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BAKERY FATS

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I. EDIBLE OILS

Fats and oils occur naturally in a wide range of sources. There are many hundreds of vegetable oil-bearing seeds which grow in different parts of the world but only a few yield substantial amounts of oil and are of economic importance today. Animal fats are rendered from the slaughtered carcasses of animals considered edible to man, as well as from marine sources such as whale, menhaden and herring.

Why are fats and oils important in our diet? Of the three basic foods we consume (carbohydrates, proteins and fats), fats contain the highest energy density. Also, some of these fats and oils contain essential body building blocks that are not manufactured by the body, but are essential for proper functioning of a healthy body. Finally, fats contribute pleasing flavors and textures to foods. Thus, we have no alternative but to include these fats and oils in our diets.

The terms "fats" and "oils" are often used interchangeably, and may be a cause of some confusion. Simply put, the difference between a fat and an oil is a matter of consistency; a fat is solid, and an oil is liquid at room temperature. Some materials are borderline. For example, coconut oil is liquid at room temperature in tropical climates (>24°C), but is solid in a cold climate.

A. SOURCES OF EDIBLE FATS AND OILS

Since there are no substitutes for fats and oils we have to obtain them from all the natural animal and/or vegetable sources available to us. From a practical standpoint we will concentrate our attention on those fats and oils that represent economical and commercial values to our world economies. The commonest sources of these fats and oils are 1) vegetable and 2) animal.

1. Vegetable Sources.

Only about 22 vegetable oils are commercially developed on a large scale today, and 12 of them constitute more than 95% of the world vegetable oil production. This class includes the seed group sources, such as cottonseed, groundnut, rapeseed, safflower, sesame, soybean and sunflower, and also trees such as coconut and palm trees. In Table 1 we enumerate the oil content of commercially important oil-bearing fruits, nuts and seeds.

Table 1.
OIL CONTENT OF
IMPORTANT SOURCES

Source	Oil. %
Tree Fruits and Nuts	
Babassu	60-65
Coconut (Copra)	65-68
Palm Fruit	45-50
Palm Kernel	45-50
Seeds from Dicotyledons	
Cottonseed	18-20
Groundnut (Peanut)	45-50
Rapeseed	40-45
Sesame	50-55
Soybean	18-20
Sunflower	35-45

Babassu.

This tree is the babassu palm which occurs in Brazil in the Amazon territory. The babassu palm tree starts bearing fruit after ten years and may live up to 200 years. The fruit bunch contains on the average 200 nuts. The nut has a very thick, hard shell and contains between three and seven seeds, which have a high oil content.

Coconut (as copra).

Coconut palms are found in the coastal regions in Asia and in the Pacific Islands. The tree starts to bear about ten fruits after 5 or 6 years and about eighty fruits (nuts) at full growth (thirty years). The ripe coconuts are husked by removing the fibrous shell, then the shell is split, and the meat is dried to obtain copra, the oil-containing material.

Cottonseed.

Cottonseed is a by-product of cotton production. It has been cultivated from time immemorial and many varieties have been developed from the wild species found in the tropical regions of both hemispheres. The main producing areas are the United States, India, Pakistan, China, Turkey, Egypt and the Sudan. The seeds remaining after the removal of the cotton fibers are either bald or covered with lint.

Olive.

The olive tree is the oldest cultured tree in the world. It thrives best in a subtropical climate. Its growing region stretches from across Asia Minor, the southern USSR, and Iran to the Punjab in India. However, it is grown mainly on the shores of the Mediterranean sea. The fruit grows on medium-sized trees with greyish-green leaves and, when mature, looks not unlike an unripe damson. An average tree bears from 20 to 40 pounds of fruit.

Palm (fruit).

The oil palm most probably originated in Nigeria, in Africa. Its planting region extends from 600 miles north and south of the equator. Oil palm trees start to bear fruit after 4 or 5 years and reach their full yield after 15 years. They bear fruit for up to 25 years. The fruit bunch contains 700 to 900 fruitlets and weighs between 35 and 40 pounds, each fruitlet containing two or three kernels. Palm oil is extracted from the fleshy part after boiling and pulping the fruit.

Palm kernel.

Palm kernel oil is obtained from the kernels which lie in the center of the palm fruit. It is different from the palm oil extracted from the fleshy part which surrounds it and resembles coconut oil in its constituents, properties and application.

Groundnut (peanut).

The groundnut, or peanut, originated in South America, but was brought to West Africa by the Portuguese in the 16th century. For commercial purposes the main cultivation areas are India, China, West Africa and the United States. The name is derived from the fact that the flower head, or peg, before it sets its fruit, bends and buries the young seeds in the ground where they grow to maturation. The pod holds up to four seeds, and a single fully grown plant may produce forty or more pods.

Rapeseed.

Rape is traditionally the most important oilseed crop in Western Europe. France, Germany and Sweden are the main producing countries in Europe. On the other hand, Canada is one of the most important rapeseed producing countries next to India and China. From a nutritional point of view rapeseed oil and meal poses certain physiological and toxic problems, due to the presence of a high concentration of erucic acid in the oil and glucosinolates in the meal. New cultivars were developed in Canada that eliminated those undesirable characteristics, and in 1978 they were given the name CANOLA. The edible oil processed from the seeds of canola cultivars is known in the trade as canola oil, but is sometimes referred to as LEAR (low erucic acid rapeseed).

