

Frying Oil Series

The Use Of Palm Oil In Frying

Kurt G Berger

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The Use of Palm Oil in Frying

Preface

Archaeological evidence from Egyptian tombs shows that palm oil was in use for food at least 5,000 years ago (1). The oil palm is a native of equatorial West Africa and palm oil is obtained from the flesh of the fruit; making it easier to extract, compared to other oils obtained from seeds. This is undoubtedly why palm oil has a very long history of food use in its producing regions.

Trade statistics show that palm oil has been exported to Europe from West Africa since the 18th century; but for a long time it was only for industrial uses. Early in the 20th century refinery techniques were developed, which enabled small quantities of good quality African crude palm oil to be used in food applications.

However, substantial availability of food grade palm oil had to await developments after the 1939-45 war. On a personal note, the author was working in the research laboratory of a large London food manufacturer on applications of oils and fats. At that time all the industry's supplies were by allocation from the Ministry of Food; and manufacturers had no freedom of choice until 1953. Not long after this the chief chemist of one of our suppliers came to us and said, "you really ought to try out refined palm oil for frying now that a reliable quality product is available from Malaysia". We followed up this suggestion and found it to be useful for a number of products.

Usually, the production of vegetable oils is to satisfy domestic requirements first; development of export trade comes later. In Malaysia however, the development of oil palm was primarily as a source of an export crop. It was seen by the Government as a means of providing a living for landless people; and by the existing plantation industry as a diversification from rubber production, which was in decline. The move proved successful, and by 1974 about 1 million tonnes of oil was available for export. It then became necessary to introduce palm oil to markets other than Western Europe. However, the food industry elsewhere was wary of a new ingredient – how will a changed product formula be received by the consumers? As palm oil production continues to increase and further new users become interested, this question continues to be asked.

Frying involves close contact between the oil used and the raw food being cooked. Oil is absorbed by the food and contributes significantly to its flavour and nutritional properties, and becomes a major component of the final product consumed. This is shown by the figures in the table, taken from the database of the United States Department of Agriculture (USDA).

Typical Mean Oil Content of Selected Fried Foods

Food Item	Mean \pm standard deviation (g/100 g edible portion)
Potato chips	34.60 \pm 0.25 (n=158)
Corn chips	33.40 \pm 0.28 (n=94)
Tortilla chips	26.20 \pm 0.49 (n=41)
Doughnuts - plain	22.90 \pm 1.40 (n=18)
Onion rings	18.69 \pm 1.41 (n=11)
Chicken breast – breaded	18.10 \pm 0.37 (n=57)
Fish fillet – battered or breaded	12.90 \pm 0.80 (n=11)
French fries	14.8
Part-fried French fries	7.6

n = number of samples analysed

Note: The American term 'potato chips' refers to thin fried potato slices packed in bags and sold as snack food. In the United Kingdom (UK), the product is called 'potato crisps', while the UK term 'chips' refers to French fries. To avoid confusion, the terms 'potato crisps' and 'French fries' will be used throughout.

This handbook provides information on the characteristics of palm oil products relevant to their use in frying, followed by a chapter on good practice in frying, including quality control aspects; both for home and industry use. Technical literature on the use of palm oil is reviewed, as is the back-up information obtained in numerous experiments at the Malaysian Palm Oil Board (formerly the Palm Oil Research Institute of Malaysia) and elsewhere.

The oil used in frying plays an important role in the eating quality of the food product and in its shelf life. An extensive methodology has been developed to measure relevant changes in the quality of frying oil during use. These methods have been fully

described in the technical literature. The detailed procedures therefore need not concern us here, though the analytical results used to evaluate oil quality will be discussed.

A review of the technical literature shows that gradually food scientists found frying performance of palm oil compared favourably with that of alternate oils; and palm oil could be used in various ways in the manufacture of their products. An attempt was made to put together, from various trade sources, information on the global amount of palm oil products used in frying; and though incomplete the figures indicated that frying is probably the largest single application of palm oil in food products.

References

1. Friedel, M.C. (1897) on fatty materials found in an Egyptian tomb in Abydos. *Comptes Rendus* Vol 24, 648-651

Characteristics Of Palm Oil Products Used In Frying

The following products have found applications in frying:

- Refined palm oil
- Refined standard palm olein
- Refined double fractionated palm olein
- Refined palm stearin
- Red palm oil or olein

Palm oil can be fractionated by cooling it to a temperature at which higher melting components crystallise out. The resulting slurry is then filtered to obtain a filter cake, the stearin, and a filtrate, the olein. The standard process is carried out on a very large scale, as many users prefer olein in a number of applications. As will be seen in the following tables, palm olein has a more liquid character than palm oil, but still contains significant solid content at room temperature. More liquid grades of olein can be obtained by modifying the conditions of fractionation, or by refractionating the standard olein to remove further solids. These grades of olein are obtained in lower yield (as one would expect) and consequently are somewhat more expensive.

The physical characteristics and fatty acid composition of palm oil and its fractions are shown in Table 1.1 below.

Table 1.1
Characteristics of Palm Oil and Palm Olein

	Palm Oil	Palm Olein			
		Standard	PL60	PL62	PL65
Iodine value (Wiji)	53	58	60.8	62.9	66.4
Melting point (°C)	36	21.6	15.6	14.5	12.0
Cloud point (°C)	-	8.8	5.6	5.0	2.2
Cold stability at:					
15°C (hour)	-	-	36	Still clear after 138 hours	Still clear after 138 hours
10°C	-	-	<1.5	<6	<18
Solid fat content (%)					
5°C	-	51.1	27.9	2.5	1.4
10°C	50.3	37.0	19.5	0.5	-
15°C	-	19.2	1.3	-	-
20°C	23.2	5.9	0.5	-	-
25°C	13.7	-	-	-	-
30°C	8.5	-	-	-	-
35°C	5.8	-	-	-	-
40°C	3.5	-	-	-	-
Fatty acid composition (%)					
12:0	0.2	0.2	0.3	0.3	0.4
14:0	1.1	1.0	1.1	1.1	1.1
16:0	44.0	39.8	36.1	34.7	31.5
16:1	0.1	0.2	-	-	-
18:0	4.5	4.4	3.8	3.7	3.2
18:1	39.2	42.5	45.4	46.1	49.2
18:2	10.1	11.2	12.5	13.1	13.7
18:3	0.4	0.4	0.2	0.3	0.3
20:0	0.4	0.4	0.4	0.4	0.4
Other	-	-	0.2	0.2	0.2
	(1)	(2)	(3)	(3)	(3)

It will be seen that, as the unsaturation of the olein increases, its cold stability increases. The melting point and cloud point will be lowered and the tendency to deposit solids at a low temperature reduced. The importance of cold stability is that when buying liquid cooking oil, the customer expects the oil to be clear at the temperature of the supermarket.

The glyceride composition of typical palm oil is summarised in Table 1.2. (4)

Table 1.2
Glyceride Composition of Palm Oil

Glyceride Type	%	Major Components
Trisaturated	8.5	PPP
Mono-unsaturated	37.8	POP, PPO
Di-unsaturated	35.1	POO, PPL
More highly unsaturated	18.6	OOO, PLO, OOL

P= palmitic acid, O= oleic acid, L = linoleic acid

The tripalmitin content in palm oil contributes significantly to its melting point of 36°C. The proportion of tripalmitin is progressively reduced in the grades of olein shown in Table 1.1, but the remaining quantity has an important influence on the physical stability at lower temperatures. Another factor influencing the physical stability is the level of saturated diglycerides present: in particular 1,3 dipalmitoyl glycerol. (5)

The physical stability of some industrial samples of single and double fractionated palm olein of comparable iodine value is summarised in Table 1.3. (5) (6)

Table 1.3
Resistance to Crystallisation and Cloud Point of Palm Oleins

Storage Temperature °C	Time to Remain Clear			
	Single Fractionated Olein IV60	Double Fractionated Olein IV60	Single Fractionated Olein IV62	Double Fractionated Olein IV62
5	< 3 hours	< 3 hours	< 3 hours	< 3 hours
10	> 5 hours	< 3 hours	> 5 hours	1 day
15	> 1 day	< 1 day	> 1 day	< 4 days
20	> 20 days	< 4 days	> 20 days	> 60 days

In order to obtain cooking oil with physical stability superior to that attainable with palm olein, palm olein may be blended with one or more of the more unsaturated vegetable oils.

The effects on physical stability of blending two grades of palm olein with sunflower oil are shown in Tables 1.4 and 1.5 below.

Table 1.4
Properties of Palm Olein (IV60) Blends with Sunflower Oil

Palm Olein	Sunflower Oil	Cloud Point (°C)	Cold Test	Days clear at:			
				5°C	10°C	15°C	20°C
0	100	-10	+	← Indefinite →			
10	90	-9.5	+	90	> 240	> 240	> 240
20	80	-7.5	+	< 5	180	> 240	> 240
30	70	-6.5	-	< 3	< 10	< 120	> 240
50	50	-2.7	-	< 1	< 1	< 5	> 60
90	10	3.5	-	< 1	< 1	< 1	> 10

Table 1.5
Properties of Palm Olein (IV65) Blends with Sunflower Oil

Palm Olein	Sunflower Oil	Cloud Point (°C)	Cold Test	Days clear at:			
				5°C	10°C	15°C	20°C
0	100	-10.4	+	← Indefinite →			
10	90	-9.8	+	90	> 240	> 240	> 240
20	80	-9.0	+	7	180	> 240	> 240
30	70	-7.0	+	3	20	240	> 240
50	50	-4.5	-	> 1	< 5	< 10	> 240
90	10	+1.0	-	< 1	< 2	< 2	> 40

Tables 1.6 and 1.7 show data for blends with Safflower oil.

Table 1.6
Properties of Palm Olein (IV60) Blends with Safflower Oil

Palm Olein	Safflower Oil	Cloud Point (°C)	Cold Test	Days clear at:			
				5°C	10°C	15°C	20°C
0	100	-9.1	+	← Indefinite →			
10	90	-10.0	+	>17	180	> 240	> 240
20	80	-9.0	+	3	37	> 240	> 240
30	70	-7.0	-	1	4	< 120	> 240
50	50	-2.5	-	< 1	< 2	< 10	< 120
90	10	+3.6	-	< 1	< 1	< 1	< 120

Table 1.7
Properties of Palm Olein (IV65) Blends with Safflower Oil

Palm Olein	Safflower Oil	Cloud Point (°C)	Cold Test	Days clear at:			
				5°C	10°C	15°C	20°C
0	100	-9.1	+	← Indefinite →			
10	90	-9.8	+	25	180	> 240	> 240
20	80	-8.0	+	74	180	> 240	> 240
30	70	-7.6	+	32	1	240	> 240
50	50	-4.7	-	< 1	< 2	18	> 240
90	10	+0.8	-	< 1	< 1	< 2	< 60

(7)

Cold stability tests of palm olein blends with canola oil (low erucic acid rapeseed oil) are given in Table 1.8

Table 1.8
Cold Stability of Palm Olein Blends with Canola Oil

Blend Ratio Palm Olein: Canola	Single Fractionated Olein IV56		Double Fractionated Olein IV60	
	Time Remaining Clear		Time Remaining Clear	
	at 10°C	at 20°C	at 10°C	at 20°C
100:0	< 1 hour	< 1 day	< 1 day	< 10 days
70:30	~ 3 hours	< 3 days	< 1 day	< 15 days
50:50	< 6 hours	< 6 days	< 5 days	> 3 months
30:70	1 day	Clear	< 20 days	> 3 months
0:100	Clear	Clear	Clear	Clear

Stability tests for blends of two industrial samples of palm olein with soya bean oil are given in Table 1.9.

Table 1.9
Cold Stability of Palm Olein Blends with Soya bean Oil

Blend Ratio Palm Olein: Soya bean Oil	Palm Olein IV60				Palm Olein IV65					
	Time remaining clear at:			Cold Test	Cloud Point (°C)	Days remaining clear at:			Cold Test	Cloud Point (°C)
	10°C	15°C	20°C			10°C	15°C	20°C		
10:90	> 120d	> 120d	> 120d	+	-7.1	> 120	120	> 120	+	-8.2
30:70	10d	> 35d	> 120d	-	-4.0	90	120	> 120	+	-5.2
50:50	< 2d	11d	74d	-	-1.3	3	34	> 120	-	-3.0
70:30	> 5h	> 5h	44d	-	-	1	13	> 120	-	-
100:0	> 5h	> 5h	7d	-	3.5	1	4	35	-	1.0

d = days, h = hours, AOCS = American Oil Chemists Society

(8)

The data in Tables 1.4 to 1.9 shows that, depending on the ambient temperature expected, a blend can be chosen that will remain clear.

Frying tests with palm olein blends are described in a later chapter. Some blends of palm olein with other oils are available on supermarket shelves in England.

Minor Components of Palm Oil

Tocols

Some of the minor components of palm oil are of particular interest in frying applications because of their antioxidant properties; in particular, the tocols, compounds of the vitamin E group. The tocol content of crude palm oil and refined products is given in Table 1.10.

Table 1.10
Tocol Content of Palm Oil

		α - Tocopherol (ppm)	α - Tocotrienol (ppm)	γ - Tocotrienol (ppm)	δ - Tocotrienol (ppm)	Total (ppm)
Crude Palm Oil	Mean (n=9)	162	165	324	81	774
	Range	136-241	90-205	273-439	67-94	635-890
Refined Palm Oil	Mean (n=3)	117	117	158	31	426
	Range	85-180	99-147	67-239	5-62	256-630
Refined Palm Olein	Mean (n=8)	141	152	218	49	561
	Range	107-163	131-177	113-293	28-68	478-673

n = number of samples analysed
(9)

Palm oil is unique among the common vegetable oils because it contains unsaturated tocotrienols. While they have a lower biological vitamin E activity than α -tocopherol, unsaturated tocotrienols have a somewhat greater antioxidant activity than the corresponding saturated compounds (see Chapter 4 on antioxidants in frying).

It should be noted that some tocols are lost during refining, mainly during the high temperature treatment in the deodoriser. Analyses from various refineries have shown that the extent of loss averages about 40%, depending on the processing conditions employed.

An important function of the tocols in palm oil is to protect the unsaturated fatty acid components of the oil from oxidation. It is, therefore, of interest to compare the ratio of tocol content to polyunsaturated fatty acids in the common vegetable oils (see Table 1.11).

Table 1.11
Tocol Content and Unsaturation of Some Refined Vegetable Oils

Oil	PUFA (%)	Tocol (mg/kg)	Ratio PUFA / Tocol
Palm Oil	10	498	50
Palm Olein	11	662	60
Rapeseed Oil	38	271	7
Soya bean Oil	60	1,162	19
Sunflower Oil	54	636	12
Groundnut Oil	22	331	15

PUFA = polyunsaturated fatty acids

Palm oil and palm olein have a markedly higher proportion of tocols in relation to the polyunsaturated fatty acid content than other oils. It is thought that this is an important factor in their exceptionally good resistance to oxidation at high temperature during frying.

Sterols

As with all vegetable oils, a mixture of sterols is found in crude palm oil, most of which are also found in the refined products.

The sterol composition of fifteen samples of crude palm oil obtained from different geographic origins was determined by Downes (Table 1.12). Six earlier publications gave figures in good agreement with the range in this table.

Table 1.12
Sterol Composition (%) of Crude Palm Oil

Sterol	Highest	Lowest	Average
β -Sitosterol	62.1	58.3	57.4
Campesterol	29.1	18.7	22.6
Stigmasterol	13.9	6.9	11.4
Cholesterol	5.4	2.2	3.8
δ^7 -Avenasterol	5.1	none detected	1.5
δ^5 -Avenasterol	2.8	none detected	1.8
δ^7 -Stigmasterol	2.4	0.2	1.0
Total sterols (ppm)	627	362	491

(11)

Gordon (12) found that avenasterols have antioxidant activity; at levels up to 50 ppm this activity is likely to be significant.

Hydrocarbons

The major hydrocarbon present in crude palm oil is squalene, at 200-500 ppm. Squalene is an aliphatic triterpene made up of six isoprene units with six isolated double bonds. It has been shown to have antioxidant properties (13). The types of non-terpenoid hydrocarbons present (total 30-50 ppm) are listed in Table 1.13. (14)

Table 1.13
Non-terpenoid Hydrocarbons Found in Crude Palm Oil

Hydrocarbon Type	Chain Length
n-Alkane	C ₁₂ H ₂₆ to C ₃₆ H ₇₄
n-Alkene	C ₁₂ H ₂₄ to C ₂₀ H ₄₀
Alkadiene	C ₁₅ H ₂₈ to C ₁₇ H ₃₂
Alkatriene	C ₁₈ H ₃₂ and C ₁₉ H ₃₄

Note: n-alkanes exclude C₁₄H₃₀, C₃₂H₆₆, C₃₄H₇₀ and C₃₅H₇₂

Ubiquinone

Crude palm oil contains 10-80 ppm of ubiquinone 10 and up to 5 ppm of ubiquinone 9. These compounds are related to vitamin K and have antioxidant properties. (15)

Phenolic Compounds

B.W. Audley (16) found a number of acidic and neutral phenolic compounds in crude palm oil, totalling about 100 ppm. Most of these compounds have antioxidant properties; and a major proportion of the compounds remain in the oil after refining. They are listed in Table 1.14.

Table 1.14
Phenolic Compounds Found in Crude Palm Oil

Acids	Alcohols	Aldehydes
P-Hydroxy benzoic	P-Hydroxybenzoyl	P-Hydroxybenzaldehyde
Vanillic	Vanillyl	Vanillin
Syringic	Syringyl	Syringaldehyde
P-Coumaric	P-Coumaryl	Coniferaldehyde
Ferulic	Caffeyl	Sinapaldehyde
	Coniferyl	

Carotenoids and Red Palm Oil

Unrefined palm oil has a very high content of carotenoids, the precursors of vitamin A. The main compounds present are β - and α -carotene, in addition to a number of minor components. The carotenoid compounds are removed during refining. However, by using mild refining technique, or alternatively, by de-acidifying using short path distillation in a molecular still, refined palm oil can be obtained; which retains most of its carotenoid content. This oil is used in some frying applications.

The carotenoids have antioxidant properties by virtue of their activity as singlet oxygen quenchers.

The carotenoid content of red palm oil and crude palm oil is shown in Table 1.15.

Table 1.15
Carotenoid Composition (%) of Deacidified and Deodorised Red Palm Oil and Crude Palm Oil

Carotene	Red Palm Oil	Crude Palm Oil
Phytoene	2.0	1.3
Phytofluene	1.2	0.1
Cis- β -carotene	0.8	0.7
β -Carotene	47.4	56.0
α -carotene	37.0	35.1
Cis- α -carotene	6.9	2.5
ξ -carotene	1.3	0.7
γ -carotene	0.5	0.3
σ -carotene	0.6	0.8
Neurosporene	Trace	0.3
β -zeacarotene	0.5	0.7
α -zeacarotene	0.3	0.2
Lycopene	1.5	1.3
Total (ppm)	550	670

(17)

Summary

Palm oil has an unusually complex mixture of components with antioxidant properties, and the chemical reactions involved in oxidation are also complex. The various antioxidant components act on different parts of the oxidation reactions chain, and some are effective at high temperature. Later chapters contain evidence of the superior properties of palm oil products in this respect.

The compositional factors of palm oil that contribute to its good behaviour may be listed as follows:

1. moderate content of linoleic acid and negligible content of the easily oxidised linolenic acid;
2. high content of the natural antioxidants of the tocol group; and
3. contributory antioxidant activity from a number of the other minor components.

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Good Practice In Frying

It has often been said that the cooking of food was one of the first steps in the evolution of civilised man. It certainly enabled early man to render a wide variety of natural products digestible, and create new flavours and textures to make food not merely nutritious but also enjoyable.

Four basic traditional methods of cooking can be distinguished:

- a. Direct exposure of food to the heat of fire – roasting
- b. Exposure of food to hot air – oven baking
- c. Heating the food in water – poaching or boiling
- d. Heating the food in fat – frying

It is useful to compare frying with other cooking processes listed above. The temperature of boiling water is normally at 100°C equivalent to 212°F. It is somewhat lower at high altitudes and a few degrees higher when there are dissolved substances such as sugar in the water. Thus, boiling raises the food uniformly to 100°C.

In baking or roasting, the outside of the food becomes appreciably hotter than the inside depending on the oven temperature. As a result, the food develops a crusty brown surface layer with attractive texture and flavour. The centre of the food however is no hotter than 100°C or so due to the water in its composition.

The same is true in frying; but there are big differences in the efficiency of heat transfer. Air is not a good conductor of heat, and therefore oven cooking is slow; although where there is direct flame or a hot surface, radiation plays an additional useful part in heating the food. Liquids are much more effective in transferring heat, and frying is more effective than boiling because fat is at a much higher temperature. Different temperatures are required for various foods and some recommendations are given in Table 2.1.

Table 2.1
Usual Frying Temperatures for Some Foods

Food Item	Recommended Temperature
Potatoes – French fries: blanching	165°C
Potatoes – French fries: finishing	185°C
Potato crisps	170-175°C
Doughnuts	185°C
Chicken - large pieces	165°C
Chicken - small pieces	175°C
Meat cutlets	165-170°C
Instant noodles	130°C
Extruded pellets for expansion	185-205°C

French fries for restaurant trade and supermarket frozen food cabinet are prepared and blanched industrially in large continuous fryers, frozen for storage and transport, and later finished off in a short second frying.

For most products the range 175-185°C is satisfactory. Large pieces, such as chicken require a somewhat lower temperature and longer time to ensure adequate cooking at the centre.

At frying temperature, complex chemical changes take place. Initially, these changes create desirable flavours, cause the gelatinisation of starch, the denaturation of proteins, and some changes in the oil. In other words, the food becomes cooked. However, if the temperature or cooking time is not controlled, too much “chemistry” occurs and the food is spoilt. The principles involved in getting good results in frying are discussed in this chapter.

The three main methods of frying are shallow pan frying, deep frying in batch fryers and deep frying in continuous fryers.

