Local Repeatedly-Used Deep Frying Oils Are Generally Safe

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A review of the literature indicates that food scientists and health authorities in several countries, especially member countries of the European Union, are still very concerned about the potential health hazards of oxidized products and lipid polymers formed in repeatedly-used deep frying oils. During the frying process at temperatures of 170° – 200°C, steam formed from moisture in the food being fried help volatile products rise to the surface of the frying medium and into the kitchen atmosphere, imparting a mixture of fried-flavours and off-flavours. The non-volatile compounds formed, however, gradually build up in the oil as it is being repeatedly-used for food frying operations. These non-volatiles, primarily "polar compounds" (PC) and to a lesser extent lipid polymers, get absorbed into fried foods and eventually end up in our body system. Available local data suggests that deep-frying oil samples obtained from food hawkers and those produced under simulated deep-frying conditions in the laboratory, are generally safe as they contain PC within safe limits and rarely exceed the upper limit (UL) of 25%. This contrasts with the situation in some European countries where a very high proportion of frying oil samples collected from fast-food restaurants were reported to contain PC exceeding this UL. Appropriately, promotion of Hazard Analysis and Critical Control Points (HACCP) certification and gazetting of food regulations to limit the PC content in frying oils have been introduced in these countries to protect the health of consumers. Meanwhile, simple gadgets/test kits are available commercially to monitor the quality of the frying oil. This would greatly assist kitchen supervisors at restaurants and franchised fried-food outlets to know when best to change a batch of frying oil before the ULs of frying oil quality are breached.

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Recently, interest on the health impact of use of repeatedly-fried oils was rekindled as members of the public and feature writers of the local popular press queried the fate of such used fried oils from local franchised fast-food businesses. It is well-established that the frying oil used deteriorates in quality with frying time, accelerated by the formation of oxidized and polymerized lipid species in the frying medium. The formation of these undesirable products would limit the period of use of each batch of frying oil, particularly when no top-up with fresh oil is made. This means that each batch of frying oil would have to be discarded when deterioration in its physical and chemical properties begin to adverse affect the organoleptic properties of the fried products.

Reports in the literature indicate that in the frying fast-food business or industry, a batch of frying oil is discarded anywhere from 1 to 4 days depending on the operation hours[1]. In Japan, it has been reported that restaurant frying oils used for about 3 hours daily at 180°C are discarded only after 9 days[2]; this works out to be a total of 27 hours of frying time at 180°C! No such information is available for the local scenario and this should form food for thought for our local budding food scientists.

The present review looks at the national legislation on frying oils in some countries around the globe and some local research data on repeatedly-used or heated frying oils, with the purpose to obtain a general statement regarding their safety of use in the local context.

What changes occur in the oil during the frying process?

During deep-frying of food at temperatures in the region of 170° – 200°C, the oil used come under a heavy three-prong attack, namely:

1. **Hydrolysis** – Moisture from the food being fried vaporises and hydrolyses triglycerides (TGs) in the frying oil to glycerol, free fatty acids (FFAs), monoglycerides (MGs) and diglycerides (DGs);
2. **Oxidation** – Triglyceride molecules in the frying oil undergo **primary oxidation** to unstable lipid species called "hydroperoxides" which cleave to form **secondary oxidation products** which comprise

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non-volatile and volatile compounds. Some of these secondary products polymerize **(tertiary oxidation)**, increasing the oil viscosity, cause browning on the surface, and darken the oil[3]; and

3. **Thermal Polymerisation** – High temperatures of the frying operation produce high molecular cyclic fatty acid (FA) monomers, and TG dimers and oligomers[4,5,6].

The volatile secondary oxidation products (aldehyde breakdown products, alcohol and hydrocarbons such as pentane), acrolein formed from glycerol, and short-chain fatty acids move to the surface, aided by steam formed from moisture in the food fried. Both pleasant fried flavours (contributed mainly by 2,4-decedienal from linoleic acid) and abnoxious odours (eg. from acrolein) are formed.

