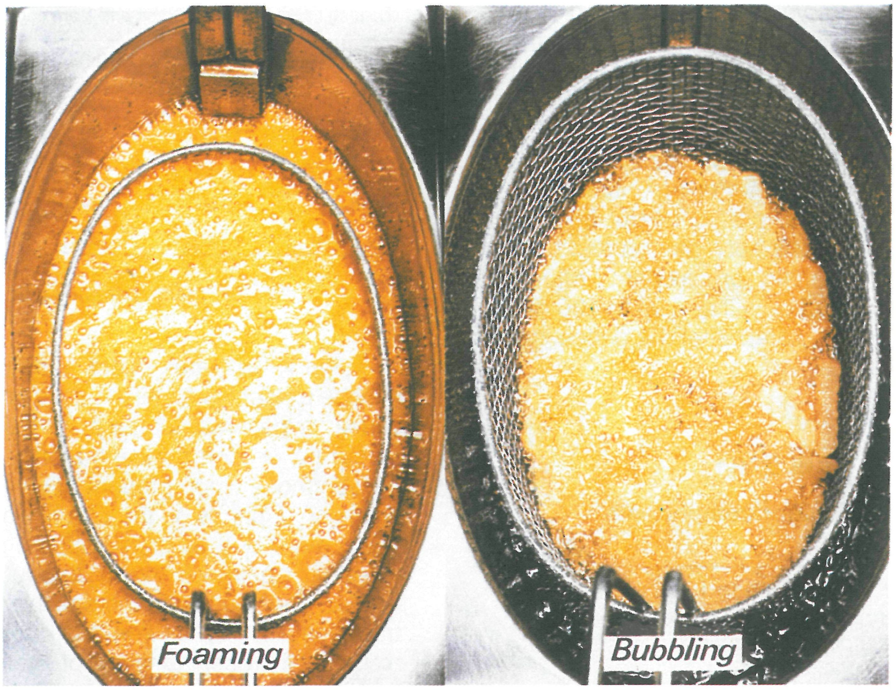

Figure 1
Comparison of foaming and bubbling oil in the frying of potato chips
(Courtesy of Craig Millar)

Foaming is usually associated with an increase in the oxidised triglyceride components in the oil, as these are surface-active and stabilise the foam. Blumenthall & Stier[12] claim that the large surface area of the foam is a site for further oxidation, releasing oxidised components into the oil when the foam bubbles burst, thus further degrading the oil. The concentration of non-oxidised triglycerides, which stabilise the foam, is therefore a useful criterion of oil quality, and Table IX illustrates the influence of polydimethyl siloxane on the quality of a sunflowerseed oil during different periods of heating, and with different concentrations of silicon anti-foam agent. The beneficial action of the silicon anti-foam is clearly illustrated, even when the agent is present at concentrations as low as 0.04 mg/kg. Levels of up to 2 mg/kg are normally recommended, as some of the anti-foam agent is lost on the fried food during processing.

Transport and Storage

Catering establishments normally receive their oil in drums (or fats in boxes), whereas industrial units usually receive their oils by bulk road tanker. Melting of boxed fat needs care - an often overlooked risk can be to add lumps of solid fat to the fryer in such a careless way that some of the heating surfaces are bare. They can then overheat, causing burning of any traces of fat, burn-out of the heater, or even fire.