Safflower.

Safflower is a dry land crop which grows best in arid climates on land with a high water table. Its origin is traced to the Near East but it is also grown in India, Africa and Europe. The plant is characterized by a vigorous root system which will penetrate the soil 6-12 ft. The above ground portion is about 3 ft tall and quite bushy. The heads of the plant contain 20-100 seeds. The seed, about the size of a barley grain, has a hard fibrous hull surrounding the meat or kernel. The versatility obtainable from the safflower plant is seen in the different types of oils in the different varieties (High EFA 80%, High Oleic 75%). The oil is refined by conventional equipment.

Sesame.

The original locality of sesame is not known, but it is grown in China, India, Africa, Japan, Indonesia, Thailand, Egypt, Mexico and elsewhere. The seeds are white and dark colored, commercially known as "white" and "black"; the "white" varieties yield oil superior to that from the "black", and is generally used for the same purposes as olive oil.

Soybean.

The soybean grows best in warm, temperate areas with continental warm summers, such as the so-called cotton and maize belt in the USA, and in China and Brazil. The soybean originated in Manchuria, and spread to China and later to Japan. The soybean came to USA in the 19th century, and despite its low oil content it is now the most important oil-bearing crop in the world because of the high protein meal.

Sunflower.

The wild sunflower is believed to have originated in the southern part of the USA and Mexico. It was brought to Spain by the Spaniards in 1569 and from there it was spread through out Europe. Its cultivation as an oilseed crop began in Russia and some East European countries and later in Argentina. It is extremely adaptable to different types of climate, occuring as it does in temperate, sub-tropical and tropical countries. Today, the sunflower is the second largest world source of vegetable oil.

2. Animal Sources.

Fats from animal sources are classified into three groups.

Milk fats.

The fats of this group are derived from the milk of domesticated land animals and are all comparatively similar in composition. They are distinguished from other fats by the presence of a wide assortment of low molecular weight fatty acids. They are the only fats containing the short chain fatty acid butyric acid. Also, they contain a small amount of monounsaturated fatty acids, trace amounts of highly unsaturated acids, small amounts of odd numbered chain length and branched fatty acids. All of these fats are edible and the butterfat from cows and water buffalo is the most important.

Animal fats.

This group consist of the rendered body fats of domestic land animals such as hogs (lard), cattle (tallow) and sheep. They contain considerable amount of fully saturated triglycerides which confer on them a wide plastic range. They are important edible fats, but a considerable amount of the total production is derived from parts of the carcasses that are unfit for human consumption, and is sold as inedible for the manufacture of soaps and lubricating greases.

Marine oils.

Fish oils are derived from several small oily fish species such as sardines, herring and menhaden. The whole fish are processed to yield oil as the primary product, and the remaining residue is used for animal feed or fertilizer. Whales are still taken, by ships operating in the arctic region, for their oil. The oils of the marine oil group contain large proportions of long chain saturated fatty acids as well as long chain unsaturated acids containing more than three double bonds.

B. CHEMISTRY OF FATS AND OILS

1. Structure and Composition.

Chemically speaking, fats are esters of aliphatic carboxylic acids, which contain the carboxyl group and an aliphatic carbon chain of variable length. The generalized formula is R-COOH, where R is the aliphatic group. A few example formulas are:

CH_3-COOH	$CH_3(CH_2)_{10}$-COOH	$CH_3(CH_2)_7CH=CH(CH_2)_7$-COOH
Acetic acid	Lauric acid	Oleic acid

2. Triglycerides.

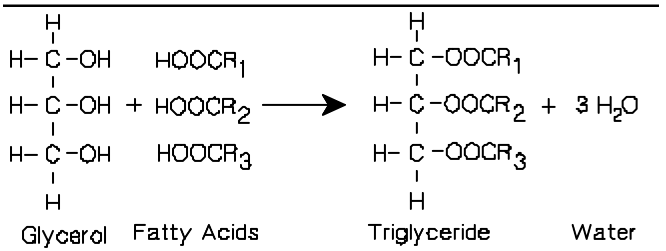


Figure 1. Formation of a mixed triglyceride from glycerol and three fatty acid molecules.

These esters are derived from the reaction of a single molecule of the alcohol glycerol and three molecules of fatty acids to yield one molecule of a triglyceride and three molecules of water as shown in Figure 1. When the fatty acids are identical, the product is a simple triglyceride. An example is triolein, a major triglyceride in olive oil, in which all three fatty acids are oleic acid. A mixed triglyceride has two or three different fatty acids joined to the glycerol part. An example is palmitooleostearin (usually abbreviated POS), a component of cocoa butter, in which R_1 is palmitic acid, R_2 is oleic acid, and R_3 is stearic acid.

3. Nomenclature of Fatty Acids.

With very few exceptions, the carboxylic acids from which fats are derived are all straight chain compounds, ranging in size from four to twenty four carbons. Only the acids containing an even number of carbon atoms are present in any substantial amounts, although a few tenths of a percent of acids containing 15 and 17 carbon atoms are found in some fats. The fatty acids can be saturated, monounsaturated or polyunsaturated, with two or more double bonds.