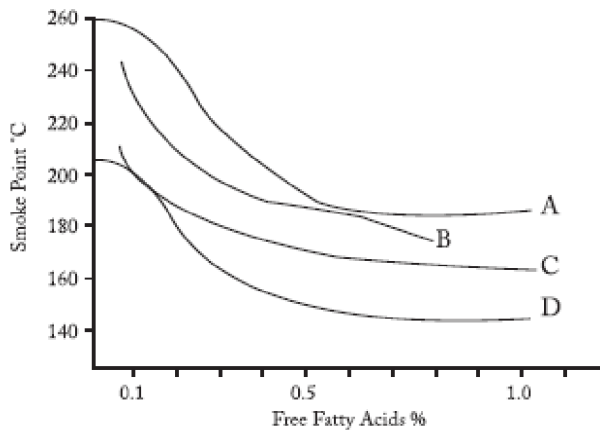
Shallow Pan Frying

In essence, shallow pan frying is a very simple process - a little oil is heated in the pan, and when it is hot enough, the food is added. Where appropriate the food item is turned over when the underside has browned.

For some foods, such as fried egg, it is easy to see when it is sufficiently cooked. For other foods, the cook must rely on experience to make the judgement. At the end of cooking most of the oil would be absorbed into the food, the residue is discarded and the pan is washed. The food is usually intended for immediate consumption and therefore, provided the oil is not rancid when used, its keeping properties are unimportant.

There is one major difficulty in this simple process; that is the judgement of the correct oil temperature. As shown in Table 2.1, for most foods temperature of 170-180°C is optimal, but the domestic cook has no means of measuring this. One suggestion is to heat the oil until it starts to smoke. However, the smoke point of oil is dependent on its content of some minor components especially the free fatty acids. The effect of free fatty acids on smoke point is shown in Figure 2.1.

Figure 2.1
The Effect of Free Fatty Acids on Smoke Point



Curves A (1), C (2) and D (1) were obtained by adding quantities of fatty acids to the oil: for curve A, soya bean oil and for curve D, babassu oil. The latter is a lauric oil with a high proportion of short chain fatty acids and in consequence a low smoke point.

Curve B (3) was obtained with used frying oils and demonstrates that volatile decomposition products other than fatty acids also contribute to the smoke point.

A useful recommendation to enable a cook to judge the temperature is to test the oil by putting in a small cube of bread. If no bubbles are formed, the oil is not hot enough. Vigorous bubbling indicates it is too hot.

Frying is a short process and requires constant attention. A call to the telephone or the front door can easily result in overheating, spoiling of the food, or worse, fire. It is best to take the pan off the heat if an interruption is inevitable. It is also important that the food should not be too wet when put into the pan: excessive splashing can occur, and risks setting the pan on fire. Accidents with the frying pan are a significant cause of domestic fires.

Deep Frying

Equipment

Many details of design have an effect on the quality of the frying oil, the fried product and the economy of the operation. This section lists the desirable design and construction features of the various components of the equipment for deep frying.

Batch Process

A typical batch fryer consists of a square or rectangular pan, holding 5-20 kg of oil and fitted with a basket. It has electrical heating elements at the bottom; or for heating by gas or oil, it may be fitted with tubes through which direct flames are passed, or be heated by direct flames on the base.

Some important designs and selection considerations may be listed.

1. The fryer should be made of stainless steel. No part of equipment should contain copper, brass or other copper alloy parts; since copper is a catalyst for oxidation at very low concentrations.
2. The size of the fryer should be chosen in relation to the expected throughput. It is not desirable to have a large volume of oil being kept hot for a relatively small quantity of food to be fried. There should be a minimum amount of "dead space" in the fryer. Restaurants usually experience a peak demand period of say 1½-2 hours, with intermittent or occasional demand at other times. Oil deterioration is greatest during the slack periods and may severely reduce the time before oil must be discarded. In practice therefore, it is worth

considering the provision of two or more small fryers, which together have a capacity to meet peak demand. During slack periods only one fryer needs to be kept ready for use.

3. A good design feature provides a cool zone below the heating element, where food debris can collect and be removed.
4. The fryer should be fitted with an exhaust hood and an extraction fan to remove fumes. It is desirable to have a filter to trap odours, solids and condensate from the fumes. The hood and trunking must be designed so that condensate cannot drip back into the frying oil.
5. There should be a temperature controlled heating system. Heating may be direct; such as gas or oil fired, or indirect by electric heating elements. Indirect heating is much preferred, and it has been proved in controlled experiments (H, Zeddelman 1979) that direct heating causes much more rapid deterioration of the frying oil. This is because the flames cause hot spots on the pan, which can reach 400°C, at which temperature oil decomposes very rapidly. The electric element on the other hand will have a much more even and lower surface temperature of 220–250°C. It was also shown that a larger surface area heating element with a low heat input per unit area (2 W/cm²) is less damaging than a smaller element (providing 10 W/cm²) with the same total heat input.

The temperature control system needs to be carefully designed.

- a. Different temperature settings are required for different foods. An accuracy of $\pm 2^\circ\text{C}$ is needed.
- b. When a batch of cold raw food is placed in the fryer, the oil temperature drops rapidly. The heat input needs to be high to recover the correct frying temperature quickly. However, there should be no tendency to overshoot the frying temperature.

The reliability of the thermostats in batch fryers should be frequently checked, preferably daily. Evidence of temperature variability has been reported for fryers in regular use in 21 industrial canteens. They were all adjusted to 180°C, but 50% were found to exceed, at times, the desirable maximum of 200°C. Temperatures ranging from 140°C to 240°C were found (4).

6. The fryer should be fitted with an indicating thermometer.
7. Batch fryers should be provided with a well-fitting lid to be placed over the oil when not in use.
8. Fryers should be designed so that the oil can be conveniently drained off and passed through a fine stainless steel mesh filter.
9. Pressure fryers are particularly useful for products in relatively large pieces, such as fried chicken. The fryer is fitted with a pressure tight locking lid and a safety valve so that during frying a pressure of 1 kg/cm² builds up. It is claimed that contact between the food and the frying oil is improved, resulting in better heat transfer and more rapid cooking. Fat absorption is also reduced.
10. Specialised designs are available for specific foods:

French fries can be fried in deep baskets, while seafood, chicken pieces or meat patties need to be kept separate in shallow baskets. Frying under vacuum has found some applications for high moisture foods. For example (5), carrot slices are dehydrated to 2.9% moisture by frying for 4 minutes at 125°C with a vacuum of 20 torr. Water activity is reduced to 0.21. At the low frying temperature oil deterioration is much reduced.

Continuous Fryers

The production of fried snack food and convenience food on a manufacturing scale requires continuous fryers. Essentially they are shallow rectangular baths of hot oil, through which the food product is conveyed on a continuous mesh stainless steel band or by a series of paddles. The size of a fryer and band speed are chosen depending on the production volume and the cooking time required. Special design features are incorporated for specific products: for example, a turnover system for doughnuts and a submerger belt to hold down products and ensure complete cooking.

The main design features listed for batch fryers are also required in a suitably adapted form for continuous fryers.

Heating is often provided by indirect means. Oil is circulated by a pump through an external heat exchanger where it is heated by a thermal fluid, which is usually heated by direct gas or oil burners. This method enables very good control of temperature to be achieved, and the frying oil does not come in contact with very hot surfaces. It is necessary to fit a filter in the circulation system so that debris is in effect continuously removed. A second filter is fitted on a bypass line, which is used when the first filter needs cleaning. The amount of debris remaining in the oil is particularly high when products coated in batter or breadcrumbs are being fried. It may be necessary to have a separate conveyor to remove the debris. If debris remains in the oil it will cause rapid darkening and the adherence of burnt particles to the product is unsightly.

It is important to avoid aeration of the hot oil during circulation and filtering. Blanketing of the oil storage tank and sparging of the pump lines with nitrogen is advisable.

Pumps and pipeline joints should be checked frequently for leaks, and the return line to the fryer should discharge below the oil surface.

During production, a continuous fryer will use more than one tonne of oil per day and this is usually provided by a continuous oil make-up system actuated by a constant level device.

The efficient removal of fumes is essential and it may be necessary to scrub or filter the fumes before discharge to atmosphere in order to minimise pollution. The ventilation system should be designed so that large amounts of air are not drawn across the surface of the oil, since this causes excessive cooling and promotes oxidation. A good effect can be obtained by fitting a baffle above the oil surface. This causes a blanket of steam to be held over the surface of the oil, and by largely preventing access of air, oil oxidation is significantly reduced. This effect can be enhanced during operation by spraying fine water mist over the oil surface. Fumes are removed at the ends of the fryer.

The design should maximise throughput so that a high turnover of frying oil is achieved. The importance of this factor is dealt with later.

High turnover is achieved by utilising the surface area fully and by reducing oil volume as much as possible. A lower limit to the oil level is set by the need to cover the conveyor. Dead space at the side of the conveyor for gear wheels etc. should be minimised, as should the oil volume in the circulation and filtering system.

Frying Operations

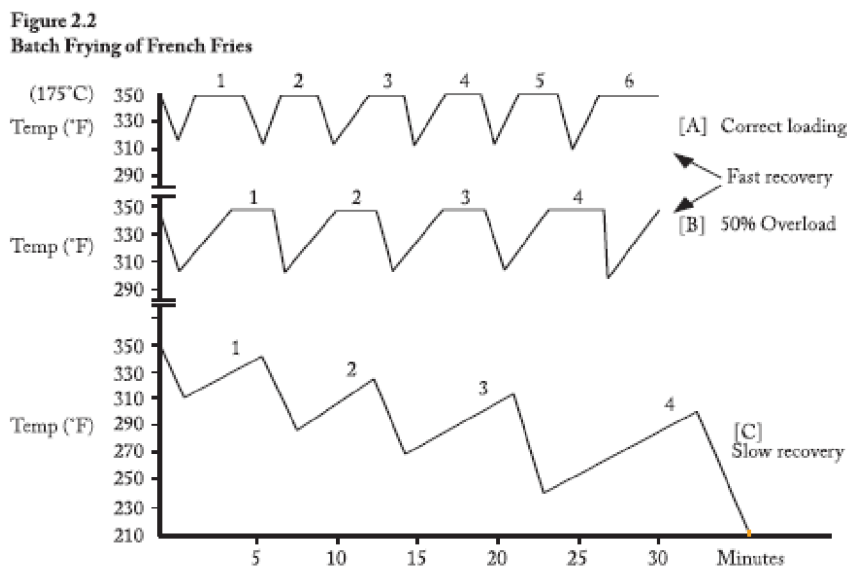
Whatever the scale of operation, the quality of a fried product depends on adequate control of the frying operation. The various aspects requiring attention are listed below:

a. Loading

Oil is undergoing chemical changes all the time that it is at a high temperature. These changes will be discussed in a later section. From an operational point of view, oil should not, as far as possible, be kept hot unless it is being used. For a batch process, the correct proportion of food to oil should not be exceeded. In general, the maximum recommended ratio is about one part food to six parts oil.

When food is put into the pan, the temperature drops rapidly. The drop in temperature depends not only on the food amount put in, but also on the amount of water to be removed from the product during cooking. Potato crisps enter the frying pan with a high moisture content of 85% and leave with only 1-2% moisture. The heat should not drop too low or the time to recover to the right temperature for the next batch will be too long. Therefore, the amount of food per batch should be limited.

The importance of loading is illustrated from the following experience in the frying of French fries in a restaurant (6). Figure 2.2 shows the temperature-time relationship in a batch fryer under different rates of loading.



Graph A is the position in a well-designed batch fryer with fast temperature recovery, when the correct amount of potatoes was fried. Graph B shows the effect in the same fryer, when a 50% larger batch was fried. More heat was taken out of the oil at the start of frying, the temperature took longer to recover and the batch then took longer to complete cooking. As a result, after one and a half hours in case A, six full batches were cooked as compared with four to five batches in case B.

The process described under condition B, and even worse, condition C is not only inefficient, the quality of the food is affected. Frying at too low a temperature results in excessive absorption of oil, and a product that is greasy, soggy and lacking in attractive flavour due to inadequate surface browning.

Graph C shows the situation when a fryer with inadequate heating was used. Temperature recovery was inadequate and the conditions became progressively worse until frying had to be stopped.

In a continuous fryer the unsatisfactory conditions illustrated in Figure 2.2 should never arise since the equipment has been selected in terms of size and heat input to deal with a known volume of food product; so that during normal production a steady state temperature profile is attained. However, disruptions to normal production also have serious consequences on product quality, as will be seen later.

b. Turnover

As indicated earlier, in order to maintain good oil quality it is necessary that there should be a high rate of turnover of the oil in the fryer. The basic argument will be restated here.

1. The high temperatures used for frying cause some chemical changes in the oil.
2. If the oil is merely being kept hot without use, deterioration would be progressive and the oil would soon be spoilt.
3. During frying, oil is absorbed by the food and is removed with the cooked product.
4. In order to maintain the oil level in the fryer, fresh oil is added at frequent intervals or, in some designs, in a continuous trickle. This fresh, unchanged oil mixes with the oil in the fryer and improves its condition.

If the rate of oil removal and replacement is high enough, the oil condition in the fryer remains good and the oil does not need to be discarded.

The results in Table 2.2, taken from a study by Lakshminarayana, (7) illustrate the point. He studied an industrial scale fryer in which 2.5 tonnes of groundnut oil was being used to fry "Sev", a product made from Bengal gram dhal dough.

Table 2.2
The Effect of Oil Turnover in a Continuous Fryer

Slow Oil Turnover		Fast Oil Turnover	
Frying Time (hour)	Free Fatty Acids (%)	Frying Time (hour)	Free Fatty Acids (%)
0	0.5	0	0.6
8	0.6	-	-
25	1.1	65	0.8
33	1.3	-	-
50	2.0	156	0.7
58	2.3	-	-
75	3.2	178	0.8
83	3.5	-	-
-	-	367	0.7
-	-	500	0.8

With slow turnover there was a continuous increase in free fatty acids and also in other measures of deterioration. With fast turnover equilibrium was achieved at a level at which the oil in the fryer remained satisfactory for continuous use. In these tests, the charge of oil (2.5 tonnes) was replaced in 13 hour (slow) and 8 hour (fast), respectively. As a general rule of thumb, one should aim to turn over the charge in a fryer within 6-10 hours.

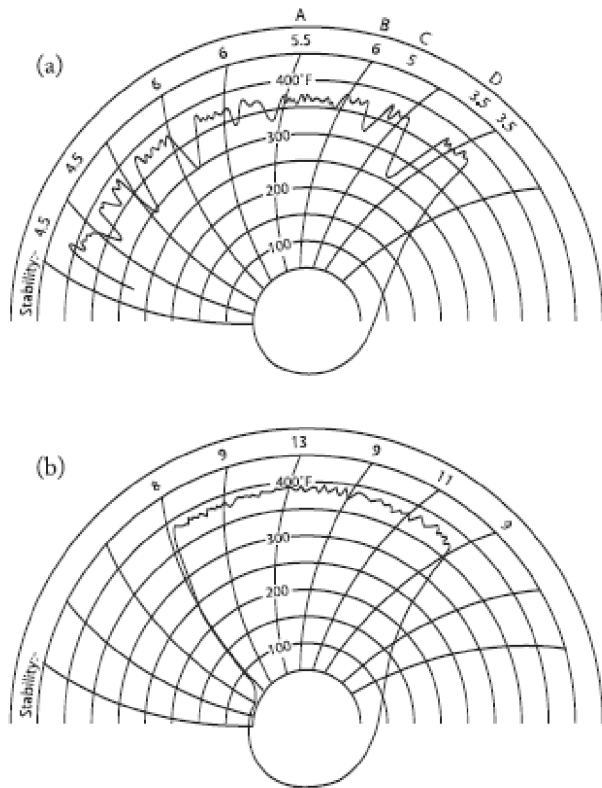
The turnover rate will be influenced by the type of food product and the fryer design.

When producing snack foods such as potato crisps that are required to have a shelf life after packaging, a continuity of fryer operation and sufficient oil turnover are of vital importance. The effect of interruptions in production on the stability of the frying oil, and hence the shelf life of the product, is illustrated in the following experience obtained in the development phase of a starch-based fried snack food (8).

Samples for storage tests were prepared in a batch fryer using groundnut oil. Although fresh oil was used each day, variable and often unsatisfactory keepability of product was experienced. The problem was investigated by installing a recording thermograph and drawing samples of oil and product at intervals. The frying oil was tested for its oxidative stability in an accelerated test at 100°C: thermograph charts are shown in Figure 2.3.

Figure 2.3
Thermograph Charts from Batch Fryer

(a) discontinuous operation, (b) continuous operation



In chart (a), each dip in the temperature recorded was caused by reduction in heat input to the fryer during a short interruption in production. This was due to a variety of reasons, such as interruption in the supply of raw food and rest breaks for the operator. Samples of oil were drawn at intervals for analysis and the results of the accelerated stability test in hours are shown around the outside of the chart.

Oil sampled immediately after a break in production showed a loss of stability, e.g. at points A, C and D, whereas a longer period of continuity between A and B actually resulted in an increase in stability, showing that, potentially, the rate of turnover could be satisfactory. This is demonstrated in chart (b), when arrangements were made for a second operator to take over whenever a break was required, so that operation was truly continuous: a higher level of quality was maintained consistently.

In a manufacturing operation, very large amounts of oil are being kept hot in the continuous fryer, and interruptions in production of any length have major consequences on product quality due to oil deterioration. Breakdown in the flow of uncooked product, the downstream operations such as flavour application (for potato crisps), the packing machinery, or the mechanical parts of the fryer can cause significant stoppages. Decisions may need to be made about cooling down the oil, and analytical services should be available to determine levels of change in the oil after a longer stoppage. In continuous operation, the turnover rate and consequently the addition of fresh oil, is usually sufficiently high to maintain a satisfactory level of quality, as shown in Table 2.2. The loss of oil quality consequent to a stoppage may require the replacement of a portion, or even all of the fryer contents, with serious implications on the economy of the process.

In a paper at a recent international conference E. Hammond (9) described the quality control adopted in a large potato crisp manufacturing plant using palm olein. A high specification was set for the fresh olein, as shown below:

Free fatty acids	max 0.1%
Peroxide value	1.0 meq/kg
Total tocols	min 800 mg/kg
Anisidine value	max 3 (usual value below 1)

Oil quality during operation was monitored by total tocol determination and anisidine values. Figures 2.4 and 2.5 show the results for total tocol and anisidine values in two operating situations. In Figure 2.4, operation was not well controlled. The fryer was brought up to temperatures some hours before frying began, resulting in a loss of tocols. Interruptions in production occurred at about 16 hours and again at 45 hours. In both cases there was a loss in tocols and a rise in anisidine values. When frying continued and fresh make-up oil was added, these parameters improved, but by the end of the week the tocol level was low. Figure 2.5, with no interruption in production, shows that a steady state was attained half way through the week, with a satisfactory tocol level.

Peroxide value and free fatty acids were also monitored, but proved less useful. Peroxides were rapidly destroyed at frying temperatures and remained at a low value, while free fatty acids showed little change.

After 12 weeks of continuous operation the tocol content of the oil in the fryer was 450-500 ppm, and product flavour was very good.

Figure 2.4
Fryer Not Well Controlled

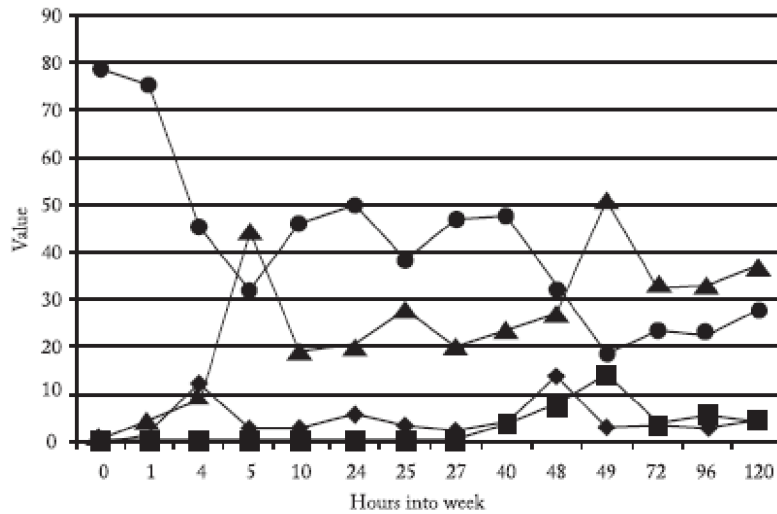
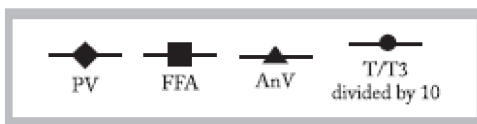
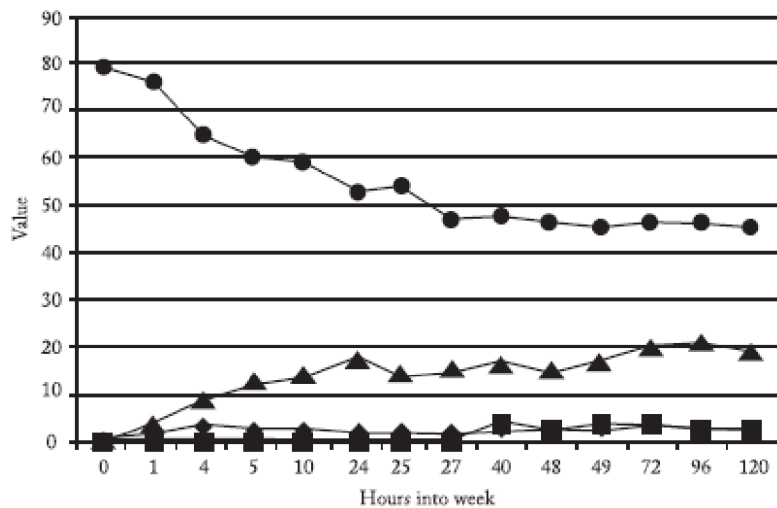


Figure 2.5
Fryer Well Controlled



Good design of a fryer can assist oil turnover, for example, by minimising dead volume in pipelines and the space required by the conveyor mechanism. Turnover is largely a factor of the amount of oil absorbed and removed by the food product. It is generally considered that for good oil quality a turnover rate of 5-10 hours is satisfactory. Turnover can be calculated according to the formula:

$$\frac{\text{Weight of oil in product*}}{\% \text{ oil in product*}} \times \frac{\text{oil production}}{\text{in per hour}} = \text{fryer}$$

* Some products, such as doughnuts, use shortening in the preparation of the dough, and this must be allowed for. Alternatively, the amount of oil used over a period of time can be measured directly, and related to the volume of oil in the fryer.

c. Maintenance

The following recommendations are generally applicable, but may need modification in particular conditions.