Several chemical and physical processes follow, namely: i) the food being fried absorbs oil as well as releases some of its own lipid content (sometimes coloured) into the frying medium, ii) charing of food particles and lipid browning darkens the oil. The immediate environment of the kitchen area gets unpleasant, especially when the smoke point of the frying medium is exceeded, as often happens when animal fat such as lard is used as the frying medium.

Meanwhile, the potentially hazardous non-volatile compounds gradually build-up in the fried oil. The majority of these products are called "**polar compounds**" (PC) formed as secondary oxidation products- eg. epoxides, polar dimmers, oxidized polymers, ketones and aldehydes (carbonyls), as well as hydrolysis products of triglycerides such as free fatty acids, monoglycerides and diglycerides. There is much uncertainty whether these products are actually harmful to humans at habitual intakes, which forms the topic of this review.

Formed at a much slower rate than PC, but also given the "bad guy" tag are the polymerized lipid species formed by tertiary oxidation and thermal polymerization. Therefore, a spectrum of physical and chemical changes, much of which are inter-related, give rise to some 140 different compounds[3], which would certainly keep the oil chemist busy. These physical and chemical events taking place during the deep-frying of food in oil are as shown in Figure 1.

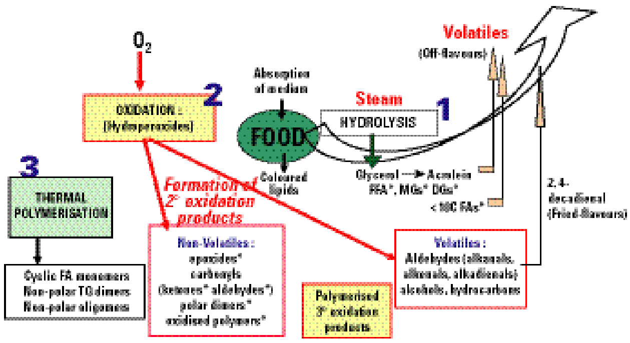

FIGURE 1 : Main events and products formed during deep – frying of foods in oil at 170°C – 200°C

[*Asterik indicates a polar compound]

What happens to these discarded oils?

Elsewhere abroad, there is a market for such oils which can be recycled as biofuel or heating fuel. When there is no market or collection system for recycling of these waste vegetable oils (WVO), the staff of the establishment would probably take them home for further edible use[1]. In the local scenario, there is popular but unsubstantiated belief that such used oils from the frying food industry end up in the *wok* of "*pasar malam*" petty traders.

Are repeatedly-used deep-frying oils safe?

This is the billion dollar question which is largely unanswered by the global scientific community. We are referring here to the PC, the lipid polymers in fried oils, and recently acrylamide formed in high-carbohydrate fried foods has joined the scare-wagon. When very high doses are fed to laboratory rats, these products of the frying process cause serious adverse effects, ranging from growth inhibition, organ enlargement, cancer and even death. But do these oxidation/polymerized products pose a health hazard at the much lower daily intakes in humans?

In early research studies conducted on safety of heated fats, the laboratory rat was fed very high concentrations of heated fats or their chemical fractions. These rats showed retarded growth, diarrhea, enlarged livers and kidneys, and elevated metabolic enzymes.[7,8,9]

Subsequent research in this area utilized less severely abused oils as the test material and still the adverse effects of consumption of repeatedly fried oils were evident. In a Malaysian study in the white rat model[10], it was shown that the long-term consumption of vegetable oils which contain 25% polar compounds induced adverse effects similar to those observed in earlier studies using severely heated fats, namely inhibited growth (Fig. II), caused enlarged liver and kidney, elevated alkaline phosphatase, poor pregnancy outcomes (smaller litter size and lower bodyweight of pups) and maternal mortality caused by excessive haemorrhage during delivery.