In saturated fatty acids, all the carbon atoms along the chain are connected to two hydrogen atoms, for example, lauric acid, as shown above. When two adjacent carbon atoms each have only one hydrogen atom attached, a double bond then connects the carbons, as shown for oleic acid. The presence of this double bond influences the physical properties and the chemical reactivity of the fatty acid, as discussed below.

Table 2.
NOMENCLATURE OF FATTY ACIDS IN FOOD FATS AND OILS

Formula	Common Name	Abbreviation
$H_3C(CH_2)_{14}COOH$	Palmitic	C16:0
$H_3C(CH_2)_{16}COOH$	Stearic	C18:0
$H_3C(CH_2)_7CH=CHCH_2(CH_2)_6COOH$	Oleic	C18:1
$H_3C(CH_2)_4(CH=CHCH_2)_2(CH_2)_6COOH$	Linoleic	C18:2
$H_3CCH_2(CH=CHCH_2)_3(CH_2)_6COOH$	Linolenic	C18:3
Omega nomenclature		
$H_3C(CH_2)_7CH=CHCH_2(CH_2)_6COOH$	Oleic	C18:1 ù9
$H_3C(CH_2)_4(CH=CHCH_2)_2(CH_2)_6COOH$	Linoleic	C18:2 ù6
$H_3CCH_2(CH=CHCH_2)_3(CH_2)_6COOH$	Linolenic	C18:3 ù3

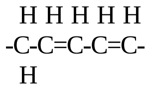
The carbon atoms of fatty acid chains are numbered consecutively, starting with the carbon atom of the carboxyl group as number 1, in accordance with the Geneva system of nomenclature. The names of fatty acids are abbreviated according to the number of carbon atoms in the molecule and degree of unsaturation (the number of double bonds in the molecule), as shown in Table 2.

While the carbon atoms are generally counted from the carboxyl end of the fatty acid, for reasons of biological activity they are also numbered from the methyl end of the molecule. Such a classification is designated by the symbol ù (omega), or "n minus" which denotes the position of the double bond closest to the terminal methyl group. For example, oleic acid, which has one double bond 9 carbon atoms from the methyl group, is termed an omega-9 or [C18:1 ù9 or n-9]. Likewise, linoleic acid, with two double bonds, has one double bond located six carbon atoms from the methyl group. This acid is thus abbreviated [C18:2 ù6 or n-6] and linolenic acid, with three double bonds, has one double bond located three carbon atoms from the methyl group is abbreviated [C18:3 ù3 or n-3] as shown in the table.

The most common fatty acids in edible fats used by man are those containing 16 or 18 carbon atoms. These include the saturated palmitic (C16:0) and stearic (C18:0) acids, the monounsaturated oleic acid (C18:1) and the polyunsaturated acids, linoleic acid with two double bonds (C18:2) and linolenic acid with three double bonds (C18:3).

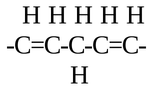
The chemical reactivity of unsaturated fatty acids is determined by the position as well as the number of the double bonds in the molecule. In other words, the reactivity markedly increases with an increase in the number of double bonds, provided they are conjugated (separated only by one single bond) or methylene-interrupted (separated by a $-CH_2-$ unit).

If a fatty acid has two isolated double bonds (separated by two or more methylene units), its reactivity is only slightly greater than that of a fatty acid which has only one double bond.



$$-\underset{H}{\overset{H}{C}}-\overset{H}{C}=\overset{H}{C}-\overset{H}{C}=\overset{H}{C}-$$

Conjugated



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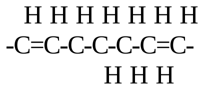
Methylene-interrupted



$$-\overset{H}{C}=\overset{H}{C}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\overset{H}{C}=\overset{H}{C}-$$

Isolated

Nutritionally speaking, of all the fatty acids the polyunsaturated linoleic (C18:2), linolenic (C18:3), arachidonic (C20:4), eicosapentaenoic (C20:5) and docosahexaenoic (C22:6) acids are of most interest. The principle source of the first two fatty acids are the vegetable oils, whereas the third is found in lard and tallow. The last two fatty acids are found in fish oil. These fatty acids are the precursors of various prostaglandins, cyclic compounds which play important roles in proper functioning of cells and general metabolism. Linoleic and linolenic acids are sometimes referred to as essential fatty acids (EFA), because mammals cannot synthesize them, but must derive them from dietary foods.

The fatty acid composition of edible fats and oils of commercial importance is presented in Appendix A, and systematic and common names of fatty acids and their sources in Appendix B.

4. Geometric and Positional Isomers.

Both geometric and positional isomers are known to exist among unsaturated fatty acids. In naturally occurring unsaturated fatty acids the double bonds are in the *cis* configuration. This means that the carbon chains on the two sides of the double bond are bent toward each other, and the hydrogen atoms on the double bond are on the same side. The corresponding *trans* configuration results when the chain is nearly straight (with a slight kink at the double bond) and the hydrogen molecules are opposite each other as shown in Figure 2. Also, positional isomers can occur in which the double bond can shift its position along the carbon chain of the fatty acid. When this occurs in oleic acid a number of so-called "iso-oleic" acids are formed; the one shown in Figure 2 has undergone double bond migration by one bond towards the carboxyl group. The *cis* isomers Naturally prevail in all the food fats and oils, although small amounts of *trans* isomers occur in fats from ruminants.