Maintenance of Batch Fryers

Starting Up

1. Put back the oil from the previous day if still in good condition. If it has solidified overnight, make sure the heating elements are well covered before switching on.
2. Start heat slowly if possible.
3. When the oil is near frying temperature top up to correct level with fresh oil.

During Frying

1. Check frying temperature.
2. Use a fine mesh skimming filter to remove floating debris.
3. Maintain level of frying oil by frequent additions of small quantities of fresh oil. The fryer should have a level marked on it.
4. During slack periods keep only one fryer hot and reduce its temperature to 150°C (300°F) until needed for use. Cover the oil.

At the End of the Day's Operations

1. Use a reliable thermometer to check the frying temperature and the operation of the thermostat.
2. Turn off the heat and allow oil to cool somewhat.
3. Remove oil from fryer and pour through a filter into a clean container. Many fryers are provided with built-in filters and storage containers.
4. Discard the food particles on the filter. Cover the oil container and leave overnight.
5. Examine the oil to decide if it needs to be replaced. (A detailed description of testing methods is given in a later section.)
6. Inspect the inside of the fryer and the heating element. Clean if necessary.
7. Clean frying baskets, skimmers, and draining racks.
8. Clean outside of fryer: adhering dirt presents a fire hazard.
9. Inspect the hood and air filter and clean if necessary.

Weekly Cleaning

1. Boil out the fryer with an alkaline detergent.
2. Remove any loose debris.
3. Rinse thoroughly three times to remove all traces of detergent.
4. Ensure that fryer is dry before replacing oil.

Maintenance of Continuous Fryers

While the above principles apply, filtration and level control are usually automatic. The surface area of hot oil is very large and therefore any periods during which oil is hot, but not being fried in, will cause significant deterioration of oil. Therefore, everything should be done to ensure a steady supply of product to be fried, and an efficient finishing and packing operation.

At the end of a day's operation the oil should be pumped through a filtering system into a holding tank. It is very desirable to incorporate a heat exchanger so that the oil can be brought down to 50°C before storage. The holding tank is preferably tall and narrow so that the exposed surface area is minimal.

For continuous fryers it is necessary to check the temperature at least daily during operation, and checks should be made at both inlet and outlet ends. If thermograph records are provided they should be stored by the quality control personnel and used to interpret variations in oil or product quality. Any undue variations require detailed investigation.

Cleaning

Thorough cleaning should be carried out every 50-100 hour of use. The following instructions have been used successfully by a large food manufacturer over a period of years.

1. Empty all the frying oil from the fryer.
2. Remove detachable fittings from the frying tank and clean them by boiling in approximately 2% detergent solution in a tank provided for this purpose, and then rinsing with clean water.
3. Fill fryer with hot water and detergent powder to make approximately 2% solution.
4. Heat the resulting solution to boiling and boil gently for at least 30 minutes.
5. After half this boiling period move the conveyor sufficiently to immerse the paddles that have so far been out of the solution.
6. During the boiling period swab the surface above the liquid level with the boiling solution using a long handled mop. This will soften carbonised deposits, which can then be removed by scraping.
7. Discontinue heating and run the contents of the fryer to waste.
8. Rinse with hot water from a hose until all the debris has been washed out, using scrapers, if necessary, to assist the removal of any adhering deposits.
9. Run hot water into the tank to the same level as before.
10. Add 1 lb. of citric acid, distributing it evenly over the area of tank.
11. Heat the resulting solution to boiling.
12. Discontinue heating, run the conveyor for 5 minutes, and then run the contents of the fryer to waste.
13. Rinse thoroughly with hot water from a hose.
14. Refit the detachable fittings.
15. Ensure that no water is left in the fryer before refilling with oil.

Note: The detergent used was a proprietary alkaline detergent based on sodium metasilicate. The concentration used should be according to the supplier's recommendation.

Specifications for Frying Oil

The initial quality of frying oil is an important factor in its performance in use.

In preparing oil specifications it is desirable not to be too restrictive; since a severely limited choice often forces up the price. The following guidelines are specifically relevant to frying.

1. Free fatty acids should be below 0.1%. They have a direct lowering effect on smoke point and at frying temperature increase the rate of formation of more free fatty acids.
2. Odour and flavour - bland, free of rancidity or foreign flavours.
3. Smoke point – above 215°C, preferably above 220°C.
4. Peroxide value – preferably below 1 meq/kg.
5. Composition - Linolenic acid should be less than 1%. Short chain acids C12 and below less than 1% and preferably below 0.25%.
6. Melting point – for solid fat normally a maximum of 40°C is desirable. For some products liquid oil is preferred. For doughnuts, fat that crystallises is needed in order for the sugar or sugar glaze to adhere to the surface: if they are packaged before sale, liquid oil would stain the carton. Palm oil has proved to be satisfactory solid fat in long term use for doughnuts.
7. Additives – the addition of 2 ppm silicone oil is wholly beneficial, particularly for batch frying operations (but should be avoided for doughnuts). As is the normal practice, refined oils should be specified to be treated with citric acid at the end of the refining process. The addition of antioxidants is mainly useful when snack foods with an extended shelf life are being made. It must, in any case, conform to the local legal requirements.
8. Heating test – useful information can be obtained from an empirical heating test. Heating for a standard time in a standard container enables judgement to be made whether there is an undue change in characteristic such as viscosity, smoke point, free fatty acids, odour or colour, which could give a problem during actual use. The conditions of test and acceptable parameters would have to be determined in relation to the actual use intended.
9. Phosphorus – below 3 ppm, preferably below 1 ppm. The following table gives suggested quality limits for frying oil.

Table 2.3
Suggested Published Quality Limits for Frying Oil

	(10)	(11)
Peroxide value (meq/kg)	0.4 max	1.0 max
Linolenic acid (%)	3 max	2 max
Colour (Lovibond Red in 5¼" cell)	2 max	Light
Free fatty acids (%)	0.1 max	0.1 max
Flash point (°C)	315	-
Smoke point (°C)	200	220
Moisture (%)	0.05 max	0.1 max
Taste	-	Bland
Melting point (°C)	-	According to application

Quality Control of Frying

The various aspects of good management of a deep frying operation have already been discussed. The important question that remains is how to judge whether deterioration of the frying oil has reached the point at which it needs to be discarded. A number of surveys have been published which show that oil quality in a significant proportion of restaurants and fast food outlets is seriously deteriorated because suitable control procedures are not in use.

Quality Control of Batch Fryers

Stevenson et al. (12) listed the tests available where there are no laboratory facilities, as follows:

- a. Colour
- b. Foaming
- c. Smoking
- d. Odour of frying oil
- e. Length of time used
- f. Sensory evaluation of product

The last item is the most important, and management should lay down clear criteria for product quality to be used by an operative or his immediate supervisor. Colour and odour of the frying oil need to be judged in the light of the particular operation. The length of time used is, in the author's opinion, not useful. As seen earlier, if the oil is kept hot during slack periods, its deterioration will be much greater than if it is fully utilised over the same time period.

The measurement of colour can be useful. In the author's experience of deep frying in a chain of restaurants, the chef's normal practice was to discard oil after a routine period of use, which varied from one kitchen to another. As an experiment, a simple colour comparator was issued to ten restaurants, with a standard colour selected by the management as the point of discard. At the end of one month's usage there was a significant overall saving in oil consumption. This approach is however limited since different frying oils will not necessarily darken at the same rate.

Excessive foaming or smoking of the oil presents a fire hazard. Persistent foam is caused by high levels of polar glycerides, particularly the higher polymers (13), while smoking is due to the presence of free fatty acids and other low molecular weight breakdown products.

At a 1988 conference on frying, Evans (14) gave a list of suitable tests where a back-up laboratory was available. Evans listed the following as being possibly the most widely used and reliable quality indicators:

- a. Colour
- b. Free fatty acids
- c. Total polar materials
- d. Polymeric triglycerides
- e. Ultra violet absorption (for conjugated dienes)

In view of the complex changes that occur it is best to rely on more than one test. In the case of fast food operations where the same products are made in many outlets, it is desirable to correlate the chosen laboratory tests with taste panel tests to define the reject point.

A significant level of free fatty acids may be present in unrefined oil such as olive oil or beef fat before use and increases due to hydrolysis and, to some extent, formation of acidic oxidation products. However, poor correlation of free fatty acids with total polar materials and with polymers has been reported (15).

Total polar materials (TPM) are of major importance because a limit of 24-25% has been adopted officially in a number of countries ((14) and see Chapter 3). The test for total polar materials presents a problem of interpretation in the case of palm oil products. Palm oil and palm olein naturally contains higher diglyceride content than other oils. Typically 6-8% is formed in palm oil and palm olein, when other oils contain only 2-3% or less. Diglyceride oils are measured as polar materials, and the total polar materials analysis for fried-in palm oil therefore has a significant component that is not due to deterioration of the oil. Allowance should be made for this in interpreting the results. However, this point is sometimes ignored, and consequently leads to unfavourable interpretation of the results, for example in the review by Melton (16).

This difficulty is acknowledged by Sebedio et al. (17) who suggested that a determination of the polymer content of used oil would be more reliable.

More recently, Shimizu et al. (18) compared the frying performance of diacylglycerol and triacylglycerol oils. 5-mm thick potato slices were fried in a batch fryer, 8 batches per hour for 8 hours at an average temperature of 170°C. Measurement of a number of parameters on the used oils showed little difference. However, the total polar materials test on unused diglyceride oil gave a result of over 80%, rising to 90% after use for 8 hours. Not surprisingly, the total polar materials test was considered to be unsuitable for use on diglyceride oils.

It will be seen that in many of the comparisons reviewed in Chapter 5, palm olein or palm oil develops lower total polar materials during frying despite the higher starting point.

The analysis for total polar materials has been widely used. In a review of quality procedures for used frying oils, Paul and Mittal (19) recommended that regulations should contain a limit of 24% for total polar materials.

Sampling carried out by Dobarganes and Marquez-Ruiz (20) showed that total polar materials exceeded the recommended limit in a high proportion of batch fryers examined, as summarised in Table 2.4.

Table 2.4
Total Polar Materials of Used Frying Oils

	Batch Fryers		Continuous Fryers
	Domestic	Restaurants etc.	
No. of samples	72	190	82
TPM% range	10.5-42.1	3.1-61.4	4.2-27.3
No. of samples with TPM > 25%	24 (33%)	69 (36%)	3 (3.6%)

Note: In the continuous fryers producing potato products, doughnuts or fried fish, the turnover rate was generally sufficient to maintain a steady state value of total polar materials below 25%.

A number of other surveys of batch fryers have been reported, and the results are summarised in Table 2.5 below.

Table 2.5
Quality of Frying Oils in Restaurants

Country	Number of Samples	% with Total Polar Materials > 25%	
Scandinavia	100	38.0	(20)
Germany	125	35.2	(20)
France	31	48.4	(20)
Spain	174	34.5	(20)
Not Specified	20	60.0	(20)
Chile	77	20.0	(21)
Spain	19	58.0	(22)

Clearly, a substantial proportion of actual restaurant frying was carried out with oils in a condition beyond the discard point.

The study by Soriano (22) was carried out in university canteens. After training of staff and the implementation of an HACCP system, a second survey found no results higher than 23% total polar materials. The training was based on the following list of ten items:

1. Good personal hygiene is necessary.
2. Oil must be properly stored and correctly documented upon receipt.
3. Frying must be done adequately.
4. Oil must be filtered.
5. General cleanup of the fryer, baskets, hood and oil filters is essential.
6. The rate of frying and turnover rate of oil must be done correctly.
7. Capacity and use of equipment and utensils must be correct.
8. Food should be immersed in the oil after it has reached a temperature of about 180°C.
9. Fresh oil should never be added to used oil.
10. Excess oil must be eliminated from the food by draining it immediately after frying.

It is unclear what is intended in item 9, since during frying it is highly desirable to use fresh oil to top up the volume of oil in use. Apart from this however, the above action list is comprehensive, and was evidently a sound basis for improvement. The experience suggests that apart from defects in equipment such as thermostats, inexperience of operators and lack of training may be the general causes of the high proportion of unsatisfactory results revealed in the surveys.

Measurement of polymeric triglycerides has also received some official acceptance, with limits of 10-12%.

Some other laboratory tests have been used to characterise frying oils and are worth mentioning.

The peroxide value is a useful measure of fresh oil quality. On heating of the frying oil, the peroxide value rises, but the peroxides are rapidly decomposed at high temperature. The value obtained in the laboratory on used oil most probably reflects the oxidation occurring between sampling and analysis.

The anisidine value is given by involatile oxidation products of glycerides and can therefore be a useful measure of oil abuse. Tompkins (23) found that the anisidine value showed good correlation with the polymer content of used oils, as well as with various odorous aldehydes.

The iodine value of used oil is a direct measure of the loss of unsaturated bonds resulting from chemical changes.

The viscosity increases due to the formation of larger molecules through polymerisation.

The dielectric constant is strongly influenced by the formation of polar materials.

The two latter physical measurements are the basis of instruments designed to measure frying oil quality.

The measurement of petroleum insoluble oxidised fatty acids was the basis of a limit for rejection of used oil proposed by the German Society for Fat Research (DGF) at a level of 1% of oxidised acids. It is however a time consuming laboratory method. Good correlations of oxidised fatty acids with total polar materials were obtained by Billek et al. (24). Total polar materials were measured by

column chromatography on silica gel. Oxidised fatty acids also correlated well with polymeric triglycerides measured by gel permeation chromatography. The results were obtained from a large number of samples taken from snack food bars. 1% of oxidised fatty acids (the limit proposed) corresponded to 15% of polymer triglycerides and 28% of total polar materials. The oils in use were palm oil, hardened soya bean oil (iodine value 100), soya bean oil or a blend of groundnut, hardened soya bean and cottonseed oils. It is noteworthy that all the palm oil analyses were within the specified limits whereas a few of each of the other oils fell outside. This is a clear indication that palm oil proved the most robust under the severe service conditions of use in snack bars.

There is clearly a need for a soundly based measuring tool that can be used by kitchen staff to determine the rejection point for used oil, and several are available.

A number of rapid test kits have been described for measuring the quality of used frying oil, based either on chemical or on physical measurements.

Chemical Measurements

Mlinar (25) described test strips which can be dipped into the hot oil. The test strips are divided into four zones which change colour successively from blue to yellow with increasing content of free fatty acids. Attempts to correlate free fatty acids with the quality of the fried product have indicated limits between 1% and 5% for different systems, but no general limit can be laid down.

The Fri Test is a colourimetric test kit involving mixing reagents with the sample. It responds to carbonyl compounds, with the colour changing from yellow to brown.

The Rau or Oxifrit Test uses the colour change of redox indicators due to oxidised compounds in the oil; and uses an inflammable solvent.

A test for "Alkaline Contaminant Materials" has been patented (26). The test involves extracting the oil with aqueous acetone containing an indicator, and observing the colour change in the aqueous layer. It is based on the observation that alkaline materials, apparently sodium soaps of fatty acids, are formed (27) by interaction of some food components with the oil. The test was calibrated with oil containing added sodium oleate and then applied to used frying oil from a restaurant. The soap content increased from nil to 55 ppm in 10-day use. No upper limit for soap content was proposed.

In general, the use of liquid reagents, especially those containing inflammable solvents, is not advisable in kitchens.

Physical Measurements

The dielectric constant of used oil has been shown to correlate well with total polar materials in several studies. Based on this parameter, the Food Oil Sensor (FOS) has been available for some time and gives useful results; however, there are some disadvantages. A "blank" measurement needs to be made on the unused oil. If the frying operation involves the finishing of part-fried French fries and they were fried in different oil, then this oil will partly leach out into the frying bath and the "blank" measurement will no longer be valid. Contaminants from the food being cooked such as moisture or salt may also affect the reading, unless they are filtered out.

A new instrument for dielectric constant, the "FOM 200", is now available from Ebro Electronic (28a). It is portable and the probe may be inserted direct into the hot oil in the fryer. A temperature measurement is obtained simultaneously. The measuring capacitor and temperature sensor are embedded in a ceramic plate mounted on a stainless steel tube. A built-in micro controller calculates the results, which are displayed in percentage total polar materials and degree centigrade. Ten seconds are required to obtain a reading.

Ebro Electronic's literature gives results of tests carried out by Prof. Karin Schwartz at the University of Kiel. Samples of beef fat, palm oil, rapeseed oil, sesame oil, sunflower oil and soya bean oil and some mixtures of liquid oils were examined, as were partly hydrogenated rapeseed and sunflower oils and their mixture, making a total of 29 samples. Tests were carried out on fresh oils and again after they had been used past the accepted limit of 24% total polar materials. Readings on the instrument were compared with results using the high pressure liquid chromatography (HPLC) method for polar materials (IUPAC 2.507). Good correlation was obtained with a maximum deviation of 3% total polar materials and a typical accuracy of 2% total polar materials. This instrument appears to satisfy all the requirements for quality control in a restaurant kitchen. An illustration of the FOM 200 is given in Figure 2.6.

Figure 2.6
The FOM 200 Instrument for Dielectric Constant in Hot Oil



Another instrument, the "Testo265", of similar design, and working on the same principles, has recently been publicised by its makers (28b). However, no performance data is available.

Another oil tester, the "Fri-Check", consists of a steel tube, fitted with a metal cylinder like a piston (29). The tube is filled with oil and equilibrated at 50°C in a thermostat box. The piston is allowed to fall through the oil, and the time taken is measured electronically. A combination of viscosity, density and shear stress affects the time taken. Good correlations are obtained with total polar materials and also with polymers. The instrument prints out the percentage total polar materials.

A sensor for the measurement of viscosity directly in hot oil has been described (30). The sensor consists of two short steel tubes made to vibrate by piezo crystals. The damping of the vibration is related to the viscosity of the oil. In tests on various used oils, the viscosity reading correlated well with the polymer content. The instrument has not yet been commercialised.

Schwartz et al. (31) reviewed results obtained with a number of the rapid tests described above. Schwartz found that better correlation with total polar materials was obtained when zero point of the FOS is set using the calibration liquid supplied with the instrument instead of the unused oil. Using this modified procedure a collaborative study of 76 samples was carried out in ten official laboratories. Good agreement was obtained and the combined results showed that FOS reading of 4.3 corresponded with the officially adopted (in Germany) limit of 24% total polar materials.

Seven groups reported correlation coefficients between 0.93 and 0.99 for FOS readings with total polar materials. Two groups also obtained adequate correlations (0.74-0.75) for the Fri Test and the Oxifrit or Rau Test with total polar materials; poor correlation with total polar materials was reported for the free fatty acid test strips (17).

Al-Khatani (32) also reported highly significant correlations for the FOS, the Oxifrit Test and the Fri Test with total polar materials. He found correlation of peroxide value and free fatty acids with total polar materials was not significant. Samples from a large number of independent fast food outlets were examined.

Table 2.6 gives the proposed interpretation of FOS readings.

Table 2.6
Frying with Quality Measurement by FOS

FOS Value	TPM	Quality
< 2.3	< 10%	Fresh
3.0	15%	Still good
> 3.5	> 18%	Near discard
> 4.3	> 24%	Spoilt

Quality Control of Continuous Fryers

The methods described above are also applicable to continuous fryers; and in the case of food products for immediate consumption such as doughnuts, they are adequate. However, where snack food is required to have a shelf life, a test must be conducted for the keeping properties of the frying oil and preferably also of the oil extracted from the freshly made product.

For this purpose, one of the available accelerated tests such as Rancimat is suitable or alternatively, and perhaps better, a direct analysis for antioxidant in the oil, as used by Hammond (9) in the work discussed earlier in this chapter.

In a study of a commercial production of potato crisps, du Plessis (33) compared various tests for quality prediction. He found the following order of usefulness.

Total tocopherol content > Dielectric constant (by FOS) >
free fatty acids > Tertiary butyl hydroquinone analysis >
anisidine value > Rancimat

At the end of the accelerated storage tests on potato crisps at 35°C for 30 days, tocopherol level of the extracted oil was 459 ppm (oil used for 3 hours) and 427 ppm (oil used for 30 hours).

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Official Regulations & Guidelines For Quality Control

Fresh Oils

General quality standards for edible oils and fats have been incorporated in law in many countries, but items specific to frying oils are less common. Antioxidants that may be used are incorporated in the general standards. In some instances silicone additives are also mentioned.

For example, in Belgium 3 mg/kg dimethyl polysiloxane and in Australia 10 mg/kg are permitted. On the other hand, in France and Sweden silicone additives are prohibited on the grounds that they would hide the excessive tendency to foam of deteriorated frying oil. France, Belgium and Chile limit the linolenic acid content of oils to be used for frying to 2%.

Used Oils

The most important criterion for any food is the organoleptic quality - does it look and taste attractive? It is therefore very appropriate that most authorities regard oil to be deteriorated if the taste or flavour of the fried food is unacceptable. However, this criterion is based on a subjective judgement. A second important factor is whether the food presents a health risk due to the condition of the frying oil. Experiments under unrealistically extreme conditions have produced oils with some toxic effects on experimental animals but only when the oil is altered well beyond the stage at which the food would be unacceptable.