For the bulk liquid oils, the average vehicle carries up to 25 tons of fat in a tank of cylindrical or near cylindrical shape, mounted on a four- or six-wheeled rigid chassis or as part of an articulated unit. The tank will be so mounted that it slopes down toward the outlet, or different outlets if divisions exist within the main unit. The tank will be lagged with a layer of mineral wool 50 mm or more thick, the whole being covered with metal sleeving. Fat is normally loaded at a temperature of about 45 °C at the works, and, with the temperature drop not exceeding 1 °C per hour, it can be expected to arrive at its destination at well above the melting point, should this be above ambient. However, delays do occur, giving rise to exceptionally long journey times and, for this reason, steam pipes are normally installed in the bottom of the vehicles' tanks. These can be connected to the customer's steam main on arrival for melting of any solidified oil. Discharge of the vehicle is either by an engine-driven pump or by introduction of compressed air above the oil in the tank. In either case, delivery is by flexible hose, several lengths of which are carried on the vehicle. To allow undivided tankers to deliver part loads, modern vehicles will have reversible pumps or accessory oil lines to clear the intake pipe to the receiving tank, thereby helping to avoid blockage of the line with solidified fat between deliveries. If it is necessary to reheat the vehicle contents, then this must be done with care to avoid local overheating and damage to the fat, and it is essential that no fat be drawn off until at least 75% of the load is liquid. While some gain in speed may be achieved by drawing liquid oil from the bottom of the road tanker and pumping it in again at the top, this causes a risk of oxidation, and it is therefore safer to allow natural convection to do the work. Oxidation is also inhibited by blanketing the oil with nitrogen in bulk storage tanks, and also in the road tanker, where the agitation of transport might otherwise promote aeration.

Oil delivery tankers should, in the UK, be registered with the Seed Crushers and Oil Processors Association (SCOPA), which has a scheme to ensure that only suitable tankers are used, and that their tankers carry no industrial chemical cargoes prior to an edible-oil delivery.

The storage time involved from refining to use should normally be less than 5 days, and bulk storage tanks should be sized to this throughout. Care should be taken not to introduce any copper from drums, tanks, funnels or valves. The last-mentioned item is of most importance, as copper alloys are very useful in the construction of taps, valves and heating coils, but should be avoided when these are for edible-oil installations.

Oil oxidation is auto-catalytic, and an oxidised oil can therefore promote and accelerate oxidation in fresh oil. Care should therefore be taken not to load deliveries of fresh oil on top of old stock, as any peroxides or secondary oxidation products present in the old oil will promote oxidation in the fresh delivery. Care should also be taken not to aerate the oil, and, as mentioned above, if possible, the oil in the tanks should be blanketed with nitrogen. The main cause of aeration is in the discharge of fresh oil into a land tank, as illustrated in Figure 2. In this diagram, fresh oil is being pumped into a tank, and in the left-hand illustration is shown to cascade into the oil from an open pipe at the top of the tank. This is a very effective way of aerating the oil. It is preferable to arrange for the oil to discharge through a bottom outlet, but here again care must be taken. It is common to displace the last few hundredweight of oil from a delivery pipe by blowing the pipe with compressed air. It is easy to allow the compressed air supply to continue for some time after the last traces of oil have been displaced from the pipe, thus blowing air in at the bottom of the tank, and ensuring full aeration of the oil. Some suitable system of valving and pressure monitoring can be used to avoid this.

Oils that have melting points above ambient should be kept warm, but not overheated. This should be no problem in lagged tanks. Oil should not normally be circulated in the tank, e.g. to promote melting of any solid deposits, as this will promote aeration and oxidation.