Although double bonds in natural polyunsaturated fatty acids normally occur in a non-conjugated (methylene-interrupted) configuration, the migration reaction tends to form a conjugated system. The chemical relationship of these was shown above.

As the number of double bonds increase in the molecule the number of geometrical and positional isomers increases. As a general rule, *trans* isomers melt at higher temperatures than the corresponding *cis* isomers, are less soluble, and react more slowly. In positional isomerism, migration of the double bonds also occurs to produce many isomers of the original (*cis*) fatty acids. It occurs very readily during the hydrogenation of an oil and advantage is taken of this in the production of many shortenings, margarines and many specialty products. Hence, it is important to note that in the partial hydrogenation of an oil in the presence of a metallic catalyst to produce a plastic shortening, the composition of the unhydrogenated components of the oil has an effect on the desired properties, edible qualities and functional properties of the finished product due to the formation of a host of geometric and positional isomers.

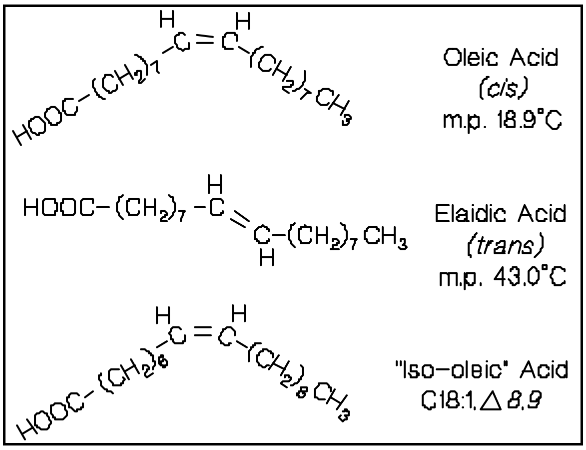


Figure 2. Effect of *cis* and *trans* configuration on linearity of fatty acid chains.

5. Nonglyceride Components of Fats and Oils.

All fats and oils contain small amounts of nonglyceride components. They may range from 5% to less than 0.2%. They are removed by hydration or by reaction with alkali during the course of ordinary refining.

Phosphatides.

The substances generally removed are phospholipids, carbohydrates and carbohydrate derivatives, protein fragments, and various resinous and mucilaginous materials. Also, during the course of alkali refining partial removal of the sterols and carotenoid pigments take place in addition to the removal of the free fatty acids present in the crude oil or fat.

Phosphatides are esters of phosphoric acid with mono or diglyceride; the phosphatidyl part is further esterified with ethanolamine, choline, or inositol (Figure 3). The ethanolamine and choline compounds carry both positive and negative charges, while the inositol compound is only negatively charged. Lecithin is the mixture of phosphatides obtained from vegetable oils, that has been purified and treated to make it functional in food processing. If one of the fatty acids is hydrolyzed from the compound shown in Figure 3, the product is known as lysolecithin. Table 3 presents the phosphatide content of some crude fats and oils.

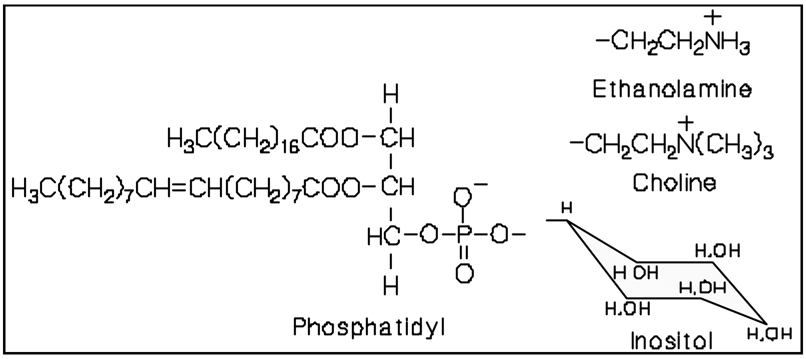


Figure 3. Structure of the components of lecithin; phosphatidyl-ethanolamine, phosphatidyl-choline, and phosphatidyl-inositol.

Table 3.
PHOSPHATIDE CONTENT OF SOME FATS AND OILS

Fat or Oil	Phosphatide, %
Cottonseed	0.7 - 0.9
Corn	1.0 - 2.0
Palm	0.05 - 0.10
Peanut	0.3 - 0.4
Sesame	0.1
Rapeseed	0.1
Soybean	1.1 - 3.2
Butter	0.6 - 1.4
Lard	0.05

Sterols.

Sterols are crystalline, alcoholic substances found in the unsaponifiable matter of plants and animals. Sterols of animal origin all have the same skeletal structure of twenty seven carbon atoms whereas those of plant origin are either C28 or C29 compounds. Although sterols are found in both animal and vegetable oils, there is a substantial difference biologically between the two classes. Plant sterols derived from the diet do not constitute a source of the cholesterol of the animal organism; they are not even absorbed from the intestine but are excreted in the feces. Vegetable oil sterols collectively are termed "phytosterols". Cholesterol, the primary animal fat sterol, is not found in vegetable oils. Sitosterol and stigmasterol are the best known vegetable oil sterols.