Careful long-term experiments (1) comparing unheated oil with oil heated for long periods at normal frying temperature found no adverse effects and it was concluded that "Frying fats heated under the conditions of a good commercial practice are not detrimental to the health of the test animals". Similar studies by other research groups gave similar results. Nonetheless, there is clearly a case for legislating on the point at which used oil should be discarded, and such legislation needs to be based on a relevant analytically determined limit.

Currently, rather few countries have adopted legislation but where it exists it is often based on the pioneering studies carried out by the DGF.

In 1973, DGF defined frying oil as deteriorated if:

1. the taste or flavour is unacceptable; or
2. if the smoke point is below 170°C and the petroleum ether insoluble oxidised fatty acids are above 0.75%; or
3. if the oxidised fatty acids are above 1%.

However, the determination of oxidised fatty acids is time consuming and requires considerable skill. A simple chromatographic method for total polar materials using separation on silica gel columns was developed by Gertz (2) and shown to correlate well with oxidised fatty acids. All polar materials are absorbed on the column; and a figure for total polar materials can therefore be obtained indirectly from the eluted unchanged triglycerides, or directly by eluting adsorbed material with a strong solvent.

The availability of this method enabled the DGF to set a limit of 27% TPM.

Legislation

Legislation on analytical limits for used oils is summarised in Table 3.1, based on D. Firestone. (3)

Table 3.1
Legislative Limits for Used Frying Oils

Country	Minimum		Maximum			
	Smoke Point °C	Acid Value %	Free Fatty Acids %	Oxidised Fatty Acids %	TPM %	Polymers %
Austria	170	2.5		1	27	
Belgium	170				25	10
Chile	170		2.5	1	25	
France					25	
Italy					25	
Netherlands						16
S. Africa					25	16
Spain					25	

Note:

1. The Belgian law also sets an upper limit for the viscosity at 50 °C of 37 Pa/sec for solid fats and 27 Pa/sec for liquid oils.
2. The term “polymers” includes dimers.

In addition to these analytical limits, some regulations include various items of good practice.

Guidelines

Expert bodies in a number of countries have issued authoritative guidelines on frying oils. In addition to aspects of good practice, all of which were dealt with in our earlier discussion, they often include analytical criteria. Enforcement of good practice in the food industry is in the hands of the local authorities, which employ food inspectors. During on-site inspections they may take samples for analysis in an official laboratory. The criteria used are based on the guidelines of the national body involved.

Although the analytical limits may not be incorporated in the country's laws, they would provide strong support in the case of an action, based on the general food law of food being unfit for consumption.

As an example, the committee of chemical experts of the German local authorities adopted limits in 1991 based on the work of the DGF, as follows:

1. Sensory characteristics
2. Petroleum insoluble fatty acids - maximum 0.7%
3. Total polar materials - maximum 24%
4. Smoke point - minimum 170°C
5. Maximum difference in smoke point between unused and used oil - 50°C
6. Acid value - maximum 2.0%

Some court cases based on these criteria were successful and resulted in a general improvement in the frying practice in restaurants (4).

According to Firestone (5), analytical guidelines are also used in the following countries:

Hungary	TPM	25% max
Netherlands	Acid value	4.5% max
	Polymers	16% max
Japan	Smoke point	170°C min
	Acid value	2.5% max
	Carbonyl value	50 max
Finland	TPM	25%
	Acid value	for vegetables oils 2.0 max for solid fats 2.5 max
	Smoke point	for vegetables oils 180°C min for solid fats 170°C min
	Fri Test	vegetable oils 2 max (scale 1-3)
	Oxifrit Test	below 3 (scale 1-4)
	FOS	below 4 (scale 0-6)

Other Scandinavian countries also recommend the use of the Fri Test or the Oxifrit Test by food inspectors.

The Swedish National Food Administration has issued formal guidelines for deep frying, which recommend the use of the FOS or the Oxifrit Test and list a number of items of basic good practice.

The Finnish National Food Administration developed a useful report form to be used by a health inspector for use during a visit to a production unit. It would also be useful as a checklist for a supervisor of a commercial kitchen operation. It is reproduced on the next page.

**INSPECTION FORM –
FINLAND NATIONAL FOOD ADMINISTRATION
(For The Food Laboratory, To Be Filled Out By The Health Inspector)**

No. and Date _____

Amount of fat in kettle _____ Added daily _____

Fat totally renewed, date _____

How often will the fat be renewed totally _____

Criteria for total removal (except time) _____

How long daily will the fat be kept hot _____

At the time of sampling, how long kept hot _____

Fat temperature, reported _____ measured _____

Filtering and storage of the fat _____

What will be fried just now _____

What else will be fried _____

Date of the kettle _____

Cleaning of the kettle, last (when) _____

How was the kettle cleaned _____

Sensory evaluation of the fried food: _____

Taste _____ Smell _____ Colour _____

Observations on the spot: _____

Overall cleanliness _____

Smoke _____ Ventilation _____

The DGF adopted eight recommendations for the proper use of frying oils at its symposium on Deep Fat Frying in Hagen in March 2000:

1. The principal quality index for deep fat frying should be sensory parameters of the food being fried.
2. Analysis of suspect frying fats and oils should utilise two tests to confirm abuse. Recommended analyses should include total polar materials (maximum of 24%) and polymeric materials (maximum 12%).
3. The use of rapid tests for monitoring oil quality is recommended. Rapid tests should correlate with internationally recognised standard methods, provide an objective index, be easy to use, be safe for use in the food processing/preparation area, quantify oil degradation, and be rugged enough for field use.
4. There are no health concerns associated with consumption of frying fats and oils that have not been abused at normal frying conditions.
5. New and improved methods should be developed to provide fats and oils chemists and the food industry with tools to conduct work more quickly and easily, yet are environmentally friendly, and use less hazardous solvent systems.

6. Basic research focussed on understanding the dynamics of deep fat frying and the frying process is encouraged. Research should be cross-disciplinary, encompassing oil chemistry, food engineering, sensory science, food chemistry and nutritional sciences.
7. One of the basic tools to ensure food and oil quality is filtration. Filter materials should be used to maintain oil quality as needed.
8. Used, but not abused, frying oils may be topped up or diluted with fresh oil with no adverse effects on quality. Abused fats and oils were defined in the first two recommendations developed during this program. However, it remains to be defined what constitutes a long-life frying oil claim in keeping with the first two recommendations.

In conclusion, it may be said that quality problems are more likely to arise in batch frying operations in restaurants and fast food outlets, especially where frying is necessarily discontinuous and often carried out by relatively unskilled workers. Various surveys indicate that quality standards in many establishments need to be improved. A major problem appears to be inadequate control of fryer temperature. The tools for quality control are now available. The analytical methods for total polar materials and polymers are well established, with broad agreement on acceptable limits. Fast test kits suitable for on-site use by inspectors are available and correlate well with the above internationally accepted chemical tests. Doubtful or unsatisfactory result with a test kit should be backed up by a laboratory analysis.

None of the established rapid tests available are ideal for on-site use by kitchen personnel. The FOS is probably the most suitable. However, the recently available food oil monitor, FOM 200, described in Chapter 2, seems to answer all the requirements. The measurement of total polar materials has a disadvantage for palm oil in particular, as has been discussed. However, in most comparisons reported, palm oil gives lower values of total polar materials than other oils after equivalent use, even when no allowance has been made for the effect of the partial glycerides. This is a good indication of its stability in high temperature use.

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Antioxidants In Frying

Due to the high temperature used in deep frying, oxidative reactions take place, leading to loss of quality. The use of protective antioxidants is therefore a very attractive concept. The first aim is to protect the frying oil, and prolong its useful life. In the case of snack foods, antioxidants should also ensure product quality is maintained during its shelf life.

There are many publications demonstrating the effect of antioxidants. Laboratory-accelerated tests such as the Rancimat give only limited indications of effectiveness, and are carried out at lower temperatures than those used in frying. Laboratory scale frying tests give more realistic results. However, the best evidence is obtained under actual manufacturing conditions, provided that the operation and sampling procedures are well controlled.

The results of accelerated laboratory tests are conveniently expressed in terms of a "protective factor", defined as the induction period with added antioxidant divided by the induction period before addition. Some representative results are given in Table 4.1.

Table 4.1
Protective Factors for Various Antioxidants

Antioxidant	Beef Fat	Cottonseed Oil	Groundnut Oil	Sunflower Oil	Corn Oil	Palm Oil
BHA 0.01% *	19	-	-	-	-	-
BHA 0.02% *	34	1.0	1.4	-	-	-
BHT 0.01% *	9.3	-	1.9	-	-	-
BHT 0.02% *	-	1.0	2.0	-	-	-
Octylgallate 0.01% *	10	-	2.0	-	-	-
Octylgallate 0.02% *	-	1.4	-	-	-	-
Ronoxan A paste 0.2% **	-	-	2.63	2.76	2.33	3.12

BHA=butylated hydroxyanisole, BHT=butylated hydroxy toluene

(1) (2)

Notes:

* Induction periods measured by oxygen absorption at 100°C.

** Induction periods measured by Rancimat at 120°C. Ronoxan A paste is a proprietary mixture of α -tocopherol 100 mg/kg, ascorbyl palmitate 500 mg/kg and lecithin 1,400 mg/kg. The lecithin solubilises the ascorbyl palmitate and has some synergistic effect with the antioxidants.

The results demonstrated the well-established fact that antioxidants have much less effect in vegetable oils than in animal fats. Vegetable oils usually contain relatively high levels of natural antioxidants (mainly tocopherols) whereas the levels in animal fats are very low.

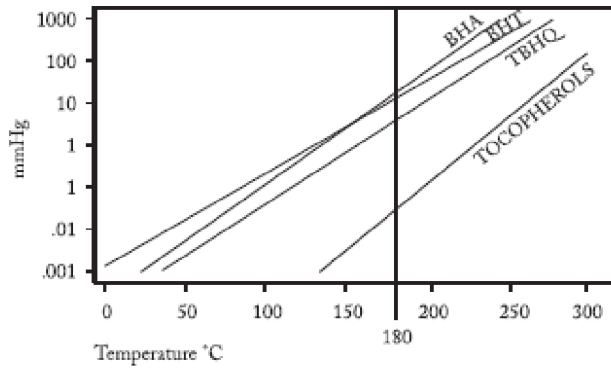
The Ronoxan A paste is rather more effective than the synthetic phenolic antioxidants.

Synthetic Phenolic Antioxidants

An important factor limiting the effectiveness of antioxidants is their volatility.

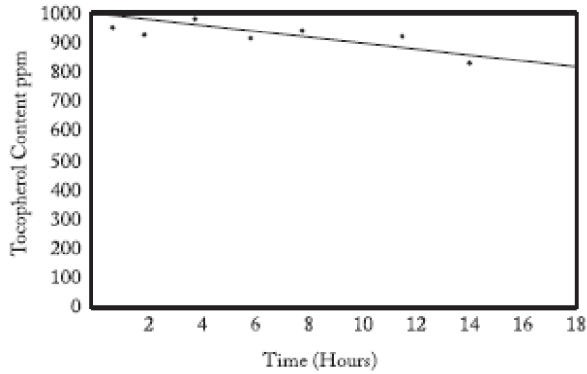
Figure 4.1 (2) shows the vapour pressures of some phenolic antioxidants and tocopherols. At 180°C, tertiary butyl hydroquinone (TBHQ) (with limited regulatory permission internationally) is somewhat less volatile than butylated hydroxyanisole (BHA) and butylated hydroxy toluene (BHT), but the tocopherols are two orders of magnitude better in this respect. Furthermore, the evolution of steam during frying increases the loss of the phenolic compounds by steam distillation.

Figure 4.1
Vapour Pressures of Some Antioxidants



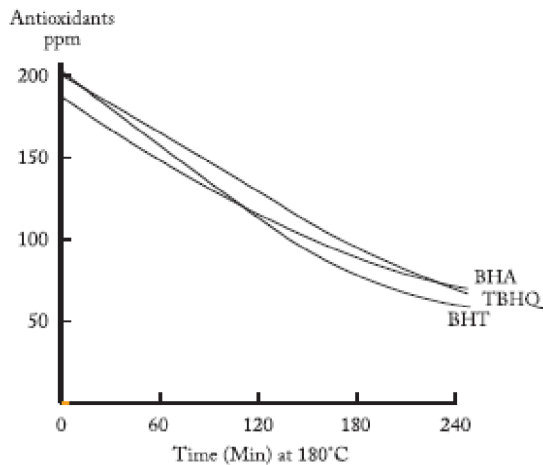
The persistence of tocopherol is illustrated in Figure 4.2

Figure 4.2
Tocopherol Loss from Corn Oil Stirred at 190°C (2)



In contrast, Figure 4.3 shows the rapid loss of the phenolic antioxidants at frying temperature.

Figure 4.3
Effect of Heat and Steam Distillation on Loss of Antioxidants from Soya bean Oil at 180°C



During the pilot plant experiments discussed earlier (in Chapter 2, Figure 2.2), experiments were also run in which BHA was added to the oil at 200 ppm. After 20 minutes of frying the level had dropped to 10 ppm. It stayed at this level due to the addition of fresh oil (containing 200 ppm) to maintain the level in the frying pan. This concentration was still sufficient to double the shelf life of the product at room temperature.

Augustine and Berry (3) reported static heating and laboratory frying tests in palm olein using BHA and BHT (see Table 4.2).

Table 4.2
Loss of Antioxidant over 2 days at 180°C

Antioxidant	BHT		BHA	
	Start	End	Start	End
Static heating	181	57	191	81
Intermittent frying	190	27	187	< 20

The greater loss during frying was attributed to steam distillation.

Augustine and Berry also (4) carried out storage tests on tapioca chips fried in palm olein containing antioxidant at about 200 ppm at 200°C. After 43 days of storage at 60°C the oil was extracted for analysis.

Various analyses of oils containing BHA and BHT showed significant oxidation (for example peroxide values of 80 and 40, respectively), and showed little difference from the control without added antioxidant. Oil treated with TBHQ was significantly in better condition.

Fritsch and co-workers (5) carried out storage tests at 45°C on pelleted snack food fried at 190°C. At 100 ppm TBHQ gave better protection (4 weeks) than BHT (2½ weeks) or BHA (1½ weeks).

The loss of TBHQ during the frying of French fries under laboratory conditions (16 batches/day for 5 days) is shown in Table 4.3 (6). The frying oil was palm olein containing 200 ppm of antioxidant; and fresh oil with 200 ppm TBHQ was used to make up the oil level at the end of each day.

Table 4.3
Loss of TBHQ during Frying

Time	TBHQ(ppm)
Start	194
8 hours	76
24 hours	13
40 hours	None detected

Asap and Augustin investigated the use of TBHQ in intermittent frying of 2-mm potato slices in palm olein (7). A control experiment (no antioxidant) (A) was compared with oil to which 200 ppm TBHQ was added once (B) during 8 days of frying, and with oil to which 200 ppm was added at the start and a further 190 ppm each day (C). The results are summarised in Table 4.4 below.

Table 4.4
Effect of Replacing Antioxidant during Frying

	Day	A	B	C
Total Polar Materials	0	5.5	5.5	5.4
	8	47.4	45.4	41.3
Dielectric Constant	0	1.36	1.36	1.38
	8	7.80	7.46	7.05
Polymers	0	0	0	0
	8	4.95	4.01	2.55
Iodine Value	0	57.2	57.2	57.2
	8	46.7	47.3	48.6
C18:2/C16:0 ratio	0	0.262	0.262	0.262
	8	0.095	0.099	0.123

The results show the protective effect of the antioxidant and the need to replace losses due to volatilisation on a regular basis.

TBHQ coated onto the surface of polythene bags has a protective effect on fried food during storage (8). Rho and co-workers submitted instant noodles fried in palm oil and stored under accelerated conditions at 63°C to a taste panel. The storage time till rancidity developed is shown in Table 4.5 below.

Table 4.5
Storage Test on Instant Noodles

Treatment	Days life at 63°C
Control – no antioxidant	18.4
200 ppm TBHQ in frying oil	27.2
200 ppm TBHQ on package	37.0
500 ppm TBHQ on package	39.8
1,000 ppm TBHQ on package	44.6

The concentration of TBHQ used was based on a fat content of 20% in the noodles.

It was concluded that the rancidity was initiated by a thin layer of oil that had migrated from the product onto the packaging surface.

As a contrast to the volatility of the synthetic antioxidants, the relative heat stability of tocopherols is shown in laboratory frying tests. Successive 50 g batches of raw French fries were fried in a mixture of soya bean oil (2 parts) and sunflower oil (1 part), with and without added tocopherols. The results are shown in Table 4.6 (2).

Table 4.6
Frying Tests – Addition of 500 ppm each of α - and γ -Tocopherols

Number of Frying	Total Tocopherols	Oxidation Tendency	Total Tocopherols	Oxidation Tendency
10	735	1.00	1,703	1.00
30	644	1.33	1,546	1.16
50	615	1.35	1,344	1.21
80	527	1.51	1,212	1.27

Notes:

- Oxidation tendency is defined as initial induction period divided by used oil induction period (from Rancimat Test at 100°C).
- Initial tocopherol content of oil blends α -275 ppm, β -13 ppm, γ -330 ppm, and δ -117 ppm.

In the study of Pongracz on Ronoxan A, ascorbyl palmitate was used in conjunction with tocopherol. It has, however, useful antioxidant effect in its own right, as demonstrated by Masson et al. (9). This group, working in Santiago, Chile, compared the storage stability of potato crisps fried in four oils of different polyunsaturated to saturated fatty acids ratios. No antioxidant was added at this stage. The oils were sunflower oil (P/S 5.2), canola oil (P/S 3.4), canola/palm olein blend (P/S 0.4), and palm olein (P/S 0.3).

Potato crisps were fried in a batch fryer, used in a continuous manner for 10 hours. Each batch of crisps was divided into two. One half was treated with 1.3% salt in a mixer, while the other half was treated with 1.3% salt to which ascorbyl palmitate had been added (as a 2% solution in ethanol). The quantity of ascorbyl palmitate was calculated to give 500 ppm in the potato crisps. After packing in bags, the crisps were stored in the dark at 60°C and examined at intervals. Table 4.7 summarises the results. For the unsaturated oils, storage was terminated at 16 days. Analytical figures at end of life were reported.

Table 4.7
Accelerated Storage Test on Potato Crisps Fried in Various Oils

Sample	Days Storage	IP (hours)	Tocols
Sunflower oil	0	12.7	701
	8	0	120
Sunflower oil + AP	0	20.3	692
	16	1.0	24
Canola oil	0	24.5	750
	16	1.6	17
Canola oil + AP	0	27.8	623
	16	4.5	142
Canola/palm olein blend	0	9.0	419
	45	0	4
Canola/palm olein blend + AP	0	14.5	432
	60	0	0
Palm olein	0	13.7	570
	60	3.6	135
Palm olein + AP	0	16.5	557
	90	3.0	0

IP = Induction period in Rancimat test at 100°C for sunflower and canola oil, and at 130°C for the canola/palm olein blend and palm olein.

AP = ascorbyl palmitate

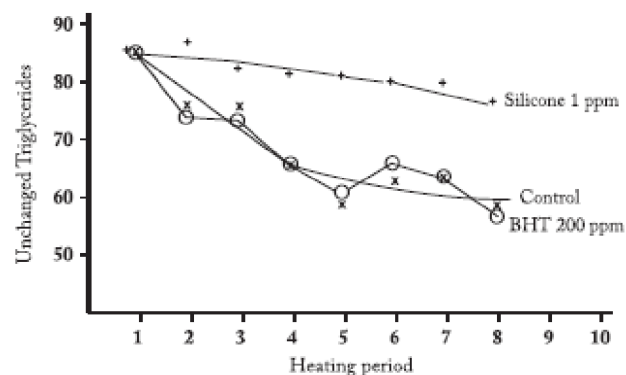
The study is of particular interest in demonstrating the effectiveness of antioxidant added after the frying process. It incidentally also shows the better keeping properties obtained from the use of palm olein in comparison with more unsaturated oils.

Silicone oil is an antioxidant with a mode of action quite different from the phenolic antioxidants.

The use of silicone oil (polydimethyl siloxane) to inhibit oxidation in frying oils was first reported and patented by Martin in 1953 (10). Freeman, in 1973, (11) showed that the effect was obtained by a mono-molecular layer of silicone on the surface of the oil, so that as little as 1 ppm in the frying oil is sufficient. Analytical determination of the unchanged triglycerides showed a marked effect during four days heating at 180°C (see Figure 4.4) and it also showed that BHT was not useful under these conditions.

Since then, the use of silicone under different conditions has been described.

Figure 4.4
Effect of Silicone on Heated Oil



Zwoboda (12), in similar laboratory heating experiments, found that with 1 ppm silicone the amount of polymerised acids formed in sunflower oil was 10%, whereas without the additive 34% were formed. After 20 actual fryings in sunflower oil the following results were obtained:

	Sunflower Oil	Sunflower Oil + 1 ppm Silicone
Polymerised Acids %	14	6
Empirical Foam Test	35	6

J.S. Rhee (13) found very good protection from silicone added to blended oil (95% partly hydrogenated soya bean oil, 5% cottonseed oil). He heated the oils at 195°C for 19 hours, during which time three batches of French fries were cooked. The results are summarised in Table 4.8.

Table 4.8
The Effect of Silicone and TBHQ in Heated Oils at 195°C

	Totox Value		AOM Stability (hours)		Viscosity at 25°C (CS)		Colour (Lovibond Red in 5¼" Cell)	
	0	10	0	10	0	10	0	10
Control	2.3	262	20	4	62	110	0.8	11
200 ppm TBHQ	2.3	252	67	4	62	104	0.8	9
1 ppm silicone	3.2	153	23	10	63	80	0.7	7.5
1 ppm silicone + 200 ppm TBHQ	2.5	106	50	12	63	72	0.8	4.4

AOM = Active Oxygen Method

It is clear that under the conditions of this test, there was a major protective effect from silicone with further improvement when TBHQ was also added. TBHQ on its own was not useful. Simulated deep frying experiments were also carried out in the laboratory using soya bean, rapeseed, safflower, corn, rice bran and palm oils. A concentration of 1 ppm of silicone oil gave considerable protection to all these oils.