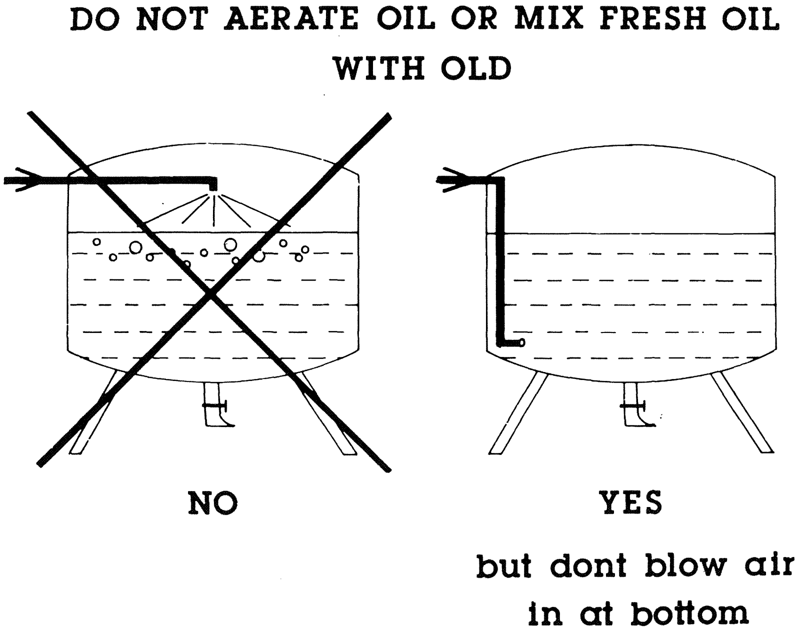

Figure 2

The Nature of the Food Fried

Oil quality may be influenced by the nature of the food fried, especially when the product introduces foreign oils, emulsifiers, trace metals, food scraps, free fatty acids, or alkaline-reacting material into the frying oil. Smith[23] reviews frying of potato products and the influence of oil quality.

The introduction of foreign oils is most troublesome when fatty fish is fried, as any highly unsaturated fish oil will cause rapid oxidation of the oil. For this reason, it is recommended that fish products should be battered before frying. Chicken fat and dairy fats may also be a hazard, in the latter case because the short-chain acids present in dairy fats may be a cause of excessive smoke. Residual fat from grilled meats such as chops or sausages should not be used to top up frying kettles, as the animal fats are of low stability, will generally be already partly oxidised, and will promote oxidation of the frying oil.

Emulsifiers are often used in the production of foods, and if these escape into the oil they will cause excessive foaming.

Some products, especially of the snack type, may introduce excessive quantities of trace metals into the oil. This is a particular problem with iron and copper, which will promote oxidation. Potato «whiteners» may improve the appearance of fried chips, but they can degrade the frying oil.

The Frying Operation

Food scraps should be removed from the oil by some form of filtration apparatus, e.g. a continuous filter unit with automatic discharge, or alternatively two batch-type filtration units working in unison. In a restaurant or batch-frying operation, the oil should be skimmed regularly. Furthermore, it is useful to arrange for a cool zone at the bottom of the fryer, e.g. below the heaters, so that scraps can fall into this zone and remain there without damaging the oil. Steps should be taken to ensure that this «cold zone» does not become overloaded, as accumulated debris may touch the bottom of the heaters and char, developing unexpected off-flavours. Free fatty acids may also migrate from the food product into the oil, and can cause excessive fume or smoke formation.

It should be possible to clean the filter at regular intervals, to discharge the foreign material removed from the oil. If this is not done, the latter can form a bed of debris, which continues to deteriorate, damaging the good oil pumped through it. In some cases this bed of material on the filter may contain high levels of, for example, iron or copper previously removed from the oil, but which will now catalyse oxidation of oil pumped through the bed. The filter should be located at the coolest part of the system, not immediately after the heat exchanger, for instance.

In order to prevent rapid build-up of deposits in the filter, it is useful to shake or blow loose breadcrumbs or batter from the coated food prior to frying, and thus minimise the risk of their falling off during the frying operation. A careful optimisation of the air flow to the blower on the coating unit can thus improve oil quality - a relationship easily overlooked.

Filtration of the oil was once a straightforward task, and none of the above precautions was considered necessary. However, the modern «light eat» breadcrumb coatings are more friable (as well as being more fryable) and easily break down to give increased amounts of particulate matter in the oil. Factory sites that optimised their filtration system some years ago may therefore need to re-investigate this aspect if the «life» of their oils appears to have deteriorated.

Filtration with filter papers or woven cloths can remove particles down to about 5 μm in diameter and lessens the development of pyrolysis products and burnt flavours. «Depth filtration» through non-woven fabrics can remove particles down to 1 μm, and may also remove microemulsified water, and thus slow oil deterioration[12]. «Active filtration» is the technique in which adsorbent materials are used to remove soluble compounds that adversely affect the oil[12,24]. With active filtration, the adsorbent material must be fully removed from the oil before food is fried. Yates[25] has evaluated passive and active filtration.

Excess quantities of breadcrumbs in the frying oil are detrimental, because flour for breadmaking must (in the UK) be fortified with iron for nutritional purposes. The iron in the breadcrumbs will contaminate the oil and catalyse oxidation.