Tocopherols.

Tocopherols are light yellow to colorless oil-soluble compounds. They occur naturally in vegetable oils and serve as an antioxidant to retard oxidation in plant tissues and as source of the essential nutrient vitamin E. There are four principle tocopherols, that differ in biological and antioxidant activity as shown in Table 4.

The listed antioxidant activities apply to heated fats. However, at ordinary atmospheric temperatures the alpha, beta and gamma tocopherols have approximately the same antioxidant activity. A little over 5% of the quantities present will be lost during the alkali refining and bleaching processes but an additional 20% loss may take place during the deodorization step, largely because of the high temperature and vacuum employed. Hydrogenation generally produces no loss.

Table 4.
RELATIVE ACTIVITY OF
TOCOPHEROL ISOMERS

Isomer	Biological	Antioxidant
Alpha	1	3
Beta	4	2
Gamma	2	2
Delta	3	1

Carotenoids and chlorophyll.

The carotenoids are widely distributed in crude animal and vegetable fats and oils although their concentration is generally low. They are soluble in fat and range in color from yellow to deep red depending upon their structure. Of all the common fats, crude palm oil has the highest content of carotenoids (0.05-0.2%). They are unstable to heat and are readily adsorbed by fuller's earth or activated carbon, and oils are bleached by high temperature during deodorization. However, certain fats and oils have a greenish color from the presence of chlorophyll, that may present a problem in the processing of some oils such as soybean and rapeseed oils.

Mono- and diglycerides.

These materials do not occur naturally, in appreciable quantities, in animal and vegetable fats and oils, except where partial hydrolysis has occurred. They are formed in the intestinal tract as the result of the normal digestion of the triglycerides. Industrially, they are usually prepared by interesterification with glycerol, giving a mixture of mono-, di- and triglycerides. They represent an important class of food emulsifiers in products such as ice cream, margarine, peanut butter as well as many other products.

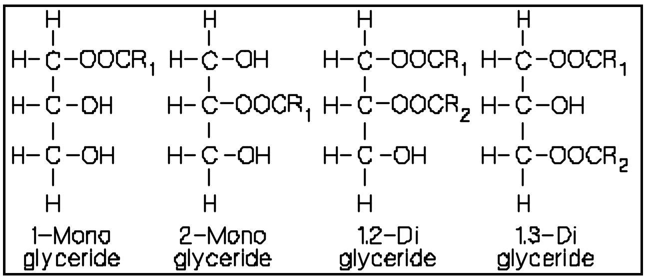


Figure 4. Chemical structures of monoglycerides and diglycerides.

Vitamins.

Most vegetable oils contain no important amounts of either vitamin A or D but are an important source of vitamin E. Of the vegetable oils palm oil has a vitamin A potency which may be as high as 400 USP units/gram. On the other hand, marine oils may contain as high as 10,000 to 15,000 USP units/gram of vitamin A.

C. REFINING OF FATS AND OILS

Probably the first methods of fat extraction were rendering procedures practiced by primitive man, following the cooking techniques used in the preparation of meats for food. Some form of crude oil and meal was produced by the Egyptians, Chinese and Phoenicians using primitive mechanical presses operated by wedges or levers. However, it would appear that the pressing of oil from olive pulp probably antedates the pressing of oil seed. These primitive pressing devices gave way to the hydraulic press, and it was not until the early 1900's that the screw press was introduced. The latter was used as a forepress unit ahead of the hydraulic press, and later ahead of solvent extraction, in order to maximize oil recovery from the pressed seed cake.

1. Rendering Animal Fats.

The term rendering means the extraction of fat or oil by heat. Nearly all animal fats are recovered by rendering. There are two general methods of rendering animal tissues: dry rendering and wet rendering.

In the dry method the tissues are dehydrated until brittle, and the fat cells break and release the fat. The frying of bacon, to cite a familiar example, is essentially a dry rendering process. However, this method is preferred for inedible products where flavor and color are secondary and the production of larger quantities of high quality residue is the prime objective. Final recovery is completed by pressing, either in hyraulic or continuous screw presses.

In wet rendering the fat cell walls are destroyed by steam under pressure, and the released fat floats on the top of the water or can be separated by centrifugation. This method is used to obtain edible fat products where color, flavor and keeping qualities are of prime importance.

2. Oilseed Milling.

All plant cells and seeds contain a certain amount of fat, in addition to carbohydrates and protein, in order to sustain their growth and well being. However, most of the fat or oil will be found in the seed or fruit in quantities adequate to sustain its germination and growth in the early stages of plantings.

Generally speaking, the methods of recovering oil follow very simple principles. The oil is either squeezed out of the seed by sheer physical pressure using either a hydraulic press or a screw press or a combination of the two, or it can be dissolved out by means of a chemical solvent. In many cases the two methods are combined, depending on the nature of the seed and the cost of the operation. The prime objectives in using any of these methods are to obtain the maximum amount of an unaltered oil which is free from undesirable impurities. Yet, these simple principles are not easy to apply, for the oil within the seed or nut is entrapped in tiny cells with impervious walls. Hence, there is need to crack open or soften up the walls of each cell to release the oil. The overall scheme of obtaining edible oil from a seed such as soybean is shown in the diagram of Figure 5.