The effect of 2 ppm silicone oil, dimethyl polysiloxane (DMPS), on deterioration of frying oil was demonstrated by Jorge et al. in batch fryers using sunflower oil (14). Batches of French fries were cooked for 10 minutes with a 20-minute gap between frying. The operation continued for 6 hours. In a similar fryer, batches of French fries were fried continuously using two baskets alternatively. Table 4.9 gives the results of analyses for total polar materials.

Table 4.9
Polar Materials Formation on Frying in Sunflower Oil

	Time (hours)	Sunflower Oil (TPM%)	Sunflower Oil + DMPS (TPM%)
Discontinuous	0.0	3.2	3.3
	3.5	13.0	5.0
	6.0	20.4	7.2
Continuous	0.0	3.2	3.3
	3.8	7.2	6.3
	6.0	11.7	10.4

During continuous frying the surface is protected by the evolution of steam, and silicone gives no added protection, while in discontinuous operation the surface is exposed to oxygen between frying unless DMPS is present.

Silicone oil was used to protect vanaspati (partly hydrogenated vegetable oil) and safflower oil. During 6 hours of static heating at 180°C, the loss of linoleic acid in vanaspati was reduced. In safflower oil, 4.5% of oxidised fatty acids were formed as compared with 9% in the unprotected oil. (15)

Evans and co-workers found that the addition of 1-5 ppm of silicone oil to sunflower, cottonseed or hydrogenated soya bean oil reduced the intensity of objectionable room odours when heated to 192°C. (16)

Since the effect of silicone is due to it forming an inert barrier at the air surface, it is particularly valuable in discontinuous batch frying operations, as in restaurants outside peak periods, when oil is kept hot with only occasional use. In continuously operating frying pans, where the surface is always disturbed by the product and with the continuous evolution of steam, the protective effect is much less marked.

A secondary effect of silicone found by Freeman et al. was that convection currents in the oil were inhibited. It had been noted that, as a consequence, the temperature at the air/oil interface was appreciably lower than that in the bulk. (17)

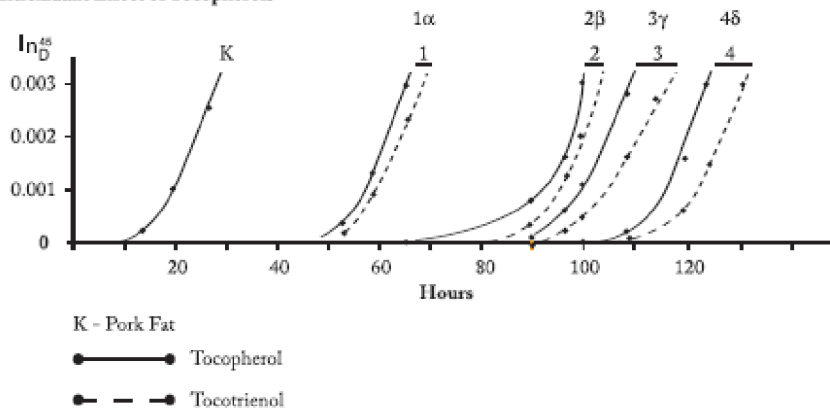
It should be noted that silicone is also widely used as an anti-foaming agent and fats containing silicone should not be used for making cakes since they will not develop a satisfactory aerated structure. Its use in the frying of doughnuts is also not advised.

Commercial frying oils can be purchased with methyl silicone. Alternatively it can be added before use. Its insoluble nature makes even dispersion difficult. One useful practical device used by the author was to make a concentrated dispersion in a small quantity of high melting fat. This is then cooled and stirred until it is partly crystallised. It is finally poured into moulds of the type used for chocolate bars and refrigerated. For use, individual squares are broken off and added to a batch of frying oil. The amount in each square is calculated for the fryer in use to give 1 ppm in the frying oil. This method is particularly useful for use in restaurants.

Natural Antioxidants

The results already discussed illustrate that α -tocopherol is more effective in frying than the synthetic phenolic antioxidants. α -tocopherol is not, however, the most effective of the tocopherols. There are four saturated and four unsaturated tocopherols. The antioxidant effect of the tocotrienols is somewhat greater than that of the corresponding tocopherols: the additional effect being due to the double bond structure (18). Accelerated test results obtained with 200 ppm in pork fat at 110°C are shown in Figure 4.5.

Figure 4.5
Antioxidant Effect of Tocopherols



Another natural product present in most oils is squalene. Its antioxidant properties were shown in a model system.

Govind Rao and Achaya (19) carried out storage tests on concentrates of methyl oleate and methyl linoleate to which either squalene or a tocopherol concentrate from safflower oil had been added. Samples were stored in glass beakers at 63°C and peroxide values determined every second day. The results are given in Table 4.10.

Table 4.10
Antioxidant Effect of Squalene

Days		Methyl oleate				Methyl linoleate			
		2	4	6	8	2	4	6	8
Peroxide Value	A	45	95	164	300	91	209	309	418
	B	13	27	100	245	27	45	146	327
	C	27	45	68	141	45	91	136	227

A = control, B = 0.02% squalene added, C = 0.02% tocopherols added

It was concluded that squalene acted as an antioxidant for an initial period with better protective action than tocopherols, and then became pro-oxidant. A similar effect has been reported for carotene.

Currently there is widespread consumer feeling against chemical additives in food, despite the fact that they are fully tested and authorised at government and international level. In consequence, there is great interest in the use of natural substances or extracts that have antioxidant properties. Peters (20), in 1937, reported the use of an extract from oats as an antioxidant for fats and fat-containing foods. In the author's own experience in the 1940's, an extract from 2-3% soya flour increased the oxidative stability of beef fat for use in a retail pudding mix. The soya flour was stirred into the hot fat and then the flour particles were centrifuged out. This method was used until synthetic antioxidants became approved food additives.

In a brief review, Pokorny (21) listed groups of natural antioxidants available from the plant kingdom. These include esters of ferulic, caffeic, sinapic and protocatechuic acids from cereals; also lignans, flavonoids, carotenoids and spice extracts. Others have reported activity from extracts of summer savoury and oregano.

Various laboratory techniques have been used to demonstrate effectiveness. For example, Nakatani (22) and co-authors used a model substrate consisting of methyl linoleate dissolved in silicone oil to compare different spice extracts. The system has the advantage of being free of antioxidants. Their results, measured by the Oil Stability Index (OSI), are given in Table 4.11.

Table 4.11
Oil Stability Index of Methyl Linoleate

Additive at 200 ppm	OSI (hour)
Nil	5.47
Cinnamon	6.45
Allspice	9.27
Nutmeg	9.57
Ginger	25.25
Rosemary	98.60
α -tocopherol	42.33
BHT	40.03

Gertz et al. (23) described a new test, the Oset Test (oxidative stability at elevated temperature), specifically designed to be relevant to frying conditions. In this test a 20-g sample of oil was heated with 1 g of silica gel (containing 10% water) at 170°C for 2 hours. The polymerised triglycerides were then determined by HPLC.

The Oset value is calculated as follows:

$$\text{Oset} = \frac{100}{\% \text{ polymer triglycerides}}$$

The application of the test to oils to which various natural compounds had been added at 2,500 mg/kg is shown in Table 4.12.

Table 4.12
Effect of Natural Antioxidants on Vegetable Oils

Oil	Substance Added	Oset Index	Oset Relative to Untreated Oil
Sunflower *	-	21	100
Sunflower *	Squalene	23	106
Sunflower *	Rapeseed sterols	29	139
Sunflower *	Oryzanol	31	144
Sunflower *	Quercetin	34	162
Sunflower *	Sunflower sterols	36	172
Rapeseed	-	44	100
Rapeseed	Squalene	48	110
Rapeseed	Rapeseed sterols	60	137
Rapeseed	Quercetin	64	146
Rapeseed	Oryzanol	65	147
Rapeseed	Sunflower sterols	85	194
Sunflower **	-	32	100
Sunflower **	Rosemary extract	69	215
Sunflower **	Ascorbyl palmitate +natural tocopherols	59	184
Sunflower **	Good Fry components	55	172

Notes: The results for Sunflower Oil ** were presented at a recent conference.
 (24)

Rosemary extract which contains several specific active compounds gives high protection to frying oil, as indicated by two different test methods (see individual results in Tables 4.11 and 4.12), and is marketed as a natural antioxidant. Its performance in laboratory frying tests had been investigated by Che Man and co-workers (25). They fried potato crisps in palm olein containing antioxidant at 200 ppm.

Potato crisps sampled after the oil had been used for 70 fryings without addition of fresh oil were stored for 14 weeks and then submitted to a sensory panel for odour tests.

The order of preference was Rosemary >BHA>Sage>BHT>Untreated Oil. This order was also followed by the results of the thiobarbituric acid test on the extracted oil.

In a second paper (26), the same group used response surface methodology to find the optimal concentration of a blend of antioxidants for overall sensory acceptability as judged by a panel of 20. The blend contained 0.06% oleoresin rosemary extract, 0.071% sage extract and 0.022% citric acid. If the C18:2/C16:0 ratio was used as the criterion, (27) then the optimum concentration of antioxidants was 0.076% oleoresin rosemary extract, 0.066% sage extract and 0.037% citric acid. There was a synergistic effect from this mixture.

Rosemary extract reduced the formation of trans fatty acids during frying, as did a mixture of rosemary extract with BHA (28). The following Table 4.13 summarises the results reported before and after eight batch fryings of potatoes in olive oil and sunflower oil.

Table 4.13
Reduction of Trans Fatty Acids Formation in Frying with Antioxidants

Sample	Trans oleic acid %		Trans linoleic acid %	
	Before	After	Before	After
Olive oil	0.045	0.082	0.123	0.144
Olive oil + 200 ppm Rosemary	0.045	0.063	0.123	0.129
Olive oil + 100 ppm Rosemary + 100 ppm BHA	0.045	0.061	0.123	0.127
SFO	0.025	0.070	0.425	0.440
SFO + 200 ppm Rosemary	0.025	0.056	0.425	0.432
SFO + 100 ppm Rosemary + 100 ppm BHA	0.025	0.060	0.425	0.426

SFO = Sunflower oil

The reductions observed were statistically significant.

While the foregoing tests show that some protective effects can be obtained for frying oils, in practice the major commodity oils other than palm oil or palm olein do not have enough stability for satisfactory use in the more demanding restaurant and industrial frying operations. Their high content of polyunsaturated fatty acids results in excessive oxidation. Traditionally, their properties have been modified by partial hydrogenation to attain the desired stability at frying temperature. The inevitable consequence is the production of a relatively high level of trans fatty acids. For example, the normal linolenic acid content of soya bean oil (7-9%) can be reduced to 2% by selective hydrogenation, but the oil will then contain about 20% of trans fatty acid isomers.

Since trans fatty acids are now generally accepted to be nutritionally undesirable, there has been considerable interest in breeding for lower unsaturation. As a result, high oleic sunflower ("Hosun") oil has become available. Its frying performance has not come up to expectation; firstly, because the natural antioxidant present, α -tocopherol, is the least effective of the tocol group, and secondly because its use fails to produce the expected fried food flavour. This is formed from the linoleic acid, present at too low a level in Hosun oil.

In order to overcome these defects, Hosun oil has been combined with a proprietary blend of specially prepared sesame oil (4%) and rice bran oil (2%) to give "Good Fry" oil. Sesame oil contains the antioxidant tocopherols (490-680 ppm), δ^5 -avenasterol (560 ppm) and δ^7 -avenasterol (56 ppm).

In addition, the oil contains about 0.5% of sesamol (29), which yields the two phenolic antioxidants, sesamol and sesaminol, when heated in the presence of water, as in the case of frying. Rice bran oil contains tocotrienols, tocopherols, δ^5 -avenasterol and also γ -oryzanol, which consists of a mixture of ferulic acid esters. Rogers et al. (30) examined in detail refined rice bran oil from five different refineries; and very variable γ -oryzanol and tocol contents were found. The Good Fry patent specifies high quality rice bran oil and a careful refining process and therefore it is probable that the three highest antioxidant contents A, D and E (see Table 4.14) found by Rogers are relevant to the Good Fry components.

Table 4.14
 γ -Oryzanol and Tocol Components of Refined Rice Bran Oil (ppm)

	Sample		
	A	D	E
Cycloartenyl ferulate	232	55	228
24-methyl cycloartenyl ferulate	314	61	74
Campesteryl ferulate	157	228	342
β -sitosterol ferulate and cycloartenyl ferulate	84	66	74
Total ferulates	787	510	718
δ -tocotrienol	48	6	104
β -tocotrienol	478	322	975
α -tocotrienol	86	n.d.	78
δ -tocopherol	17	n.d.	40
β -and γ -tocopherol	114	99	350
α -tocopherol	120	218	54
Total tocols	863	645	1,609

n.d.=none detected

Practical frying trials using Good Fry oil have been reported. In the first trial (31) it was used to prepare French fries from part-fried potatoes in a restaurant, frying 15 x 100 g potatoes per hour for 5 hours on successive days. Oil was discarded either when the organoleptic quality of the product was poor, or if the oil was foaming excessively, or was too dark.

After 40 hours of frying over 8 days the potatoes fried in Good Fry oil were still of good quality, but the oil was dark in colour and foaming. In comparison, after 40 hours, palm olein (with no Good Fry components) gave French fries, which were characterised as starting to be greasy though still of normal restaurant quality. The oil was dark and foaming. Thus the additives had enabled the Hosun oil to perform slightly better than palm olein.

Partly hydrogenated rapeseed oil was also used in the trials, and was less satisfactory.

A more extensive comparison of palm oil with Good Fry oil was carried out in normal usage in ten restaurants. The Good Fry oil showed a significant reduction in the amount of oil that became unfit for further use (32).

The Good Fry system has also been tested on potato crisps fried in an industrial scale (34). The results for palm olein and unhydrogenated rapeseed oil are summarised in Table 4.15 below.

Table 4.15
Sensory Evaluation of Potato Crisps during Storage

Time Stored (weeks)	Control Palm Olein		Palm Olein with 2% Good Fry Components		Rapeseed Oil with 6% Good Fry Components	
	Taste	Smell	Taste	Smell	Taste	Smell
0	0.13	0.3	0.13	0.06	0.36	0.07
6	0.40	0.8	0.16	0.43	0.20	0.23
10	0.80	1.6	0.20	0.80	0.80	1.70
17	1.00	2.5	0.40	1.00	1.00	1.60
22	1.16	2.2	0.53	1.40	1.67	3.00

(33)

Notes: Good Fry Components: 4% sesame oil + 2% rice bran oil
Scoring for taste: 0=perfect, 2=acceptable
Scoring for smell: 0=perfect, 2.5=acceptable

The Good Fry system gave potato crisps fried in rapeseed oil keeping properties approaching those fried in palm olein. Good Fry components added to palm olein at 2% level gave some improvements in organoleptic properties on storage. It should be noted that palm olein alone gave crisps with a storage life well beyond the 12 weeks normally required.

Other industrial scale trials showing significant improvement in shelf life were of potato crisps fried in unhydrogenated soya bean oil with 5% of the additive mix and of a pork snack product fried in lard with 3% of the additive mix. Storage life was increased from 8 weeks to 16 weeks in the latter product (34).

Research for natural products with antioxidant activity is currently a very live subject. A recent study (35) from Hong Kong examined the individual theaflavins and catechins present in black tea. Substances were tested in canola oil at 95°C by measuring oxygen consumption and loss of polyunsaturated acids. All the four catechins and four theaflavins examined were better antioxidants than BHT. The most effective in each group were (-) epigallocatechin gallate and theaflavin -3,3' digallate, respectively.

Propolis is a resinous material collected by bees and used in the construction of their hives. Chemically complex, it contains flavonoids with antioxidant activities. The effect of a methanolic extract of propolis on olive oil in comparison with synthetic antioxidants has been studied (36). Commercial olive oil with an initial peroxide value of 4.3 meq/kg was used. Samples were then stored at 60°C in the dark.

The results are summarised in Table 4.16.

Table 4.16
Antioxidant Effect of Propolis Extract, BHA and BHT in Olive Oil

Storage	Control	Propolis Extract							
		BHA 0.01%		BHT 0.01%		0.02%		0.08%	
Period (days)	PV	PV	IR	PV	IR	PV	IR	PV	IR
7	16.1	13.0	19.0	13.1	18.1	12.5	22.2	9.6	39.9
21	34.6	11.9	65.5	13.7	60.3	13.8	60.0	7.4	78.6
35	67.1	12.35	81.7	14.3	78.6	1.9	82.2	6.7	90.0

PV = Peroxide value (meq/kg)

IR = Inhibition rate = $\frac{PV_{\text{control}} - PV_{\text{test}}}{PV_{\text{control}}} \times 100$

It was concluded that the antioxidant effect of 0.08% propolis extract was superior to that of the synthetic antioxidants at 0.01%.

Parkanyiova and co-authors (37) reported an antioxidant effect during frying from plant extracts. Extraction with acetone of Sweetgrass (*Hierochloe odorata*) gave a phenolic extract with 98.8 mg/g of gallic acid equivalent (GAE), while extraction of Lovage (*Levisticum officinale*) gave an extract with 32.9 mg/g of GAE. A total of 0.1% of mixed extracts (in a ratio of 1:1) was added to rapeseed oil, used in discontinuous frying at 150°C over 5 days. Formation of polymers was reduced and the extracts acted synergistically at frying temperature, although there was no synergistic effect in an accelerated oxidation test at 100°C by the Oxipres method.

At a recent conference on biologically active phytochemicals (38) a number of papers revealed common ground between antioxidants of interest in biological systems and those relevant to edible oils. Extracts with antioxidant activity in oils and fats were reported from bilberry skins, Canadian bearberry, buckwheat leaves, grape residues, the trunk of the yucca and others.

A methanolic extract from Ajoiven powder (*carum copticum*) has been found to have excellent antioxidant properties in flaxseed oil (18:1-22.2%, 18:2-14.2%, 18:3-50%) and bahera oil (18:1-57%, 18:2-7.8%, 18:3-5.7%) (39).

Phenolics can be obtained from wastes or byproducts of food processing. Of particular interest, because large quantities are potentially available, are extracts from apple pomace and from the effluent of palm oil mills.

Laboratory tests have shown that several of these extracts have antioxidant activity at least equivalent to the permitted synthetics.

An antioxidant preparation from olive oil processing waste is currently being commercialised by the Spanish company, Genosa I+D, under the name of "Hytolive". It is based on a process patented by Instituto de la grasa, Seville, the Spanish oils and fats research institute. The major active component is hydroxytyrosol and the product is claimed to have applications in food, cosmetics and pharmaceuticals.

It is hoped that other new and economical natural antioxidants will reach the market in the near future.

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Review Of Literature On Frying In Palm Oil

Reports have appeared over more than 30 years regarding the performance of palm oil or palm olein in frying. The reports originate from a number of countries and relate both to batch fryers in restaurants and continuous fryers manufacturing snack foods.

Von Zeddelmann and Wurziger (1) carried out an extensive investigation based on laboratory heating experiments at 180°C without any frying. Their analytical results were summarised qualitatively as follows:

Oxidised Fatty Acids: soya bean oil > groundnut oil >
hardened groundnut oil > hardened fish oil >
palm oil > coconut oil

Free Fatty Acids: coconut oil > hardened fish oil >
palm oil + groundnut oil >
hardened groundnut oil > soya bean oil

Smoke Point: hardened groundnut oil > palm oil + groundnut oil >
soya bean oil > fish oil > coconut oil

They also considered the time of heating to reach selected limit values for oxidised fatty acids and acid value. Their results are shown in Table 5.1.

Table 5.1
Frying Oils - Time to Reach End of Useful Life

Oil	Acid Value 2.5 (hours)	Oxidised Acids 1% (hours)
Hardened fish oil	130	100
Hardened groundnut oil	140	92
Coconut oil	100	125
Palm oil	130	103
Groundnut oil	140	63
Soya bean oil	160	55

Taking the two criteria together, palm oil has the longest life of 103 hours.

When they examined used frying oils from commercial operations the results were not so clear cut because the other two factors of design and operating conditions varied, as well as the type of goods fried. Nevertheless, their overall conclusion was that animal fats and polyene rich vegetable oils should not be generally used for deep frying because of their sensitivity to high temperatures. Hardened groundnut oil and unhardened vegetable oil with palm oil showed the greatest stability to high temperatures both in analytical and in organoleptic tests.

Faur (2) carried out frying tests in a batch fryer in which palm oil and palm olein were compared with hydrogenated coconut oil and groundnut oil. Palm olein behaved very similarly to groundnut oil during 15 fryings. Sensory evaluation based on taste, odour and appearance placed groundnut oil before palm olein, but the differences in score were very small and probably not significant. Palm olein was preferred to palm oil because it had lower tendency to give greasy mouth feel. This was attributed to its reduced content of high melting glycerides. Faur's general conclusion was that catering establishments could consider palm olein and palm oil as excellent products for deep frying. This recommendation is particularly significant in the light of the high French standards of cuisine and their strong traditional preference for groundnut oil.

A team from the United States Department of Agriculture (USDA) Research in Athens, Georgia, compared potato crisps fried in cottonseed oil, sunflower oil and palm oil (3). Cottonseed oil was regarded as the standard frying oil for crisps at the time (1975-1978), but imports of palm oil had more than doubled in 1975 to 436,000 tonnes, with a large proportion being used for potato crisps manufacture. It was thought desirable to evaluate the quality of palm oil fried crisps after storage.

The potatoes were fried for 2 minutes at 180°C in a continuous fryer. After 12 hours of frying, samples were taken, placed in standard packaging and stored at 31°C and 50% Relative Humidity (RH) for 10 weeks. Reference samples fried in cottonseed oil were stored at 20°C until evaluation. The sensory scores of the three experimental batches deteriorated at a similar rate and all approached off-flavour at the end of storage. The colour of crisps fried in palm oil was lightest throughout storage.