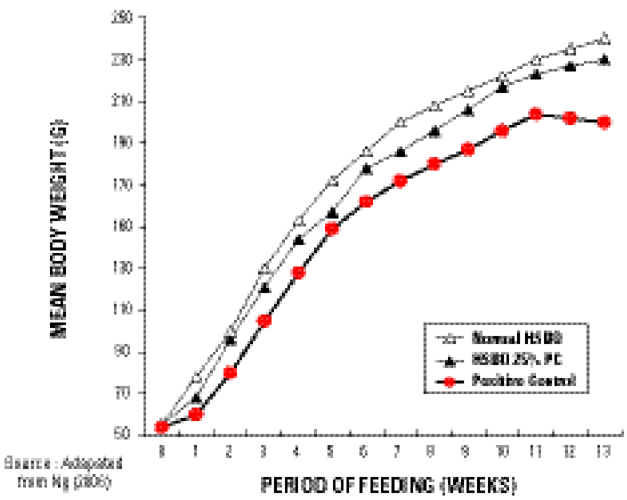

FIGURE II : Growth response of male rats fed 30% kcal of either normal hydrogenated soybean oil (HSBO), HSBO with 25% PC, or a positive control (50% PC)

In the above study[10], Ng estimated the "No observable adverse effect level" (NOAEL) of PC in frying oils to be 5.14g PC/kg body weight of rat. When extrapolated to humans using a safety factor of 100, the "maximal permissible intake" for a 65-kg person works out to be 3.34 g PC/day or 13.4g of used oil containing 25% PC. This amount of PC, although not unrealistic, is unlikely to be exceeded in the average Malaysian diet on a frequent or regular basis.

How long does it take a frying oil to attain 25% PC content?

There is no straight forward answer to the above question but it depends greatly on the frying temperature used, the content of moisture in the food being fried and whether there is topping-up of the used frying medium. In the reports of Ng[10,11], it took 9 to 10 daily five-hour cycles of frying at 180°C (total 45-50 hours) in a commercial-type fryer with a specific surface of 0.064 cm^2/g oil and with no food added nor topping-up with fresh oil to reach a PC content of 25% (Figure III).

In the study of Razali and Badri[12], however, it only took 3 days for the frying media used (palm oil, palm olein, soybean oil or hydrogenated soyabean oil) to reach a PC content of 25% when frozen French fries were intermittently fried at 180°C for 4 minutes per batch for a total frying period of 8 hours a day, over 5 consecutive days. The investigators also reported that PC content in the fried food resembled that of the frying medium. The continuous use of the fryer at 180°C for about 15 batches of French fries an hour or 120 batches of the fast food over 8 hours a day showed that the rate of formation of PC in the frying oils used was much faster in the presence of moist food compared with the situation in the absence of food reported by Ng[10,11].

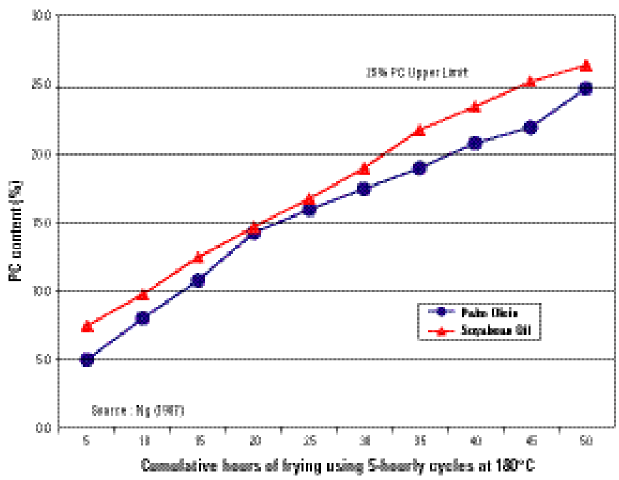

FIGURE III : Formation of PC in palm olein and soyabean oil with frying at 180° C with no food added nor oil top-up

In the study of Fauziah and associates[13], the PC content in palm olein and high oleic sunflower oil was lower at about 15% after 5 consecutive days of intermittent frying with raw potato slices 180°C, equivalent to 8-hours frying time per day. It is pertinent to note that at the end of the cumulative 40 hours of frying at 180°C, the repeatedly-used fying oil is still safe for re-use as its PC content is still a far way below the generally-used upper limit of 25% to 27%. The corresponding polymer content of both used frying oils approximated a low 1.0%.