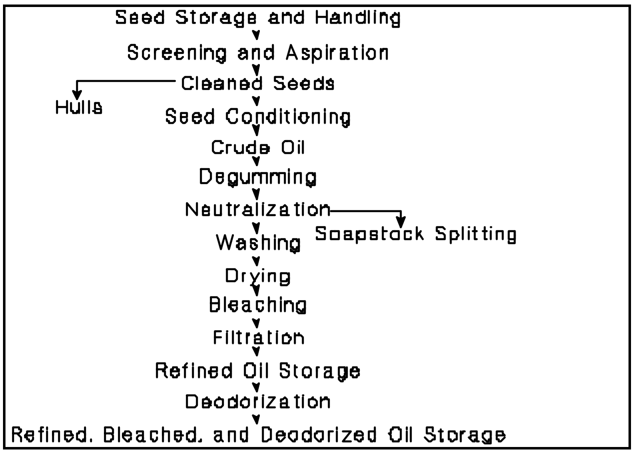


Figure 5. Steps in obtaining edible oil from a seed.

Seed storage and handling.

Soybeans are used as an example of the operations that take place prior to oil recovery. The basic finished products of any soybean processing plant are meal, hulls and oil. The beans are either stored by the farmer on the farm, or are transported to the mill elevators by rail, truck or barge. The constraints during transportation are to bring the soybeans from one point of storage to the next with the least amount of change in their condition.

The beans must be effectively cleaned prior to processing in the extraction equipment. This cleaning removes not only sand stones, dirt, but in many instances also removes undesirable foreign matter such as leaves, stems, pods and weed seed.

Upon arrival at the plant elevator, samples are taken to be analyzed for moisture, splits, oil content, protein content, free fatty acids and heat damaged beans. Upon completion of these analyses, the beans are either placed into short term storage, if their moisture content is higher than 13%, or long term storage if their moisture content is 13% or lower.

Seed dehulling and flaking.

Front end dehulling is the removal of hulls before solvent extraction of the beans, and allows a greater capacity through the plant. To accomplish this, the beans must be subjected to a thermal treatment in order to denature the proteinacious membrane which holds the hulls to the meats.

Next in line are the cracking rolls which break the beans into small pieces that are easier to condition and flake. At the same time the hulls are loosened from the meats. This is followed by the actual separation of the hulls by air classification or aspiration.

The recovered meats are flaked to a thickness ranging from 0.25 to 0.45 millimeters, in order to cause sufficient cell breakage to release the oil for ease of extraction. Their moisture content should be about 9.5 to 10.0%, and the flakes should have a temperature of 60° to 68°C at the extractor.

Oil extraction.

Extraction is the process by which oil is soaked out of small particles or flakes of material with a solvent (normally hexane, a light petroleum fraction), much like removing oil from a paint brush. To do this efficiently we need enough contact time between the solvent and the flakes, and agitation to get thorough penetration. The recovered solvent-oil mixture is called "miscella", and the extracted flakes are referred to as "spent flakes".

3. Oil Refining.

Oilseeds are naturally occurring and biologically active materials that contain many color and flavor precursors as well as degradation and breakdown products. Hence, the crude recovered oil must undergo a cleansing or refining process to remove all these impurities before entering the food manufacturing channels. The prime objective of refining crude soybean oil is the removal of all the oil-soluble impurities that are present, either in a true solution or as a suspension, in order to achieve the best possible quality standards of flavor, color, appearance and stability. In crude soybean oil are found phosphatides (gums), free fatty acids (FFA), color such as carotenoids and chlorophyll, tocopherols (vitamin E), moisture, meal fines, and dirt.

Degumming.

This is generally the first step in oil refining, and in it the gums which are naturally occuring in the crude oil are removed. Degumming of soybean oil is done for three reasons:

1) For the production of soybean lecithin.
2) To provide a crude degummed oil for transportation or long term storage.
3) To have an oil suitable for physical refining.

The dry gums are soluble in the crude oil, but will precipitate as an oil-insoluble sludge by hydrating with water. The process is enhanced, and the rehydration rate is accelerated, by the addition of chemical additives such as phosphoric and sometimes citric acids. In either case, effective mixing and contact time must be given in order to change the non-hydratable gums into the hydrated form. This step is normally achieved in a "day tank", where enough crude oil for one day's run is stored. This allows for continuous running, so equipment and conditions can be set and fine-tuned to achieve maximum control of degumming, minimizing oil losses and maximizing product quality.

Neutralization.

Crude oils contain various quantities of free fatty acids which are formed by the natural hydrolysis of the triglyceride molecule. They are removed in the caustic process, which is a single addition of caustic in aqueous solution. This supplies water for degumming, caustic for neutralizing the free fatty acids, and excess caustic for decolorizing. The sodium salts of fatty acids are soaps. The water solution of soap is heavier than oil, and in a batch process, it sinks to the bottom of the tank and is drained off.

The process can be carried out in a batch process, or by semi-continuous methods such as the Zenith process, where the oil is bubbled up through a large tank of caustic soda, forming the soap. Eventually the caustic soda is exhausted and needs to be recharged; alternatively it can be added continuously.