Analysis of the used frying oils after 10 weeks showed that palm oil had a slightly higher acidity at 0.22% but it had the lowest increase in viscosity, the least drop in iodine value and the lowest peroxide value and anisidine value.

Analysis of oil extracted from the crisps showed that the palm oil had no increase in peroxide value, unlike the other two oils, the lowest anisidine value and no loss of linoleic acid.

The team concluded, "the three oils could probably be used interchangeably". However, the analytical results indicated that under long term use in manufacture, palm oil would probably last longer. At this time the potato processing industry in the north western states of the United States of America (USA) recognised the greater economy of palm oil, since bulk shipping to Portland, Oregon was cheaper than rail transport from the middle west, and there was a favourable price differential for palm oil.

Toregard and Eriksson (4) took oil from experimental batch frying of potatoes to evaluate various analytical procedures. They concluded that sensory analysis and the chromatographic assay of polar materials were the most useful tests. Palm olein and palm oil could be used for a longer period than hydrogenated soya bean oil before reaching a limiting taste score of 2.3. The respective usable periods were 84, 80 and 44 hours. The organoleptic tests did not agree well with analytical constants. 28% total polar materials were reached by the three oils after 24, 27 and 29 hours, respectively.

Bracco and co-workers (5) from the Central Research Laboratory of Nestle compared groundnut oil with palm olein in batch fryers. Oil was heated to 180°C and potatoes were fried intermittently over more than 100 hours. The following Table 5.2 gives analytical results for the two oils after 82 hours.

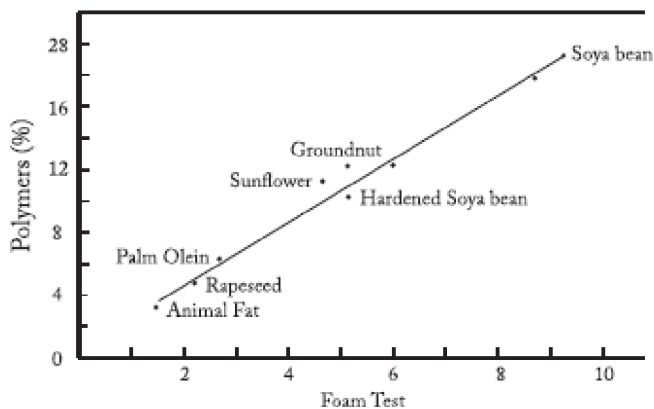
Table 5.2
Deterioration during Frying

Oil	Hours	Free Fatty Acids %	Smoke Point °C	Viscosity cP	Polymers %	Foam Index *
Groundnut oil	0	0.02	235	50	0.2	
	82	0.28	229	102	12.6	10.2
Palm oil	0	0.03	222	49	0.4	
	82	0.32	182	72	6.3	9.4

Note:* The foam index is an empirical measure of foam stability. It was defined as the time that foam from used oil remained stable at a standard height in a jacketed tube, divided by the time required by the fresh oil. The tube was heated to 180°C and 5 g of potato cubes were dipped into 35 g of the hot oil.

A number of other frying oils were tested by the same procedure. A linear relationship was found between the foam test and the polymer content, as shown in Figure 5.1.

Figure 5.1
Foam Test and Polymers after 72 hours



It was concluded that palm olein performed at least as well as groundnut oil in batch frying. Subsequently they monitored performance of palm olein in an industrial scale continuous fryer. They concluded that used palm olein showed less degradation and had a longer induction period than groundnut oil and it produced fried foods of acceptable keeping properties.

Herendi and Bethke (6) reported frying tests carried out in 20 litres of oil. The oils were heated at 180°C for 8 hours a day and 1 kg of French fries were cooked every hour. After 48 hours the proportion of non-polar materials and the smoke point were measured (See Table 5.3 below).

Table 5.3
Analysis of Used Oils

	Non-polar Materials	Smoke Point °C
Hardened palm oil	83%	186
Palm oil	72%	181
Hardened soya bean oil	71%	190
Soya bean oil	64%	177

Palm oil performed somewhat better than soya bean oil.

In 1985, Japanese consumption of palm oil for frying was estimated as more than 50,000 tonnes, (7) of which some 20,000 tonnes were used for Chinese noodles. Sakata and co-workers reported laboratory batch frying tests. They maintained oil at frying temperature for 8 hours/day for 3 days and each day fried 3 batches of Chinese noodles. The conditions chosen, with the oil kept hot but unused for long periods, were very severe. After 8 hours the tocol content was reduced from 237 ppm to 8 ppm, but when 2-ppm silicone oil was added the residual tocols were 171 ppm. Similar results were obtained for French fries. For snack foods, a blend of palm olein with either rice bran oil or corn oil was preferred, to retain the characteristic flavours of these oils.

It was concluded that palm oil had excellent properties against oxidation and was generally accepted by consumers.

Arroyo (8) studied total polar materials formed on frying potato slices in palm olein: 60 successive fryings were carried out without the addition of fresh oil. Several fryers were operated in parallel, and oil volume was maintained with used oil from one of them (which was then shut down). Under these severe conditions the total polar materials increased from 8.9% to 17.5%, still below the critical level of 25%. Most of the original 8.9% total polar materials consisted of diglycerides. These results were superior to those obtained in earlier tests (9) with sunflower oil when total polar materials increased from 3.75% to 27.3% in 60 fryings under the same conditions. It was concluded that palm olein "exhibited unique stability in frying applications".

An extensive collaborative project on the frying properties of high oleic "Hosun" oil and normal sunflower oil was sponsored with European Union (EU) funds. In these experiments palm olein was used as the reference oil. Details of the study were published in a special issue of the Spanish journal *Grasas y Aceites* in 1996. The oils were used to fry potato crisps under industrial conditions and the development of polar materials was analysed in detail on the fresh oil and over 2 days continuous frying (10).

The results were given in Table 5.4. The oils used were palm olein, sunflower oil and Hosun oil.

Table 5.4
Classes of Total Polar Materials (%) in Different Oils during 2-Day Frying

Oil Type	Day	TGP	TGD	Ox TGM	DG	FFA	Total
Palm Olein	0	0.08	0.38	0.61	6.52	0.11	7.7
	1	0.18	1.04	0.99	6.58	0.21	8.7
	2	0.19	1.09	1.02	6.35	0.25	8.9
Sunflower Oil	0	0.04	0.36	0.83	1.06	0.51	2.8
	1	0.11	1.49	1.44	1.28	0.58	4.9
	2	0.17	1.68	1.48	1.30	0.57	5.2
Hosun Oil	0	0.05	0.26	0.69	1.63	0.47	3.1
	1	0.07	0.80	1.11	1.82	0.51	4.3
	2	0.11	1.04	1.29	1.94	0.52	4.9

TGP = triglyceride polymers
 TGD = triglyceride dimers
 Ox TGM = oxidised triglyceride monomers
 DG = diglycerides
 FFA = free fatty acids

After 2 days total polar materials for the three oils were well below the recommended maximum. The figure for palm oil was mainly due to the typical level of diglycerides in the oil, and it showed no increase with use. Sunflower oil showed a higher increase in dimers and polymers than the other oils.

Table 5.5 shows the oxidative stability of the crisps during room temperature storage (11).

Table 5.5
Storage Stability of Crisps

Oil		Initial	25 weeks
Sunflower oil	α -tocopherol (mg/kg)	606	497
	OSI *	9.3	2.5
High oleic sunflower oil	α -tocopherol (mg/kg)	571	576
	OSI	21.8	18.5
Palm olein	α -tocopherol (mg/kg) **	207	198
	OSI	38.5	42.2

Notes: * Rancimat determination at 100°C on crisps
 ** Excludes other tococls

In accelerated storage tests of the crisps at 60°C the α -tocopherol and stability were at, or close to, zero after 14 days for the sunflower oil product and 35 days for the high oleic variety, whereas palm olein crisps were still stable.

The greater stability of crisps fried in palm olein was confirmed by measurement of peroxide value and hexanal during storage at room temperature (12) (13) and by sensory evaluation (14). Palm olein gave the most stable crisps, sunflower oil being the least stable.

A group of workers at the University of Zagreb (15) compared the frying performance of palm oil with the locally available blend of rapeseed oil and soya bean oil (80:20). 18 batches of sliced potatoes were fried daily for a total of 80 hours in small batch fryers and the fryers were topped up daily with fresh oil.

After 52 hours the vegetable oil blend was no longer fit for use; palm oil was usable for 80 hours. The normally accepted limit for total polar materials was reached in 44 hours with the vegetable oil blend, and in 80 hours with palm oil. Analytical data obtained at this point is shown in Table 5.6.

Table 5.6
Analytical Values at Point of Rejection

	Vegetable Oil Blend	Palm Oil
Time of Use (hour)	44	80
FFA (as Oleic Acid %)	0.33	0.46
Peroxide Value (mmole/kg)	2.1	2.2
Anisidine Value	145	89
Drop in Iodine Value	5.6	3.3
Total Polar Materials (%)	26	26
Time to Foaming (hour)	30	> 80
Colour (Lovibond Red in 5¼" Cell)	darker	lighter

Palm oil gave superior performance. It did not give the unpleasant room odour given by the vegetable oil blend.

Sebedio et al. (16) reported on oil quality during the industrial frying of French fries in palm oil prior to freezing. Samples were taken for analysis over 2 weeks of 5 working days and the quantity produced daily varied according to orders. The oil content of the product averaged at 5.5%. As a result of the low oil uptake the turnover rate in the fryer would be rather low, so the stress on the frying oil would be quite severe. However, the analytical results as summarised in Table 5.7 showed that steady state conditions were reached with acceptably low levels of free fatty acids, total polar materials and polymers. Other analyses for thiobarbituric acid value and Oxifrit Test also gave low figures.

Table 5.7
Changes in Quality Parameters of Palm Oil during Industrial Frying of Frozen French Fries

Day of Frying	Production (tonnes)	FFA (%)	FOS (unit)	Total Polar Materials (%)	Polymers (%)
0	-	< 0.05	-	13.5	0.4
1	8.3	0.14	0.6	13.4	1.4
2	9.5	0.27	1.3	17.9	1.3
3	10.7	0.24	1.1	18.5	3.5
4	15.4	0.39	1.3	21.2	4.7
5	10.0	0.41	1.4	23.4	4.2
6	12.7	0.45	1.5	17.8	5.2
7	17.5	0.39	0.8	19.9	3.3
8	17.8	0.41	1.4	16.3	4.5
9	12.6	0.33	1.0	19.6	3.7
10	6.5	0.40	1.3	21.8	1.0

It was noted that the high value for total polar materials in the fresh oil was not due to alterations in the oil, but was related to the diglyceride content. However, the figure of 13.5% total polar materials was exceptionally high for palm oil, which normally contains 5-6% diglycerides, corresponding to no more than 7-8% total polar materials. The figures obtained after frying should be interpreted after allowance was made for the initial figure, though it was pointed out that assessment of the oil quality based on the polymer content was more reliable in the case of palm oil.

Analyses for cyclic fatty acid monomers were also carried out. This component is nutritionally undesirable as it may have toxic effects. The level in the fresh oil was 0.02%, appropriate for good quality oil, while the highest values on used oil were only 0.07% and 0.10%.

It may be concluded that this thorough study of a commercial operation showed palm oil to be a very suitable frying medium for the production of part-fried French fries.

Shyu et al. (17) compared the behaviour of soya bean oil, lard and palm oil when used for the vacuum frying of carrot slices. 8 batch/day were fried for 6 days at 105°C and 20 torr. Analysis of the oils after 48 hours of frying is shown in Table 5.8.

Table 5.8
Analysis of Oils Used for Vacuum Frying of Carrots

	Palm Oil	Lard	Soya bean Oil
Peroxide Value (meq/kg)	23	26	28
Acid Value (mg/KOH/g)	0.18	0.17	0.14
Carbonyl Value (meq/kg)	15	22	28
Total Polar Materials (%)	13	14	18.5
FOS Reading	2.0	2.0	2.7
Viscosity (cP)	45	43	58

It was concluded that palm oil and lard had greater thermal stability than soya bean oil, which also showed the largest decrease in the C18:2 /C16:0 ratio.

Du Plessis and Meredith (18), working at Commonwealth Scientific and Industrial Research (CSIR), Pretoria, South Africa, carried out sensory evaluation and analysis of potato crisps taken at intervals from a commercial production line using palm olein. Crisps were stored at 35°C and 80% relative humidity. During frying the free fatty acid content rose from 0.1% for fresh oil to 0.41% after 31 hours frying. Tasting tests on samples stored for 30 days showed that the overall freshness score (on a scale of 1 to 5) had dropped to 3.3 for samples taken when free fatty acids had reached 0.41% and to 2.9 for samples taken at 0.16% of free fatty acids. The latter result was regarded as of borderline quality. It is generally recognised that product flavour is better at moderately increased free fatty acids. The samples showed adequate storage life. Total polar materials increased during the 30 hours from 8% to 12%. The latter was one half of the regulatory limit in South Africa. Polymerised glycerides increased from below 1% to 2.1%: negligible, in comparison with the behaviour of unsaturated oils.

A team from a Food Science Australia laboratory (19) carried out batch frying tests on six oils. Three were newly developed canola oil with low (LLC), medium (MLC) and high (HLC) linoleic acid content. They were compared with sunflower oil (SO), commercial palm oil (PO) and partly hydrogenated canola oil (PHC). The latter two oils contained TBHQ and 4 ppm of anti-foaming agent.

French fries were fried intermittently. They had been part-fried in tallow before freezing. Analysis and tasting tests were carried out on samples taken during 80 hours of operations.

Total polar materials were measured using the TPM Veri-Fry PRO quick test after it had been calibrated against the AOCS method. The results, reported as smooth curves, were somewhat unexpected. A level of 2% total polar materials was reached in the following order: HLC after 48 hours, PO and MLC 53 hours, LLC 56 hours, SO 57 hours, and DHC 73 hours. The dielectric constant measured by the FOS gave a similar order for the oils except for commercial palm oil. A quality limit of about 4 units had been proposed elsewhere. This was reached in the following order LLC and MLC 18 hours, HLC 25 hours, SO and PO 42 hours, and PHC 61 hours.

It was stated that palm oil was popular for fast food outlets due to its oxidative stability and good flavour stability. Their tasting tests showed mean scores for overall quality as follows: SO and LLC 6.1, PO 5.9, MLC 5.8, HLC 5.4, PHC 3.9. The scores for SO and LLC were significantly higher than the other oils ($p < 0.05$) according to the statistical analysis. The difference between 6.1 and 5.9 was however rather small, and may indicate a subconscious preference for a known flavour. The analytical results for palm oil in relation to the other oils examined were somewhat out of line with the published experience of others.

Zalewski and co-workers (20) at the Warsaw Agricultural University in Poland examined the properties of potato crisps and French fries prepared in palm olein, rapeseed oil and various blends. The products were fried intermittently and samples were examined organoleptically and analytically at intervals. The results are summarised in Table 5.9, for samples taken after 40 hours.

It was concluded that the quality of potato products fried in rapeseed oil/palm olein blends was superior to that using rapeseed oil alone.

Table 5.9
Analytical and Tasting Results on Fried Potato Products

Oil	French Fries		Crisps	
	Total Polar Materials	Taste Score	Total Polar Materials	Storage Life
PO	22	7.2	20	> 6 months
RSO	40	5.7	38	4 months
POL:RSO 50:50	32	6.2	30	5 months
HRSO	22	6.8	20	3 months
POL:POS:RSO 40:40:20	29	6.6	28	5 months

PO = palm olein (IV56)
HRSO = hydrogenated rapeseed oil
POS = palm stearin (IV48)

The work of E.W. Hammond has already been discussed in Chapter 2 (Chapter 2 (9)). It described the manufacturing operations of one of the largest snack food manufacturers in Europe. They continue to use palm olein of strict quality specifications. For some crisps products a proportion of refined red palm olein was used because it imparts an attractive golden colour to the crisps. Incidentally, the carotene content added to the nutritional quality.

Guinda et al. (21) compared the behaviour at frying temperature of palm olein with oil from mutant sunflower seeds obtained by x-radiation. The main fatty acids component of the sunflower oil were 57.7% oleic, 3% palmitoleic, 2.3% linoleic and 27.8% palmitic; while the palm olein contained 42.1% oleic, 12.3% linoleic and 38.7% palmitic acids. 2-g samples of oil were heated in open tubes (1 cm diameter) in a Rancimat apparatus at 180°C without air bubbling.

Analytical results on the oils before and after heating are shown in Table 5.10 below.

Table 5.10
Analysis of Heated Oils

	Sunflower Oil		Palm Olein	
	Initial	Heated 10 hours	Initial	Heated 10 hours
Induction period by Rancimat at 120°C (hours)	19		9	
Tocols (mg/kg)	870	200	470	Nil
Total polar materials	2.8	7.6	8.4	18.8
Oxidised monomer triglycerides	0.3	2.6	1.0	5.6
Triglyceride polymers	0.1	2.4	0.6	6.5
Diglycerides	1.8	1.9	6.4	6.4
Free fatty acids	0.6	0.7	0.3	0.3

Notes: In the palm olein, tocols had fallen to nil after 6 hours.

It was concluded that the better resistance to oxidation of the sunflower oil was due to its lower content of polyunsaturateds and higher tocopherols.

Sunflower oil, corn oil, partly hydrogenated soya bean oil (mpt 26-28°C) and partly hydrogenated palm oil (mpt 42-44°C) were used in batch fryers to cook meat croquettes and French fries at 185°C (22). The routine used was to fry for 3 periods of 30 minute/day and in between to hold the oil at 120°C for 6 hour/day. Oils were rejected when the flavour became unacceptable. Analyses at the rejection point are shown in the table 5.11.

Table 5.11
Analysis of Oils Used for Frying Meat Croquettes

	SFO	Corn Oil	HSBO	HPO
Rejection point (hours frying)	10.5	12	9	4.5
Polymers % - croquettes	8	18.5	24	3
Polymers % - French fries	3.5	4	5	1.5
Total polar materials % - croquettes	33	29	19	15
Total polar materials % - French fries	9	10	12	10

SFO = Sunflower Oil
HSBO = Partly Hydrogenated Soya Bean Oil
HPO = Hydrogenated Palm Oil

It was interesting to note the difference in analytical results depending on the product fried. The surprisingly poor performance of the hydrogenated palm oil was unable to be accounted for.

In a report at a recent conference (23), Matthaus described a comparison between high oleic (>70% 18:1), low linoleic rapeseed oil, "Natreon", palm olein, high oleic sunflower oil and partly hydrogenated rapeseed oil.

The test consisted of heating 2½ litres oil of each variety at 175°C for 1 hour, during which time 50 g of part-fried potatoes were fried for 3½ minutes. This process was carried out for 6 hours a day for a total of 72 hours. At this point Natreon contained 6% oligomers while the other oils contained 7%.

Total polar materials showed a nearly linear increase with time: final results showing Natreon with 10%, high oleic sunflower oil and partly hydrogenated rapeseed oil 11%, and palm olein 14% (initially 6%). The taste of potatoes was satisfactory for all oils at 54 hours, although the used palm olein scored lower for flavour at this point. After 54 hours lower taste scores were obtained for all oils. It was concluded that Natreon oil was comparable to the other oils in frying performance, and nutritionally superior to the partly hydrogenated rapeseed oil and the palm olein.

It is evident from this review that palm oil meets the performance requirements of the restaurant chef, the snack bar operator and the large scale food manufacturer all over the world. While there are other oils with similar performance, they are more costly. Since oil is usually the most expensive of the major ingredients of a fried food product, its price is an important factor in the overall economy of the production line.

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Review Of MPOB Projects On Frying

The Palm Oil Research Institute of Malaysia (now part of the Malaysian Palm Oil Board (MPOB)) has had a continuing programme of research on frying since its inception. The objective is to provide information facilitating the use of palm oil anywhere in the world.

In some projects the relevant physical or chemical properties were investigated, while others researched into specific applications, often in collaboration with a user or potential user.

As regards bottled oils for the retail market, two important factors are the clarity of the oil on the shelf, and its freedom from rancidity. While palm olein has exceptionally good keeping properties, its cloud point is rather high, and is improved by blending with liquid oils.

The following Table 6.1 gives results of initial studies for the induction period and cloud point for a number of oils and their blends containing 30% palm olein (1).

Table 6.1
Induction Period at 100°C and Cloud Points of Oils and Blends

Oils and Blends	Induction Period (hours)	Cloud Point (°C)
RBD Palm olein	44.0	9.6
Cottonseed	11.1	-3.0
Cottonseed / Palm olein	-	5.0
Groundnut	15.0	1.9
Groundnut / Palm olein	21.0	2.0
Corn	9.0	-9.5
Corn / Palm olein	12.0	-1.9
Olive	11.8	-10.0
Olive / Palm olein	-	-10.0
Rapeseed	11.5	-5.0
Rapeseed / Palm olein	16.0	0.0
Sesame	8.0	-
Sesame / Palm olein	7.0	0.3
Soya bean	16.0	-9.0
Soya bean / Palm olein	19.0	-2.2
Sunflower	6.0	-9.5
Sunflower / Palm olein	7.0	-2.3

RBD = Refined bleached and deodorised

It will be noted that in general the blends have better keeping properties than the 100% oils. The cloud points are suitable for bottled oils.

The effect of the permitted additive oxystearin on the cloud point of palm olein-soya bean oil mixture was determined. The results are given in Table 6.2 below (2). The effect was rather small.

Table 6.2
Cloud Point of Palm Olein/Soya bean Oil Blend

Palm Olein Content	10%	20%	40%	50%
With oxystearin (0.1%)	-7.3	-5.2	-1.7	-0.2
Without oxystearin	-6.4	-4.0	-1.6	-0.6

The measurements of physical properties were subsequently extended, and generated the information given in Tables 1.3 -1.9 in Chapter 1.

For industrial users the clarity of the oil is not important, but the ability to easily pour oil out of its container is of practical value. The AOCs pour point method was used to assess the effect of additives on this property. The results are given in Table 6.3.