In Ng's earlier study[10] shown in Fig. III above, the soyabean oil took about 45 cumulative hours of frying at 180°C, while palm olein took 50 hours, to reach the UL of 25% PC content. This reflects the better stability of palm olein compared to soybean oil as a frying medium, albeit the difference is only 5 hours longer frying time in the present case example. In the report of Fauziah et al.[13], this frying-time advantage of palm olein over high-oleic sunflower oil is only marginal.

In another study by Ng[14], the PC content of repeatedly-used frying oils of a popular local trade obtained from various locations in Kuala Lumpur and Petaling Jaya, was found to range from 6% to slightly over the UL of 25% (Fig. IV). The hawkers concerned topped-up the frying medium before re-use each day because of substantial pick-up of the frying medium by the fried food(s). The presence of food in the frying medium would be expected to accelerate the formation of PC mainly due to the hydrolysis brought about by the moisture in the food. However, the build-up of PC in this case would be slowed down somewhat by the top-up with fresh oil before reusing the left-over frying oil each day. The lesson to be learnt here is that the 25% PC level can be reached in the local hawker food trade, but only rarely.

Mazura and Azrina[15] also investigated the quality of frying oils and fatty acid composition of 3 types of fried foods obtained from the "night market" of Sri Sedang, Selangor. They reported peroxide values (PV) of 10.5 to 19.5 mEq/kg and free fatty acid (FFA) levels of 0.22% to 0.96% in the frying oil samples. The FFA level of the oil samples used to fry fish balls surprisingly had a mean FFA of 0.96 ± 0.12% which was more than twice the mean level of FFA in the oils used to fry the other two types of foods. Unfortunately, the PC content of the frying oil samples was not determined. However, these local frying oil samples can be regarded as safe based on the UL for FFA of 2.5% set in the European Union[3].

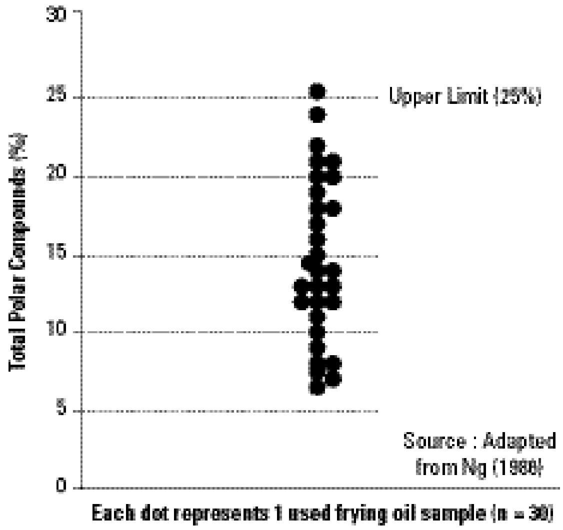

FIGURE IV : Total PC content in samples of hawker repeatedly-used frying oils collected from different locations.

More information on local analytical findings of used frying oils comes from Ismail[16] who reported comparatively low PC content of 10% and 17% and polymer levels of 2.0% and 2.8% in two separate studies where palm olein was used in large-scale frying of potato chips for 8 hours a day, and 5 days a week (total of 40 hours frying time).

In Japan, Totani et al.[2] reported that the PC content in campus-restaurant samples of frying oils which have been used at 180°C for 3 hours a day for 5 consecutive days (total 15 hours frying time) was in the range 4% to 14% and therefore, within safe limits. In the same report by these investigators, the PC content in the batter coatings of 50 samples of commercially deep-fried foods purchased randomly in Kobe ranged from 3.3% to 27.0%, with 2 samples exceeding the UL of 25%.

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In contrast, frying oil data obtained from fast-food restaurants in western nations can be quite high. Dana and Saguy[3] reported that 34.5% to 60.0% of frying oil samples from such restaurants in five European countries exceeded the 25% PC UL. Faced with this apparent frying oil danger, health authorities and food scientists in these countries have organized a series of International Symposia on Deep-Fat Frying[17] and have developed guidelines for optimal frying operations consistent with Good Manufacturing Practice (GMP).