Alkaline-reacting material has been identified as a possible cause of deterioration in frying oils[22], probably owing to migration of alkali metal irons from the food into the frying oil, where they react to form soaps. This can be a particular problem with salted food, and it should be remembered that food should be salted after frying, and not before. When salt is added to a food before frying, some of the salt will remain in the frying oil, and can build up to high concentrations. Although sodium chloride is a less active pro-oxidant than iron or copper, it is a pro-oxidant at the concentrations that may be encountered when food is salted before frying. Furthermore, the sodium chloride used will not be of analytical chemical purity, and will undoubtedly contain trace quantities of iron and copper salts, a form in which these metals are very active pro-oxidants.

Fryers that take solid fats should be provided with a special melting cycle. In some, «pulses» of heat are followed by resting periods to allow solid fat to melt without overheating.

The fryer may be heated by direct gas flames under the bottom of the vessel, but in this case the provision of a «cold zone» under the heaters cannot be easily achieved. Otherwise, electrical resistance heaters or heating coils/pipes may be installed a few inches above the bottom of the fryer to give the cold zone. Some fryers are equipped with external heat exchangers, in which oil is pumped through the fryer, through a filtration unit, and then through the heat exchanger before return to the frying bath. Rossell[26,27] has drawn attention to the toxicological hazards of any leaks of heat-transfer fluids into frying oils.

It is also important to ensure that recommended cooking temperatures are not exceeded. Table XII lists recommended cooking temperatures during batch-frying operations, although it may be possible to exceed these temperatures in continuous frying equipment when there is a fast throughput of food and a correspondingly large need for topping up with fresh oil. Obviously, small pieces of food cook more quickly whilst larger pieces may need a lower temperature to ensure heat penetration without surface burning. In general, however, the oil will have a better quality, and the food a longer shelf-life if the temperatures indicated in Table XII are not exceeded. Blumenthal & Stier[12] point out that food quality and operating efficiency are compromised if a large fryer is used at only partial capacity. The fryer needs to be matched to the throughput.

If two fryers are in use in a batch or restaurant situation, it is best to shut one down in slack periods rather than keep both hot but under-utilised. Filtered oil from the less busy unit should then be used to top up the busiest fryer, the former being topped up with new oil. This reduces oil deterioration.

In conclusion, Table XIII lists recommendations for processing, and aspects that should be avoided. The oil should be heated slowly in order to avoid overheating; it should be cooled and covered with a floating lid between frying batches and at the end of the frying operation[28]. If a lid is positioned above the surface of the oil, condensate will drip back into the oil, causing deterioration. For this reason a floating lid is best[28]; it is also more effective in excluding air. The frying kettle should be topped up regularly with fresh oil; the correct food/oil ratio of 1:6 should be used, and the oil should be filtered and/or skimmed regularly to remove food debris. In this last respect, it is important to ensure that the debris does not ignite. The debris will already be warm, will have a large surface area, and will be impregnated with unsaturated vegetable oil. Oxidation of the oil distributed over the large surface area will doubtless take place, and in some circumstances can generate sufficient heat to cause smouldering or ignition, especially if the debris is stored near the cooker, where it will be kept warm. It is possible for the oil to catch fire, e.g. after foaming. Water and forced-jet extinguishers should not be used on such a fire as these will spread the hot oil. It is best to cover the hot oil, e.g. with a fire blanket, which should be kept nearby for the purpose.