Table 6.3
The Effect of Additives on Pour Point (°C)

Palm Olein: Soya bean Oil	No additive	Tween 20 0.01%	Tween 60 0.01%
100:0	4.3	3.1	4.2
75:25	3.0	0.2	1.9
50:50	2.0	0.0	0.7
25:75	-2.0	-4.6	-0.4
0:100	< -4.0	< -6.0	< 0.0

Tween 20, a permitted food additive, had a useful effect at the low level of 0.01%. Its effect on frying properties was not investigated.

A series of frying experiments was carried out comparing vegetable oils listed in Table 6.1 with their blends with 30% palm olein (3). For this purpose a standard routine was established.

Valentine fryers using 5 kg oil were used at 180°C. 100 g of French fries were fried for 4 minutes, 10 batches in an 8-hour day for 5 days. This procedure was very similar to that used by other workers. These conditions were rather severe, since the oil was kept hot with relatively little frying. Tasting tests showed that the oil had developed distinctive burnt or rancid flavours after 4 days (32 hours) operation, while the product had off-flavours on the 5th day.

A number of analyses were carried out daily on the oils. In view of the results of the tasting tests, the oils should, in normal use, have been discarded during day 4. The results of the most useful analyses are given in Table 6.4 for samples drawn at the end of day 3. In general, the results for polymers and oxidised fatty acids were lower in the blends. It may be noted however that all the oxidised fatty acid contents were above the limit of 1% generally advised. This was an indication of the somewhat severe conditions of the test.

Table 6.4
Analysis of Frying Oils after 3 Days Use

	Rapeseed		Sunflower		Soya bean		Groundnut		Olive		Cottonseed		Corn		Sesame	
	Oil	Blend	Oil	Blend	Oil	Blend	Oil	Blend	Oil	Blend	Oil	Blend	Oil	Blend	Oil	Blend
Free Fatty Acids (%)	0.4	0.41	0.29	0.30	0.14	0.18	0.78	0.71	0.65	0.67	0.33	0.39	0.36	0.36	0.54	0.52
Viscosity at 40°C (poise)	9.7	8.7	10.0	9.9	5.3	6.0	6.8	7.5	12.0	9.8	9.5	10.6	9.6	9.9	10.1	9.0
Polymers (%)	2.8	1.8	2.8	2.3	1.4	1.2	1.5	0.7	-	-	2.8	2.2	-	-	2.2	1.4
Colour (Lowlbond Red in 5¼" cell)	9.0	8.3	3.5	5.0	-	-	14.2	16.2	2.0	2.0	4.5	4.7	8.1	8.1	8.0	8.0
Oxidised acids (%)	3.3	1.7	5.1	2.9	2.5	1.7	2.7	3.0	2.2	3.0	2.3	2.2	3.4	3.4	3.3	2.4
Smoke point (°C)	192	190	203	208	212	210	162	171	192	190	194	193	207	202	180	187

None of the other analyses show significant differences between the oils and their palm olein containing blends. It may therefore be concluded that the performance of the blends is likely to be somewhat better than that of the oils in a practical operation. In normal market conditions the blends will be more economical.

The effect of antioxidants on the frying performance was investigated in batch frying (4). Refined palm olein (iodine value 62.3) with the addition of 194 ppm of TBHQ and 2 ppm of silicone was compared with the same oil without additives.

The oils were heated to 177°C for 8 hours per day over 5 days and 500 g portions of chicken nuggets were fried for 3½ minutes every half an hour. At the end of the day the oil was topped up. Analyses were carried out on the unused oil and at the end of day 3 and day 5. The following Table 6.5 summarises the results.

Table 6.5
Analytical Values of Frying Oil with and without Antioxidants

Analysis	Palm Olein without Antioxidants			Palm Olein with Antioxidants		
	Initial	Day 3	Day 5	Initial	Day 3	Day 5
Free Fatty Acids (%)	0.04	0.45	0.76	0.04	0.33	0.48
Smoke Point (°C)	229	188	182	228	200	190
Anisidine Value	1.87	43.4	66.15	1.80	18.32	20.27
Total Tocols (ppm)	746	332	214	740	583	450
Total Polar Materials (%)	6.7	16.0	20.8	6.6	9.4	11.6
Polymers (%)	0.45	2.56	3.80	0.44	2.02	2.41
Oil Stability Index (hours at 110°)	21	17	12	49	34	32

All the results demonstrated the benefit on oil quality with the combined antioxidants but both oils were judged to be suitable for further use. Samples of chicken nuggets were submitted to a taste panel for evaluation of flavour and textural characteristics. There were only small non-significant changes during the 5 days and all the samples were of good quality. In view of the good condition of the oils this result was to be expected.

The oil absorption characteristics of soya bean and palm oil products were compared in the preparation of French fries (5). The characteristics of the oils used are given in Table 6.6.

Table 6.6
Analysis of Oils

	Palm Oil	Palm Olein	Soya bean Oil	Partly Hydrogenated Soya bean Oil
Melting Point (°C)	37.0	20.0	-	35.0
Iodine Value	52.0	56.1	135.1	73.9
Polymers (%)	0.62	0.47	0.84	1.04
Total Polar Materials (%)	7.96	7.84	5.89	5.20
Smoke Point (°C)	214	216	217	219

The part-fried frozen French fries (oil content 5%) were fried for 4 minutes at 180°C in batch fryers. 70 batches were fried at regular intervals over 5 days and the oil was kept hot for 8 hours per day.

Table 6.7 below gives the oil, polymer and total polar materials (TPM) content of the potatoes at the end of each day.

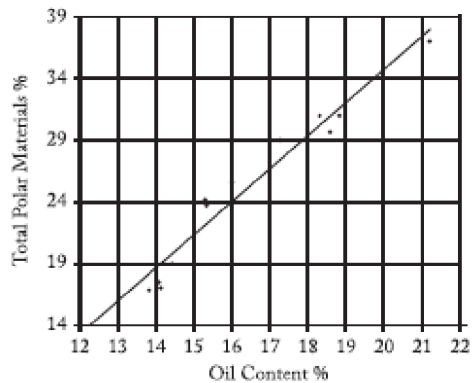
Table 6.7
Oil Absorption and Oxidation Products

Oil Used	Palm Oil			Palm Olein			Partly Hydrogenated Soya bean Oil			Soya bean Oil		
	Oil %	Polymer %	TPM %	Oil %	Polymer %	TPM %	Oil %	Polymer %	TPM %	Oil %	Polymer %	TPM %
0	5.16	0.62	7.96	5.19	0.47	7.84	5.19	1.04	5.85	5.19	0.84	5.11
1	14.15	2.35	16.57	13.87	2.12	15.85	14.10	2.68	16.60	14.32	3.24	18.00
2	14.40	-	-	14.45	-	-	14.38	-	-	14.56	-	-
3	15.39	3.60	24.18	15.36	3.81	24.39	16.00	4.22	25.54	17.19	6.55	29.33
4	17.01	-	-	16.64	-	-	16.89	-	-	19.15	-	-
5	18.67	5.14	30.00	18.37	4.96	30.21	18.82	6.17	30.33	21.22	8.29	37.40

It was noted that under the experimental conditions used, all the oils had reached levels of total polar materials at the rejection point.

There is a clear linear relationship between the oil absorbed and the content of total polar materials, as shown in Figure 6.1. The results are of general interest since the increased fat uptake, even at moderate levels of polar materials, would have some effect on product quality.

Figure 6.1
Oil Content of French Fries and Total Polar Materials of Frying Oil



A direct comparison in the batch frying of potato crisps in palm olein and in high oleic sunflower oil was carried out over 5 days. Both oils gave satisfactory performance, with insignificant differences in analyses for total polar materials, polymers, free fatty acids and smoke point at the end of 5 days (6). This conclusion is in agreement with the results reported by Appelquist for a continuous industrial frying operation (see Chapter 5).

Crisps were packed in standard metallised bag and stored at room temperature. Tasting tests and analyses were carried out at intervals. After 16 weeks no off-flavours or rancidity were detected and the general quality was considered acceptable by the taste panel. Peroxide levels (4 meq/kg) and free fatty acids (0.4%) were not significantly different at the end of storage.

A comparison of frying potatoes in corn oil, soya bean oil and palm olein purchased in a local supermarket (Kuala Lumpur) was carried out in collaboration with the local Agricultural University (7). Three batches of each oil were used for intermittent frying of 2-mm potato slices at 180°C, 10 fryings per day over 10 days. Oil was kept hot for 5 hours per day. Analysis showed that total polar materials in two out of the three batches of soya bean oil and corn oil exceeded 25% after 3 days use, while the palm olein batches lasted 4 days under the rather severe oxidising conditions. Palm olein contained no added antioxidant, soya bean oil contained BHA and the corn oil contained TBHQ. The polymer content was also lower in the palm olein than the other oils. It was also observed that a sticky deposit formed on the fryer with corn and soya bean oils and there was more persistent foam formation. Used soya bean oil gave off-odours when heating up for reuse.

It was concluded that palm olein showed greater staying power and would be more economical in use.

A comparison was carried out between continuous production and batch frying of potato crisps in palm olein (8). The continuous fryer held 2 tonnes of oil and produced 4 tonnes of crisps in an 8-hour day, and oil was discarded if the free fatty acids content reached 0.5%. The batch fryer was also operated for 8 hours per day, during which 45 batches of potato slices were fried for 4 minutes at 180°C. Oil was replenished with about 30% fresh oil at the end of the day.

The results are summarised in Tables 6.8 and 6.9.

Table 6.8
Changes in Total Polar Materials and Polymer Compounds during Industrial and Batch Frying of Potato Crisps

Frying Time (hours into week)	Total Polar Materials (%)		Polymer Compounds (%)	
	Industrial	Batch	Industrial	Batch
0	5.9	6.0	< 0.5	< 0.5
8	8.1	11.3	1.2	1.6
16	9.5	13.4	1.6	2.0
24	9.2	12.7	1.4	2.4
32	9.7	14.0	1.5	2.3
40	10.1	15.8 (frying stopped)	1.9	2.6 (frying stopped)
79	11.0		1.7	
119	9.8		1.8	
158	10.4		1.9	
197	10.2		2.4	
236	9.9		1.9	
276	10.3		1.6	
316	10.0		1.8	
1900	11.0		2.3	

Table 6.9
Changes in Total Tocopherols and Tocotrienols and Induction Period during Industrial and Batch Frying of Potato Crisps

Frying Time (hours into week)	Total Tocotrienols and Tocopherols (ppm)		Induction Period (hours, OSI at 110°C)	
	Industrial	Batch	Industrial	Batch
0	810	816	24.2	24.4
8	672	505	22.8	19.0
16	540	-	20.2	-
24	551	328	21.4	16.8
32	545	210	20.8	12.3
40	556	101 (frying stopped)	21.0	9.7 (frying stopped)
79	519		19.6	
119	533		22.3	
158	540		22.1	
197	520		21.8	
236	529		20.0	
276	530		21.0	
316	548		22.5	
1900	527		22.9	

The batch frying operation was stopped when the oil had reached the discard limit for free fatty acids. At this point the total polar materials and polymers were well below the accepted rejection limits. The tocopherols and induction period had fallen, and would soon reach unacceptably low levels if the oil continued in use. In contrast, all these characteristics were at a stable and satisfactory level in the continuous operation, as was the free fatty acid content (0.24%). This was due to the high turnover (8-10 hours) of the operation. The oil was clearly suitable for continued use.

Collaborative Studies with other Research Institutes

Studies of the behaviour of rice bran oil and double fractionated (super) palm olein were carried out together with the Korean Advanced Institute of Science and Technology (9). Firstly, the effects of heating at 180°C were examined. Oil was heated in a batch fryer without agitation and samples were withdrawn for analysis at intervals, without affecting the surface area exposed.

The results obtained are shown in Table 6.10.

Table 6.10
Chemical and Physical Changes due to Heating

Analytical Characteristics	Heating Time (hours)	Rice Bran Oil	Super Palm Olein
Free Fatty Acids (%)	0	0.17	0.23
	50	0.64	1.30
Smoke Point (°C)	0	224	213
	50	198	191
Colour (Lovibond Red in 5¼" Cell)	0	4.3	3.1
	50	38.0	32.1
Yellow Colour	0	40	30
	50	30	25
Iodine Value	0	102.5	62
	50	83	53
Loss of Unsaturated Acids (%)	50	19.8	16.1

The increase in free fatty acids was greater in palm olein than in rice bran oil, but other characteristics changed more in the rice bran oil.

The flavour stability of the two oils and their blends was also evaluated (10). The samples were stored in sealed serum bottles at 60°C in the dark and headspace analysis was carried out by gas chromatography. The formation of volatiles and the evolution of hydrogen over time are shown in Figures 6.2 and 6.3 below.

Figure 6.2
Effect of Storage Time on Formation of Volatile Compounds in Headspace of Oils

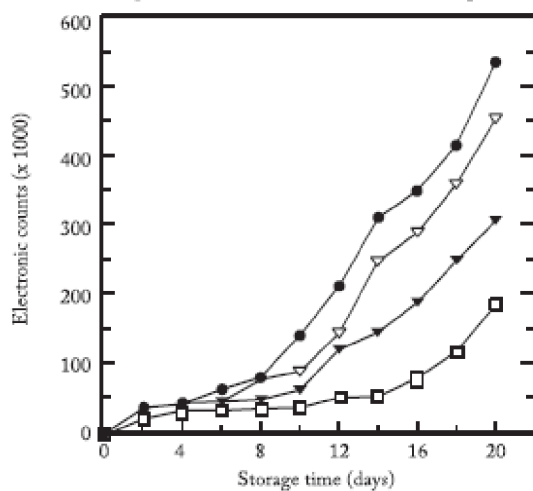
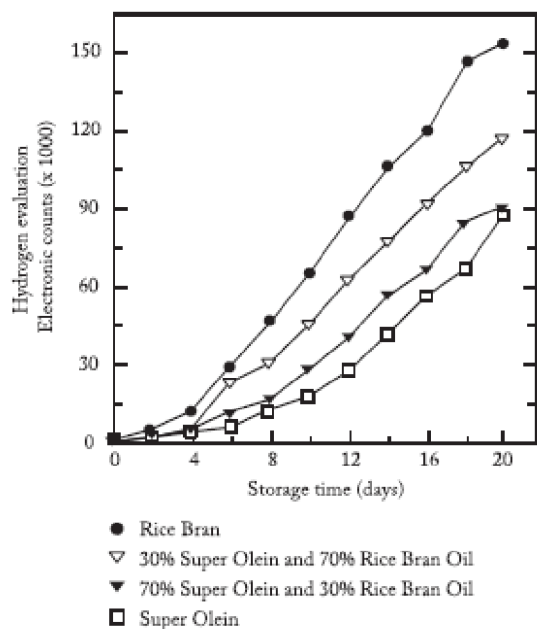


Figure 6.3
Effect of Storage Time on Hydrogen Content in Headspace of Oils



The main volatiles formed from lipid oxidation were butane, pentane, propanal and hexanal. According to E.N. Frankel, a well-known authority on autoxidation, flavour quality showed a very good inverse correlation with the content of total volatile compounds. Hydrogen was released from the carboxyl groups of fatty acids during the early stage of autoxidation.

The induction period of the oils was measured by Rancimat at 130°C. For superolein it decreased from 6.6 hours to 3.8 in 20-day storage and for rice bran oil from 2.6 to 2.0 hours, with the blends giving intermediate results. The overall conclusion was that superolein had higher flavour stability than rice bran oil, and in the blends the superolein imparted greater flavour stability on the rice bran oil proportionally.

Another study initiated at the request of South Korean users concerned the manufacture of instant noodles. The instant noodle process is described later in Chapter 7. The request was for a frying medium that was cheaper than palm oil. It was decided to investigate blends of palm oil with palm stearin. In the study, fresh steamed noodles were obtained from a local manufacturer and immediately fried in a batch fryer. Palm oil and blends with 30-60% of palm stearin were used. The stearin had a melting point of 44.2°C and iodine value of 47.6. After frying at 132°C the noodles were packed.

The packed noodles were then cooked in boiling water for 3 minutes and submitted to a trained taste panel in triangle tests. They were tasted while hot, as would be the case in normal consumption.

The results showed that noodles fried in blends containing 50% stearin or less were not significantly different from those fried in palm oil and storage tests indicated a minimum shelf life of 4 months.

Melting point and solid fat content of the oil were considered to be the important factors for palatability. Table 6.11 gives the relevant data for commercial oil and for the blends used.

Table 6.11
Solid Fat Content of Oils for Noodle Frying

Oil	Melting Point (°C)	Solid Fat Content (by Nuclear Magnetic Resonance (NMR))						
		10°C	20°C	25°C	30°C	35°C	40°C	45°C
Commercial frying oil	33.3	53.6	23.1	15.7	9.5	6.3	3.0	-
Palm oil (PO)	36.3	53.3	23.0	16.0	9.8	6.9	3.1	-
PO/POS 70:30	39.5	56.8	28.7	20.9	13.1	9.5	5.9	4.1
PO/POS 50:50	40.7	58.6	32.4	23.8	16.5	11.9	8.0	5.9
PO/POS 40:60	41.5	59.0	34.0	24.7	17.4	13.4	9.5	6.2
Palm Stearin (POS)	44.2	63.9	39.9	29.7	21.4	16.5	12.5	8.9

It was concluded that any blend of oils with characteristics similar to those of the 50:50 POS:PO blend in the table would be satisfactory. Since the characteristics of commercial palm stearin vary over a range (11), the proportion of stearin to be used should be decided on the basis of the solid content profile of the blend.

A collaborative study was carried out with the Tubitak Marmara Research Centre in Turkey. The study had two objectives; firstly, to compare the behaviour in the frying of palm olein (iodine value 60) with locally produced olive, sunflower and soya bean oils, and secondly to examine the behaviour of blends with palm olein suitable for the retail market in Turkey.

14 batches of potatoes/day were fried over 8 hours per day for a total of 5 days. 11 analytical tests were applied, and the results are shown qualitatively in Table 6.12.

Table 6.12
Summary of Results of Used Oil Analyses

Test	Order of Performance (best oil first)			
	1	2	3	4
Colour (Lovibond Red in 5¼" Cell)	SBO	SFO	PO _o =	OO
Free Fatty Acids	SBO	SFO	PO _o	<u>OO</u>
Smoke Point	SBO	SFO	PO _o	<u>OO</u>
Foam Height	PO _o	OO	SBO	SFO
18:2 & 18:3 Reduction	OO =	SBO =	SFO	<u>SFO</u>
Iodine Value Reduction	<u>OO =</u>	<u>PO_o</u>	SBO	SFO
Peroxide Value	OO =	SBO	SFO	PO _o
Anisidine Value	<u>OO =</u>	<u>PO_o</u>	SFO	SBO
Totox	OO	PO _o	SFO =	SBO
Polymers	PO _o	OO	SBO	<u>SFO</u>
Total Polar Materials	PO _o	OO	SBO =	SFO

PO_o = Palm olein, OO=Olive oil, SFO = Sunflower oil, SBO = Soya bean oil

OO very different from the others

= approximately equal

The monounsaturated oils showed superior performance in five of the most significant tests i.e. total polar materials, polymers, foam height, iodine and anisidine values. (12)

A series of blending experiments were carried out with palm oleins of iodine value 58, 60 and 62 and local soya bean and sunflower oils (13). Blends containing 20% of palm olein (IV60) had the required physical stability. They remained clear indefinitely at 10°C and would therefore be suitable for retail sale in Turkey. Blends with higher proportions of palm olein crystallised during storage at 10°C. In frying tests these 20% palm olein blends showed improved performance compared with the oils at 100%. There were lower increases in polymers and total polar materials, lower anisidine values and a smaller drop in iodine value.

A joint project with scientists at CSIR Pretoria, South Africa had the objective of comparing: blend (A) of sunflower oil and corn oil (90:10); and with blend (B) of sunflower oil and palm olein (30:70) in the preparation of part-fried French fries before freezing. The trials were carried out in normal production runs on a factory scale.

The results of some of the analyses are shown in Figures 6.4 to 6.7 below (14).

Figure 6.4
Free Fatty Acids (FFA) Changes during Industrial Frying of French Fries

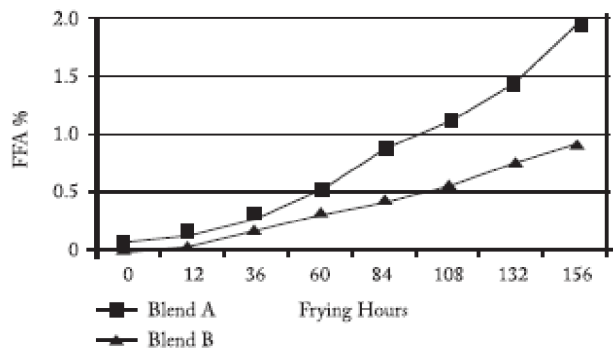


Figure 6.5
Total Polar Materials Changes during Industrial Frying of French Fries

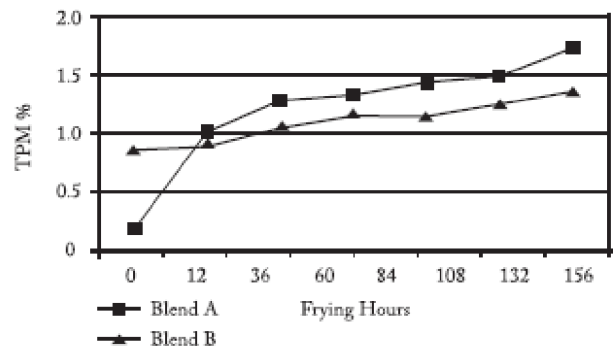


Figure 6.6
Dielectric Constant (DC) Unit Changes during Industrial Frying of French Fries

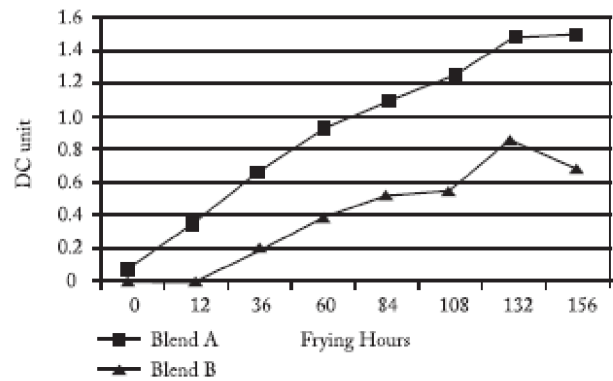
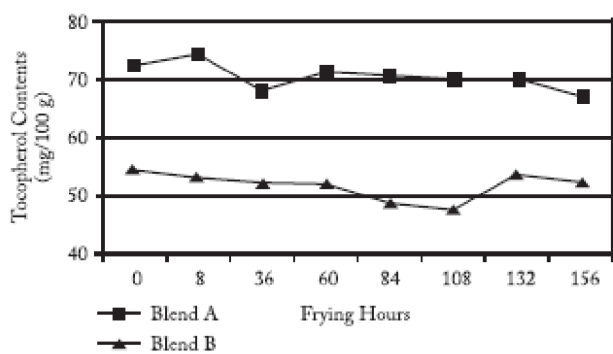


Figure 6.7
Tocopherol Contents Changes during Industrial Frying of French Fries



Free fatty acids increased more slowly with blend B, as did the total polar materials and the dielectric constant measured by FOS.