There are many variations in the choice and configuration of the equipment used for the continuous process. Nevertheless, the basic processing sequence aim is the production of the best quality soybean oil. In general, the caustic soda is metered into the pre-treated crude oil, thoroughly mixed for a specified length of time, heated in a heat exchanger and spun in a centrifuge to separate the oil from the soaps. After the removal of the soaps, the recovered oil is washed once or twice to ensure the removal of all traces of soap, and dried.

Bleaching.

Bleaching refers to the process for removing color-producing substances and for further purifying the fat or oil. Bleaching earths are natural clays (bentonites), treated with acid to improve their adsorptivity and filterability. Proper bleaching with acid-activated earth is one of the most critical steps in soybean oil processing. The dosage of acid-activated earth to be added is adjusted, so that all oxygen-containing products are removed from the bleached oil, and the oil emerging from the bleaching press shows a zero peroxide value (PV).

The process can be conducted under atmospheric pressure. The bleaching clay is added to the refined oil at 80°C, then rapidly brought up to 100-110°C and held at that temperature for 15 to 20 minutes to drive off the moisture and effect maximum bleach. Bleaching can be accomplished batchwise or continuously under partial vacuum.

Filtration.

Complete removal of bleaching earth from the oil by effective filtration is very important, since residual clay will act as a very strong prooxidant and foul the equipment down stream. Some refineries still use the old plate and frame filter presses which are very effective pieces of equipment. However, more modern filtering equipment is on the market. The recovered bleached oil should be guarded against thermal and oxidative abuses as the oil, at this point in the refining process, is in its least stable state.

Deodorization.

If the recovered oil from the previous bleaching step is to be used as a salad oil it must undergo a deodorization step for the removal of the undesirable odors and flavors caused by a host of compounds which are still present in the oil. These compounds are relatively volatile, and can be removed by bubbling live steam through the oil. Hence, deodorization is carried out under high vacuum to facilitate the removal of these objectionable volatile components, to avoid undue oxidation and hydrolysis of the oil, and to make the most efficient use of the applied steam. After deodorization, the oil is cooled, and stored ready for use.

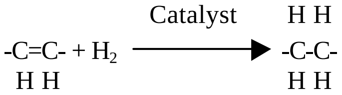
It is important to note that deodorization does not have any significant effect upon the fatty acid composition of the triglycerides of most fats and oils.

D. HYDROGENATION

Hydrogenation was carried out in 1897 to hydrogenate unsaturated organic materials, and was first applied to vegetable oils in 1903. This process is extremely important to our fats and oils industry as it imparts the desirable functional properties needed for the manufacture of numerous items in our food supply.

1. Conditions.

Hydrogenation is a means of converting liquid oils to semi-solid plastic fats suitable for shortening and margarine manufacture. Hydrogen gas is added to the double bonds of the fatty acid moieties on the triglyceride molecules, in the presence of a suitable catalyst (normally nickel). This results in an increase in the oxidative and thermal stability of the fat or oil. The gaseous hydrogen reacts with the double bonds of the unsaturated fatty acids as illustrated below:



$$\underset{\text{H H}}{\text{-C=C-}} + H_2 \xrightarrow{\text{Catalyst}} \overset{\text{H H}}{\underset{\text{H H}}{\text{-C-C-}}}$$

Also, there is an increase in the melting point of the fat. For this reason, the process is also known as *hardening*. Paralleling this is a reduction in the iodine value, which is a measure of the degree of unsaturation of the fat or oil. The average iodine value of soybean oil ranges from 125 to 135. Partially hydrogenated salad and cooking oils with an iodine value of 110-120 are on the market. On the other hand, a semi-solid plastic household shortening will have an iodine value of 90 to 95.

In order for hydrogenation to be carried out successfully, crude oil must be pretreated to remove almost all impurities. It must be degummed, neutralized and bleached. Hence, when soybean crude oil is caustic refined and bleached in the manner described previously, it becomes an easy oil to hydrogenate, since the principle catalyst poisons, phosphatides and soaps, have been removed.

Once these catalyst poisoning substances are removed the hydrogenation process is easily controlled and can be stopped at any desired point, depending upon the physical and chemical chracteristics desired in the finished product. Under normal plant operating conditions, the manufacturer is able to meet those requirements by the selection of the proper temperature pressure, catalyst type and concentration, and end point.

Almost all hydrogenations are performed batchwise in cylindrical vessels of carbon steel construction. The height of these reactors is almost twice their width, and they are equipped with a high speed agitator which maintains the hydrogen gas in finely dispersed bubbles within the circulating hot oil. Some of these vessels have additional baffles attached to the inside wall to increase the mixing of hydrogen and oil inside the reactor.

All vessels are equipped with heating and cooling coils for proper control of the reaction temperature, and an inlet port for the introduction and dispersion of the hydrogen gas. A relief vent valve is attached to the unit, as well as all necessary instrumentation for monitoring the reaction. When the desired degree of hydrogenation has been attained, as determined by either the refractive index (RI) or by the congeal point (CP), the charge may be cooled, either in the same vessel or by transferring it to another tank of the same size or slightly larger, situated below it. Using a separate cooling tank transforms the batch process to a semi-continuous one.

At this point the catalyst is removed by filtration, which can be aided by the addition of small amount of acid-activated earth and citric acid to ensure the complete removal of the colloidal nickel catalyst. Table 5 illustrates the effect of hydrogenation (plus winterization, removing high-melting triglycerides) on the fatty acid composition of soybean oil.