Steps should be taken not to overheat the oil, and in this respect it is important to check the thermostat. The fume extraction equipment should also be checked to ensure that there is not an excessive draught of fresh air above the surface of the oil. This will not only cool the oil, but will also promote oxidation. It is also important to ensure that any fumes condensing in the extraction equipment do not drip or run back into the frying kettle. In slack periods the kettle should not therefore be kept hot and should not be covered with a lid situated several inches above the fat, as this has the same effect. A floating stainless steel lid has been recommended for this purpose[28] in cases where it is necessary to cover the hot oil. Action should be taken to ensure that the circulation of hot oil is not impeded, e.g. by allowing the oil filter to block. If this happens, oil in the heat exchanger, or above the heating elements, will be subjected to excessive temperatures during the period of interrupted circulation. Food should not be salted before frying, as this will lead to contamination of the oil by sodium chloride and any impurities in the sodium chloride, which are pro-oxidants. Wet food should not be fried as the additional moisture will cool the oil and cause additional hydrolysis of the fat. In this respect, however, it must be mentioned that the steam evolved during cooking does in fact help protect the oil. The moisture normally present in food therefore has a beneficial effect on the oil; this is because the evolution of steam during the frying process causes a type of deodorisation of the oil, as the escaping steam bubbles carry with them volatile material, such as aldehydes and ketones, which are thus steam-distilled out of the oil. Furthermore, the steam forms a blanket above the surface of the oil, inhibiting access of atmospheric oxygen.

Since the fried food absorbs oil, the level of oil in the fryer will fall. It is usual to replace this with fresh oil. The amount of fresh oil added is related to the turnover rate. This may be expressed as a ratio:

$$\text{Oil turnover} = \frac{\text{weight of oil in fryer}}{\text{average weight of fresh oil added per hour}} \qquad \text{(Banks}^{29}\text{)}$$

or, alternatively, as the time taken to replace 100% of the original oil charge. However, it should be remembered that an 8-hour turnover will not correspond to all of the original oil being replaced in the 8 hours, as at each fresh addition the oil already in the fryer becomes diluted by the new oil, and will be at a reduced concentration in the oil removed by the food.

Based on fryer design, a 5-12 hour turnover is normal for continuous production. In intermediate frying, with idling periods, longer turnover times are likely. Since idling puts more stress on the oil than active frying, longer turnover times amount to inefficient oil use. Fryer oil quality cannot be maintained with turnover times of 20 hours or more[29], and after a few days it will be necessary to remove and discard some oil manually to enable a top-up with fresh oil. Oil turnover rate should be a primary factor in any thoughts about changes to fryer use.

A steady state is usually achieved in the fryer after four oil turnovers, and analytical values stabilise. This reflects blending of new and used oil at a constant rate, and uniform take-up by the food being fried. This steady state should be achieved before any finished product evaluations are undertaken.

TABLE XII

Cooking temperatures for batch frying

Food	Temperature	
	°C	°F
Potato chips - blanch	166-188	330-370
- fry	188	370
Potato crisps and straws	175	347
Fish fillets - battered and breaded	170-180	338-356
Fish cakes - breaded	188	370
Meat - battered and breaded cutlets	182	360
- lean chops (uncoated)	177	350
Chicken - large, battered and breaded	163-177	325-350
- small, battered and breaded	170-185	338-365
- pre-cooked, battered and breaded	170-185	338-365
Scampi - battered	180-185	356-365
Doughnuts	190	375
Choux paste	180	356
Onion rings - battered and breaded	180-185	356-365
Fruit fritters - battered	175-180	347-356
Vegetables	165	330
- battered and breaded	185	365
Maize snacks	190	375
Pre-cooked rice	190	375
Croutons	155	310
Nuts - almonds	115	240
cashews	135	275
peanuts	177	350
blanched peanuts	149	300
Chinese noodles - battered	190	375
Croquets - breaded	190	375

Finally, stringent measures should be taken to avoid any contact with copper metal. All pipes, especially valves, thermometer pockets, electrical heating elements, and other fittings, should be checked to ensure that they are not constructed from any copper-containing alloy. There have been occasions when batch-frying baskets have developed holes, which have been given temporary repairs with short lengths of twisted copper wire. No doubt this can also happen in continuous frying installations, where the conveyor belt carrying the food into the fryer may develop a fault. It may be expedient to carry out a quick repair with a piece of twisted copper wire, rather than close the plant and call for the maintenance crew, but this must damage the quality of the oil. While a production manager may be able to justify this as a short-term measure, steps should be taken to ensure that a proper repair is carried out with the utmost speed, and the copper wire used initially should be removed. It would, of course, be much better to provide short lengths of soft stainless steel wire in situations where temporary repairs of this nature might become necessary.