The total polar materials figure for blend B started at a higher level, due to its content of 70% palm olein, containing diglycerides. However, the subsequent increase was much slower. The tocopherol content remained rather stable in both blends at a satisfactory level.

Colour measurements were also made. Initially blend B was appreciably darker, but colour increased more slowly, and after about 80 hours frying, the difference was not significant. On the basis of the chemical changes it was concluded that blend B performed better. However, it had another important advantage in this particular product. Before entering the freezer, the oil on the surface of the French fries must be progressively solidified, otherwise the French fries stick together in a lump. Due to the solid fat content of the palm olein, blend B solidified more quickly raising the capacity of the pre-cooler. As a result, productivity could be increased by about 30%.

The manufacture and characteristics of red palm olein are described in Chapter 1. Its applications in food preparation have been investigated (15). When submitted to a trained taste panel the oil was characterised as bland in flavour and of very good quality, superior to unrefined oil prepared from fresh fruit in the laboratory. Its use in stir-fried foods, curries and satay sauce imparts a bright reddish colouring that was judged more attractive than refined oil. French fries had an attractive golden colour.

Red palm olein is now being used by some European manufacturers in the industrial frying of premium quality potato crisps principally to obtain the improved colour. Since carotenoids are gradually destroyed at frying temperatures, the red palm oil is used as an additive to the main frying oil, and an appropriate concentration is maintained by continuous addition. The use of red palm oil has the benefit of increasing the carotenoid intake, nutritionally beneficial as pro-vitamin A and as a biological antioxidant, since β -carotene acts as a singlet oxygen quencher.

Pilot Scale Continuous Fryer

Many of the frying trials reviewed in Chapters 5 and 6 were carried out in batch fryers, under conditions similar to those used in fast food outlets and restaurant kitchens. The conditions obtained in large commercial fryers are different and therefore the conclusions from batch experiments must be applied to continuous operations with caution. On the other hand, carrying out experimental work in a commercial plant is expensive and may be difficult to schedule. The Malaysian Palm Oil Board therefore decided to specify and commission the construction of a pilot scale continuous fryer. This would enable investigations of direct relevance to be carried out for manufacturers. The plant was built by Heat and Control Ltd. of Australia. Some data for the thermal properties of palm olein was required for the engineering design. Results for the thermal conductivity are given in Table 6.13, and results for specific heat over a range of temperatures are given in Table 6.14, where they are compared with figures for soya bean oil, from Bailey's Industrial Oil and Fat Products.

Table 6.13
Thermal Conductivity of Palm Olein

Temperature (°C)	W/mK
	Palm Olein
20	0.1535
30	0.1527
40	0.1520
50	0.1513
60	0.1506
70	0.1499
80	0.1491
90	0.1484
100	0.1477
110	0.1470
120	0.1463
130	0.1455
140	0.1448
150	0.1441
160	0.1434
170	0.1426
180	0.1419
190	0.1412
200	0.1405
210	0.1398
220	0.1390

Source: Heat and Control Ltd. Australia

Table 6.14
Specific Heat of Palm Olein and Soya bean Oil

Temperature (°C)	kJ/kg/°C	
	Palm Olein *	Soya bean Oil
100	2.177	2.127
125	2.252	2.214
150	2.323	2.260
175	2.386	2.340
200	2.449	2.486
225	2.553	2.545

Source: Heat and Control Ltd. Australia

The pilot plant has now been installed and commissioned. A detailed description of the plant and the results of a performance test are given below (16).

Pilot Scale Continuous Fryer - Detailed Description of Plant

Fresh Oil Tank (1a)

The cylindrical storage tank is made of stainless steel with a v-shaped bottom. It holds about 400 litres of fresh oil with minimum air headspace. The frying oil is unloaded by pumping from IBC tank (1,000 litres capacity, under nitrogen protection) via a stainless steel discharge pipe which extends close to the bottom; thus, minimising splashing during filling. It is also equipped with a heating element (located close to the bottom) and thermostat to heat the oil if solidification took place and also for use during detergent cleaning of the tank.

Used Oil Tank (1b)

The Used Oil Tank is constructed from the same material and similar in design to the Fresh Oil Tank except its capacity is about half, i.e. 200 litres, for overnight and weekend storage of used oil. At the end of the day's operation, the used oil (from the fryer, cooled down to around 100°C) is pumped back via a stainless steel pipe, filter basket (filter cloth, 100 micron) and stainless steel discharge pipe which extends close to the bottom to minimise splashing. During next day's operation the used oil is returned to the fryer by gravitational action, such that only oil above the v-shaped bottom is transferred. Usually small amount of fresh oil from the Fresh Oil Tank is added to fill-up the oil level in the fryer during the start-up. As the frying progresses, fresh oil from the Fresh Oil Tank is automatically and continuously added to compensate the oil loss during use.

Main Control Panel (2)

The Main Control Panel automatically controls processing steps such as slicing, washing/conditioning, frying temperatures, oil level, filtration and addition of fresh oil and seasoning/flavouring. The temperature profile during heating and active frying can be monitored via display indicator and recorded in a diskette. A sub-control panel is used for controlling an inclined conveyor to transfer/convey fresh unpeeled potatoes to a batch hopper, peeler and inspection conveyor.

Loading (3)

Loading of the fresh unpeeled potatoes from storage is done manually by a processing operator onto the horizontal conveyor.

Horizontal & Inclined Conveyor (4)

The Horizontal and Inclined Conveyor is used to transfer fresh unpeeled potatoes from storage to a batch hopper. Each has a control unit that can be used to vary the speed of the conveyor belt according to production throughput.

Inclined Conveyor (5)

The Inclined Conveyor is used to convey fresh unpeeled potatoes from batch hopper to Hobart Peeler Unit. The speed is controlled by the sub-control panel.

Hobart Peeler Unit (6)

The Hobart Peeler Unit is a semi-automatic unit equipped with a hopper and the peeling time can be varied by the sub-control panel. Potatoes are automatically peeled by an abrasive mechanism in this unit.

Inspection Table (7)

After peeling is completed, a processing operator will open the hatch of the Hobart Peeler Unit, allowing the peeled potatoes to be conveyed over the Inspection Table/sorter into a batch hopper.

Inclined Conveyor (8)

The Inclined Conveyor is used to continuously convey peeled potatoes from the batch hopper to the Knott Slicer unit. The speed of the conveyor is controlled by the Main Control Panel.

Knott Slicer & Conditioner (9)

Peeled potatoes are automatically sliced, either straight-cut or wavy-cut, in the Knott Slicer unit. The potato slices are carried by water flume into the Conditioner unit. Conditioning/washing of potato slices is done with clean tap water to reduce starch content from the potato slices and minimise sticking during frying.

Air Blower (10)

The Air Blower unit is used to drain water from the surface of potato slices as these slices are continuously conveyed to fryer.

Fryer (11)

After passing the Air Blower unit the potato slices are taken on a stainless steel wiremesh conveyor into the hot frying oil (180°C). The Main Control Panel can vary the speed of the conveyor. The total oil volume in the Fryer, including connecting pipes and piping of the heating element, is about 200 litres. During frying the oil is continuously circulated through a wire-mesh filter box (200 micron) and the heating element and back to the Fryer.

Seasoning Unit (12)

After frying is completed, potato crisps (usually with moisture content around 1.5%) are conveyed by stainless steel wire-mesh conveyor to an inspection table/sorter and transferred to the tumble drum of the Seasoning Unit. Dried seasoning such as salt, cheese, chilli powder etc. is sprayed/dusted (the amount of which can be controlled) as the potato crisps enter the tumble drum. After coming out of the tumble drum, the seasoned potato crisps are carried by an inclined conveyor to the Weighing and Packaging Unit.

Weighing and Packaging Unit (13)

The Weighing and Packaging Unit is an automatic vertical form-fill seal system. Seasoned potato crisps are discharged from the inclined conveyor into a dual weighing channel. Each channel can weigh about 60 grams of potato crisps and operates one after another continuously. The potato crisps are then introduced into metallised film packaging, and can either be nitrogen packed or air packed.

Rotary Table (14)

The Rotary Table acts as temporary holding stage for the packed potato crisps as they are discharged and conveyed from the Weighing and Packaging Unit. When sufficient packs have accumulated, they are manually transferred to paper box for storage.

Illustrations of the pilot plant are given in Figures 6.8, 6.9 and 6.10.

Figure 6.8
Conveyors



Figure 6.9
Slicer and Conditioner



Figure 6.10
Fryer



Pilot Scale Continuous Fryer - Results of Performance Tests

These results in Table 6.15 indicate that the oil had reached a steady state condition at about 42 hours use, and continued to be in good condition thereafter.

Table 6.15
Performance Test of Continuous Fryer

Frying Time (hours)	Free Fatty Acids (%)	Peroxide Value (meq/kg)	Colour (Lovibond Red in 5 ¼" Cell)	Rancimat 110°C (hours)
0	0.02	0.39	1.1	22
14	0.17	2.18	3.3	14
28	0.12	3.20	5.1	16
42	0.25	3.73	6.5	15
56	0.22	2.58	7.0	15
70	0.19	2.05	6.9	16
84	0.24	2.76	7.0	15

To demonstrate the effect of a reduced turnover rate on the quality of the frying oil in the pilot plant, it was run at full feed rate (50 kg/hr) and at a reduced rate of 32 kg/hr, so that turnover rate of 8 hour and 14 hour were obtained.

A high quality palm olein with the following characteristics was used:

Iodine Value	56.8
Colour (Lovibond Red in 5¼" Cell)	1.1
Free Fatty Acids (%)	0.03
Peroxide Value (meq/kg)	0.1
Anisidine Value	0.87
Smoke Point (°C)	226
Total Tocols (ppm)	620

Frying was carried out continuously for 8 hour/day over a 10-day period. Oil samples were taken at intervals and held at -21°C until analysed.

The results are presented in Table 6.16.

Table 6.16
Analysis of Frying Oil Used at Different Throughput Rates

Oil turnover	Free Fatty Acids (%)		Smoke Point (°C)		Total Polar Materials (%)		Polymers (%)	
	8 hr	14 hr	8 hr	14 hr	8 hr	14 hr	8 hr	14 hr
Frying time (hours)								
0	0.03	0.03	226	226	5.7	5.7	0.4	0.4
14	0.18	0.16	198	201	9.9	10.5	1.9	1.7
28	0.24	0.25	192	192	9.4	11.1	2.0	2.1
42	0.22	0.32	195	184	10.3	9.9	1.5	2.0
56	0.25	0.39	192	180	10.5	12.4	1.7	2.3
70	0.22	-	195	-	9.7	-	1.9	-
81	0.24	-	192	-	10.1	-	1.8	-

It was clear that at 56 hours the oil with turnover rate of 8 hours had reached a steady state condition of quality, which was then maintained. On the other hand, at a turnover rate of 14 hours, quality loss was continuing, and in particular the smoke point was approaching unacceptable levels. This run was therefore stopped.

It may be noted that, in both runs the results for total polar materials and for polymers were at a satisfying level throughout.

Preferences

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How Much Palm Oil Is Used In Frying

We have attempted to build up a worldwide picture of the amount of palm oil used for frying. Production, import and consumption statistics are available for palm oil from Oil World (publisher ISTA, Mielke) for individual countries. Malaysian official bodies also publish figures for individual palm oil products; palm olein being the one of principal interest for frying use.

For many countries, reliable estimates of usage in large scale frying have been obtained from industrial contacts and trade statistics and checked with import data.

Estimates for restaurant use are based on trade information, while domestic use is calculated on the basis of known food habits, and palm oil availability.

Large Scale Industrial Frying

a. Instant Noodles

Instant noodles are today one of the main fried food products worldwide, produced mainly in the Far East. They are a great success story among convenience foods.

They were first developed and marketed in Japan in 1958 and large-scale continuous fryers were introduced in 1963. A flow diagram of the production is shown in Figure 7.1. Cooking is firstly by steam to gelatinise the starch and then by frying.

Deep-frying of the noodles is an integral part of the production process. Frying serves three purposes: in this case, it reduces the moisture of the product to a level at which microbiological growth is prevented, it imparts flavour and texture, and it improves the nutritional content by incorporation of fat. Before consumption, the instant noodles are merely rehydrated by the addition of boiling water. The choice of fat influences the stability and organoleptic quality of the product. Whereas initially the fat used in Japan and South Korea was beef tallow or lard, this has now largely been replaced by palm oil. Sometimes a blend is used to impart the accustomed meaty flavour. During frying, oil is absorbed into the noodle, resulting in a final fat content of 19-22%. The high stability of palm oil during frying and the subsequent storage ensures an adequate shelf life.

An estimate of the usage of palm oil products for noodles in the main producing countries is given in Table 7.1.

Figure 7.1
Flow Diagram Of Instant Noodle Process

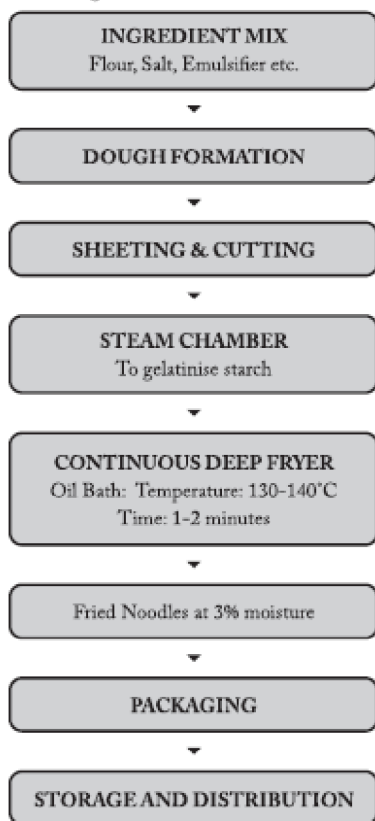


Table 7.1
Palm Oil in Instant Noodles

Country	Estimated Tonnage
China	500,000
Japan	120,000
South Korea	100,000
Indonesia	160,000
Taiwan	14,000
Thailand	29,000
Malaysia	7,000
Hong Kong	4,000
Singapore	4,000
United Kingdom	3,000
Total	941,000

b. Potato Crisps and Other Starch-based Snack Foods

Potato crisps are now consumed and manufactured across the world, and palm oil or palm olein are very widely used, sometimes in a blend with rapeseed or other liquid oil. For example, in the performance study of high oleic sunflower oil for frying crisps discussed in earlier chapters, palm olein was used as the reference oil, being referred to as the “main oil” used in industry.

Estimates obtained from industrial sources are for the UK (105,000 tonnes), Netherlands (30,000 tonnes) and for one large manufacturer in Belgium (12,000 tonnes). A calculation for the rest of the EU based on production data from the European Snack Foods Association is 228,000 tonnes, making a total of 375,000 tonnes.

c. French Fries

The preparation of raw potatoes for French fries is a time consuming and laborious business in the restaurant kitchen. Instead, most restaurants and institutional caterers buy in part-fried frozen French fries, which then only need a short second frying before service.

Before freezing, the part-fried product is cooled in an air stream. At this point it is important that the oil on the surface of the potatoes solidifies, otherwise the individual pieces stick together in a lump after freezing. For this reason oil that crystallises at room temperature is used, and palm oil or a blend containing a small proportion of partly hydrogenated palm oil is widely used. From trade statistics it has been calculated that the 15 countries of the EU use about 120,000 tonnes palm oil per annum.

The product is also widely used outside Western Europe, but no estimate has been attempted, due to lack of data.

Indian Subcontinent

The food processing industry in Bangladesh uses almost 105,000 tonnes palm olein. In Pakistan the corresponding figure is 80,000 tonnes. No estimate could be obtained for India.

Africa

Large scale industrial frying is only established in Egypt and South Africa, using respectively, 25,000 and 60,000 tonnes annually. The main products are potato based.

Middle East

Table 7.2 is based on import statistics for 2003 and industry sources of information.

Table 7.2
Palm Olein Usage in Middle East

Country	Palm Olein Imports (tonnes)	Palm Olein in Industrial Frying (tonnes)
United Arab Emirates	225,000	*30,000
Saudi Arabia	210,000	*100,000
Oman	37,000	*18,000
Jordan	27,000	12,000
Syria	23,000	2,000
Yemen	70,000	20,000
Turkey	152,000	**35,000
Total		187,000

Notes: * Double fractionated palm olein (minimum iodine value 60) is preferred for snack food frying.

** Palm olein is used as 70% of a blend with other vegetable oils.

d. Restaurant and Domestic Use Europe

In the UK, 55,000 tonnes of palm oil is packed in boxes for use in restaurant frying. For some users a proportion of partly hydrogenated palm oil is added. For the Netherlands 74,000 tonnes is estimated. When these figures are extrapolated to the EU as a whole, a total usage of 642,000 tonnes is obtained. Considering the current EU annual imports of 3.3 million tonnes of palm oil products, this figure seems conservative.

Indian sub-continent

In Bangladesh 205,000 tonnes of palm oil products are used, mainly as olein. The most important items are potato-based and deep-fried pulse items, locally called chanachur and pianzoo, also dhal bhaja and deep-fried vegetables.

In Pakistan frying is mainly carried out with vanaspati, which has palm oil or partly hydrogenated palm olein as the main component. A conservative estimate of usage of palm oil is 200,000 tonnes.

Malaysia

40,000 tonnes of palm oil products are used in fast food restaurants.

Africa

Many countries in Africa are vegetable oil producers. Palm oil is produced in Ghana, Nigeria and their neighbours, while elsewhere oil seeds are grown. However, production is insufficient and both palm oil and palm olein are widely imported. The olein is used for restaurant and domestic frying and the quantities used are shown in Table 7.3.

When these figures are examined in relation to the populations, it is notable that, for example, Benin (7 million people) and Togo (5 million) import much larger quantities than Nigeria (123 million). The Nigerian government restricts direct imports of palm oil products and periodically imposes a total ban. In consequence, a considerable cross border trade has developed with neighbouring countries to satisfy consumer demands.

Table 7.3
Palm Olein Imports in Africa for Domestic and Industrial Frying

Country	Imports (tonnes)
Egypt	220,000
Algeria	93,000
Tunisia	6,000
Sudan	29,000
Kenya	3,600
Tanzania	22,400
Mozambique	11,000
Mauritania	22,000
Guinea	4,800
Nigeria	13,300
Ghana	53,600
Benin	30,000
Togo	43,500
South Africa	24,300
Total	576,500

There are important gaps in the information we have been able to obtain. In particular, we have nothing on Indian usage, although it imports nearly 1 million tonnes of palm olein. We have no specific information on domestic and restaurant usage in China, India or Japan, with large populations. However, we know from their food customs that fried foods are very popular. To form a conservative estimate we have taken their palm olein imports, subtracted the industrial usage as in Table 7.1, and assumed that one half of this total is used in this way. This amounts to 900,000 tonnes. A grand total is arrived at below.

Table 7.4
Total of Estimated Palm Oil Usage for Frying

Industrial use	1,893,000
Domestic and restaurant use	
Africa	576,500
Europe *	642,000
Bangladesh	205,000
Pakistan	200,000
Malaysia	40,000
China, India, Japan	900,000
Total	4,456,500

Note: * This figure does not include domestic usage. Palm olein is not retailed in Europe. Palm oil is a major component of cooking fats, but no estimate has been attempted.

The USA has been omitted from our analysis. Although a major producer of fried snack foods and of fried products from fast food restaurants, the USA is using only small quantities of palm oil products for food. This was not always the case. In the 1980s, at a time when world palm oil availability was still relatively small, the USA was a major consumer, particularly for frying of potato products. However in 1986 a widespread advertising and political campaign was launched against "tropical oils", primarily on grounds of trade rivalry, though based on unjustified claims of nutritional harm. While the political attack was not supported by the United States government, the adverse publicity forced manufacturers concerned about public perception of their products to abandon the use of palm oil. In consequence, the industry has used soya bean oil and other oils in a partly hydrogenated form for frying. While these products usually have adequate stability for high temperature use, they contain high levels of trans fatty acids, now recognised as nutritionally less desirable than saturated acids. It is now the United States government policy to reduce the trans fatty acid content of foods, and labelling regulations have been strengthened to inform the consumer. Furthermore, a Washington-based consumerist group, the Centre for Science in the Public Interest, has started lobbying against trans fatty acids in food. (It may be of interest that it was this group that was vociferously opposed to "tropical oils" in 1986-7)

In consequence, some use of palm oil products is now returning in the USA. At present, this is mainly in blended shortenings for bakery and similar products, but the future may see a return of palm oil usage for industrial frying.

Conclusion

The survey presented in Chapter 7 is admittedly incomplete for lack of data. Nevertheless it demonstrates the worldwide usage of palm oil in very substantial quantity for frying. The other chapters collect published evidence from scientists in many countries of the satisfactory performance of palm oil products and provide technical information to enable further growth in its use.