Comparing the analytical findings of local studies and those conducted abroad on frying oils, it becomes evident that our repeatedly-used frying oils obtained from hawkers of fried foods and from simulated frying conditions in the laboratory are generally safe. Having said this, however, information on the PC levels in frying oils still-in-use and at the point of discard in the numerous outlets of fast-food giants in the country is left largely unanswered.

How can I tell the PC level?

You cannot estimate the PC content of frying oils with accuracy just by its colour and smell. There are chemical tests which can be used. Basically there are three main types, namely: tests for PC, carbonyl compounds (aldehydes and ketones) and oxidized products (redox indicators). Measurement of PC content is considered the most appropriate[18,19,20] and focus should be placed on this method.

The reference method for measuring PC content is the International Union of Physical and Applied Chemistry (IUPAC) Standard Method 2.507 based on adsorption chromatography on silica gel. Recently, an alternative method based on a mini silica gel column is reported to work just as well[21].

A new gadget called "testo 265" based on the measurement of dielectric constant of the oil was recently introduced to measure PC in frying oils. This new tool promises to be user friendly as you can put the test region of the gadget directly into frying oil at temperatures of up to 210°C[22].

Regulatory Aspects

Not many countries around the world have national regulations controlling the level of PC in frying oils. In the European Union, however, member countries have national food laws which cap the PC level at 25%; Austria and Switzerland permit a slightly higher UL of 27%[3,18].

The Food and Drug Administration of the United States has not established specific guidelines to control the quality of frying fats since adverse effects of frying fats on human health have not been established. In the meantime, frying fats quality are subject to guidelines provided by the Food Code which is a general reference document for state and local government agencies responsible for overseeing food safety in retail establishments[23].

Similarly the Malaysian Food Act and Regulations, September 2005[24] has no provision for frying oil quality. Food safety, which includes aspects of food handling and food processing, are addressed by specific food safety programmes such as GMP and HACCP.

In the area on international trade, member countries look towards Codex Alimentarius to set food standards or guidelines. For the moment, however, Codex has not yet developed guidelines for fried oil quality.

Are there any other products formed in fried foods that may pose a health hazard?

Polar compounds have taken centre stage as the "bad guys" in fried oils for many years now. Western nations in Europe have responded by stipulating their upper limits in their national legislations. However, lurking in the shadows of fried oils and fast gaining attention as potential health hazards are compounds called "acrylamide".

Acrylamide is formed during frying of food at 170° – 200°C, particular those high in carbohydrate such as potatoes and cereal products. However, the compound gained a respite when the WHO/FAO Expert Committee on Food Additives ruled that acrylamide contamination of the foods of humans were within acceptable limits and below the NOAEL of

0.5 mg/kg bodyweight per day[25]. New evidence prompted another Joint Expert Committee of Food Additives (JECFA) review which gave a closely-similar verdict, namely: "the adverse effects of acrylamide relative to non-cancer endpoints, including nervous system damage and reproductive and developmental problems, are unlikely at the estimated average intakes"[26].

Take home messages

Available data suggests that frying oils used in the preparation of fast-foods in local night markets and restaurants contain PC levels within safe limits, i.e. below the UL of 25%. The stringent need for high quality fried products to meet customer expectations in these businesses would necessitate the frying oil used to be discarded before they begin to impart obvious off-flavours to the fried foods. The data in this review suggests that a batch of frying oil used to prepare fast foods at around 180°C, with no top-up with fresh oil, should be discarded at or before the end of the 3rd day. Overall, the evidence presented did not give reason(s) to refute that local repeatedly-used deep frying oils may be regarded as generally safe.

Finally, the age-old saying of "eat in moderation' still holds while you tuck away your favourite French fries and *goreng* whatever, from your regular office or neighbourhood hawker stall. For such foods, it would be prudent to order "small" servings.

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