It is also rumoured[30] that disgruntled employees, such as those recently made redundant, have thrown small copper coins into oil storage tanks. While storage tanks should be frequently checked for cleanliness, this is especially so if a deterioration of oil quality is noted.

It is also necessary to clean the fryer regularly in order to remove traces of polymerised oil, which will promote degradation of subsequent oil batches. This may be achieved by boiling out with an alkaline solution, or use of hot detergent. This cleaning treatment should be carried out once a week with fryers subjected to heavy use with unsaturated oils. The fryer should then be rinsed with dilute acid to neutralise the alkali, and finally washed thoroughly with clean hot water to remove traces of soap or detergent, and dried prior to refilling with oil. Failure to remove alkaline cleaning compounds is claimed to be a prime cause of oil degradation[12].

TABLE XIII

Processing do's and don'ts

Processing do's
Heat up very slowly.
Avoid overheating.
Cool and then cover between batches and at end of frying operation.
Filter/skim to remove food debris from contact with hot oil (i.e. do not pump good oil through a bed of decomposing debris).
Use correct food/oil ratio (1:6).
Top up regularly with fresh oil. Oil turnover rate 5-12 hours.
Clean fryer regularly with strong detergent or boil out with aqueous alkali.
Clean thoroughly with clear water to remove soaps or detergent, and dry.
Processing don'ts
Don't overheat - check thermostat
Don't allow drip-back from fume hood
Don't use excessive fume extraction draught
Don't allow oil filter to block
Don't interrupt circulation of hot oil
Don't salt food before frying
Don't allow any copper metal
Don't fry wet food
Don't run plant with oil turnover times of more than 12 hours

Evaluation during Use

Several methods of evaluating a frying oil have been recommended[31,32]. The simplest of these, and one used by small catering establishments, is the colour of the oil. This is a fairly reliable guide if a single grade of oil is used, and experience relating oil colour against the taste of the fried food is developed. Where staff change, e.g. on a shift system, such a procedure can be put onto a reasonably reliable footing by reference to some standard samples of oil chosen to represent various stages of degradation. Care should be taken, however, not to confuse standards established with one oil or fried food product with quality criteria for oil of a different type. Palm-based products, for instance, darken more quickly than other types of frying oil, but this does not reflect a lower quality[1]. Visual inspection of the foam height above the fried food is also a good indication of oil quality to trained kitchen staff. Excessive foam formation can of course be a fire hazard.

In an industrial establishment, determination of the free fatty acid level is often more appropriate, as it is an objective measurement, which can be automated with an automatic titration apparatus incorporating electrical end-point detection. Indeed, electrical end-point detection may be needed with manual titration, as the darker colours of the used oils can obscure the visual end-point with coloured indicators[33]. Depending on the oil or fat used as the frying medium, a free fatty acid (FFA) level of about 2.0% (measured as oleic acid) is usually regarded as the desired point for the oils used in frying battered and/or breaded foods, while in potato chip frying FFA concentrations of up to 5% may be tolerated in some locations. Several countries have regulations or guidelines restricting use of frying oils to those with acidities (calculated as oleic) below a specified level; these include Austria (1.25%), Belgium (2.5%), Germany (1.0%), Japan (1.25%), and the Netherlands (2.25%)[34]. Higher FFA levels may be tolerated by manufacturers in some applications, especially when unrefined virgin oils such as olive oil or beef tallow are employed. Milnar[35] reported a rapid method of measuring FFA developed by the 3M Corporation. This comprises a paper strip impregnated with indicators and reagents and separated into strips by polymerised liquid silicone bands, which separate zones of the paper into distinct «reaction flasks». The strips performed very well in ten fast-food stores according to Milnar[35], but the present author has heard less glowing accounts of evaluations carried out in the UK.

In some countries, frying oils must be rejected when the content of polar compounds reaches a specified level. This is the case in Germany, for instance[36], and in France a recently issued amendment to the decree of H/3/1908 specifies that fats and oils with more than 25% polar components are unfit for human consumption[37]. A weighed amount of fat is dissolved in petroleum ether:diethyl ether (87:13) and passed through a silica column to absorb polar compounds. The eluate is collected and evaporated, and the non-polar portion weighed. A major drawback is the 3½ hours needed per analysis[32].

The German legislation led to the development of the Rau test, which is in effect a simplified laboratory test in which a sample of the oil is dissolved in a solvent and mixed with specified amounts of a reagent (bromothymol blue) that develops characteristic colours with abused oils. This test has been taken up by the Merck Chemical Company of Darmstadt, West Germany, and it now offers a commercial version of this test kit, namely the OxiFrit test. In the UK, this kit may be obtained from Merck's UK agent BDH. Merk also offers the colorimetric Fritest kit, which is sensitive to carbonyl compounds. The sample is mixed with reagent and compared with three diagnostic colours representing good, intermediate and bad. One problem with these kits is the use of potentially hazardous chemicals, which limits application in the kitchen area. Robern & Gray[38] also criticise the use of flammable solvents near a hot fryer.

As the original Rau test was developed in response to German legislation in which it is not permissible to use frying oils containing more than 24% polymerised and oxidised material, the test is good at recognising degraded oils. It may not be so good if earlier rejection points are specified in some establishments. Its efficiency is also reported to vary quite considerably depending on the nature of the frying medium, e.g. solid oil (palm), liquid oil, or tallow[31], especially if a colour that develops naturally in the fat, or that migrates from a food being cooked, might confuse interpretation of the colour developed in the test. A «food oil sensor» is offered by Northern Instruments Corp. of Minnesota. This is a hand-held unit, which measures the dielectric constant of the oil, and thus assesses the level of polar components such as oxidised oil, free fatty acid, etc.[39] One of these units has been assessed by the Leatherhead Food RA, and by an RA Member, who borrowed the Food RA instrument. It appeared unduly sensitive to cold draughts of air, and to the level of moisture in the oil, and needs calibrating for each type of oil used for frying[32]. As far as is known, it was withdrawn from sale in Europe.

Various other methods of assessing the condition of used frying oils have been reviewed by Billek, Guhr & Waibel[36] and Paradis & Newar[40].

None of these tests is fully satisfactory - a fact illustrated by the number and variety of approaches, and, in view of this, the Leatherhead Food RA undertook research work into the topic. It was discovered that the viscosity of the oil increases as it deteriorates, owing to the formation of oxidised and polymerised fatty acids. A vibrating reed sensor was therefore developed, which can measure the viscosity of a hot frying oil during use[41] (Plate I). This unit is not yet commercially available. The present patent holder (GEC-Marconi) has entered into a partnership with Walter Rau to manufacture and market this instrument. It is understood that there are still some teething troubles with the design of the probe, in particular with the location of the thermocouple within the probe and the speed of temperature compensation. However, the latest reports indicate that Walter Rau has encountered insurmountable engineering problems, and is likely to discontinue development work on the sensor.

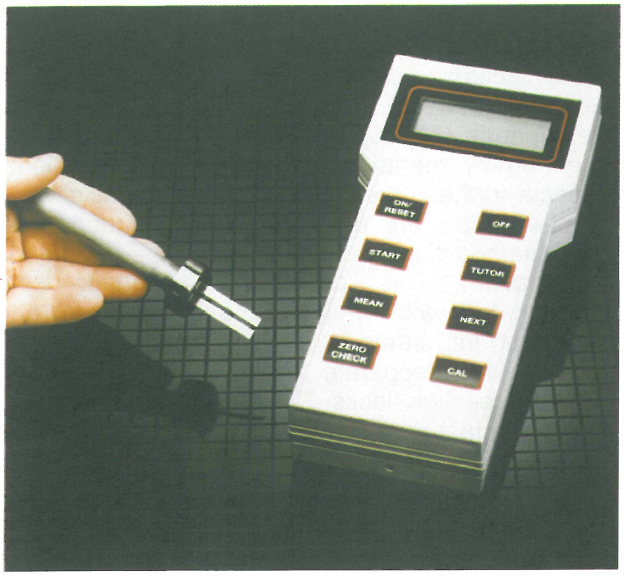

Plate I
Frying Oil Quality Meter

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