Table 5.
EFFECT OF HYDROGENATION ON SOY OIL COMPOSITION

Fatty Acid		Refined, Bleached, and Deodorized Oil	Partially Hydrogenated and Winterized Oil
Palmitic	C16:0	11	9
Stearic	C18:0	4	4
Oleic	C18:1	21	49
Linoleic	C18:2	54	35
Linolenic	C18:3	9	3
Eicosanoic	C20:1	tr	0
Erucic	C22:1	tr	0

2. Selectivity.

Frequent reference is made in the literature to the selectivity of hydrogenation. This is based on the fact that the greater the degree of unsaturation of a fatty acid, the greater is its tendency to add hydrogen. Thus, linolenic acid with three double bonds tends to be hydrogenated before linoleic acid, which in turn tends to be hydrogenated before oleic acid.

$$\text{Linolenic} \xrightarrow{K_1} \text{Linoleic} \xrightarrow{K_2} \text{Oleic} \xrightarrow{K_3} \text{Stearic}$$

During the hydrogenation of oils there is a considerable tendency toward the formation of isomeric unsaturated fatty acids with properties different from the naturally occuring forms. Such isomers may originate from one or more of the following reactions:

1) Addition of hydrogen at a double bond;
2) Conversion of natural *cis* to *trans* form;
3) Migration of the double bond.

The relative reaction rates of the various unsaturated fatty acids normally found in soybean oil are: oleic acid, 1; linoleic acid, 50; isolinoleic (double bonds at 9:10 and 15:16 positions), 5; and linolenic acid, 100.

The degree to which the double bond of a fatty acid can be isomerized to a conjugated system greatly influences its reactivity with hydrogen, and influences the selectivity of the hydrogenation reaction. The isolinoleic acid cited above, is the fatty acid isomer produced during hydrogenation of the normal linolenic acid at the middle double bond (12:13). Its low reactivity is due to the fact that the double bond is isolated.

Table 6.
INFLUENCE OF PROCESS CONDITIONS

	PARAMETER EFFECTED		
INCREASE IN	H_2 Concentration at Catalyst Surface	Preferential Selectivity	Trans-Isomer Formation
H_2 Pressure	+++	---	---
Temperature	---	+++	+++
Agitation	+++	---	---

For the hydrogenation reaction to be highly selective, conditions must exist that will accelerate the rate of isomerization, which will favor the maximum formation of the highly reactive conjugated double bond fatty acids. These conditions are high catalyst concentration and high temperature, with the relative rate of hydrogenation retarded by minimal agitation and hydrogen pressure. On the other hand, for the hydrogenation reaction to be non-selective, high hydrogen concentration on the catalyst's surface is maintained by high pressure and efficient agitation, and isomerization is limited by low catalyst concentration and low temperature. These interactions are summarized in Table 6.

Table 7.
HYDROGENATION CONDITIONS AFFECTING SELECTIVITY

Reaction Parameter	Selective Hydrogenation	Non-Selective Hydrogenation
Temperature	High	Low
H_2 Pressure	Low (1 Atm)	High (>3 Atm)
Agitation	Low	High
Catalyst concentration	High (0.05% Ni)	Low (0.02% Ni)
Catalyst type	Selective	Non-selective
Trans-isomer formed	High amount	Low amount
SFI curve shape	Steep	Shallow

A single change in any of the process parameters, with the others held constant, will have an effect on the reaction selectivity, the extent of *trans* isomer formation, and the rate of the reaction. These differences, taken together, produce changes in the solid fat index (SFI) profile of the hydrogenated fat. Since the SFI is a key factor in the functionality of the margarine or shortening produced from the hydrogenated fat, the connection between hydrogenation reaction conditions and final product quality is clear. Table 7 gives reaction parameters for selective and non-selective hydrogenation. A single change in any of the process parameters, with the others held constant, will have an effect on the reaction selectivity, the extent of *trans* isomer formation, and the rate of the reaction.

E. UTILIZATION OF FATS AND OILS

The subjects of refining and hydrogenation of fats and oils have been discussed previously. Now, the oil refiner has on hand refined and bleached (RB) liquid oil, partially hydrogenated base stocks and refined, bleached, and deodorized (RBD) salad oil. He has the option of selling the RBD salad oil as is or he can further modify it by one of the following processes.

1. Winterization.

Winterization is a dry fractionation step intended to provide two or more products from the same original material. When practiced with triglycerides two or more different melting fractions based on solubility at a given temperature are obtained. Originally this process was applied to cottonseed oil for the removal of the high-melting triglycerides by subjecting the oil to slow crystallization in outside tanks during winter, hence the term "winterization" was adopted. Today mechanical refrigeration is used to winterize cottonseed, partially hydrogenated soybean oil, and a host of other oils. It is essential to have the refrigeration system so arranged that the temperature of the coolant can be easily varied and positively controlled. Another essential feature of the process is a slow rate of chilling. However, the exact duration of the holding period depends upon the degree of winterization desired.

Dewaxing of corn and sunflower oils for the removal of waxes to prevent clouding is another form of the dry winterization process. Generally speaking, edible oils intended for use as a salad oils must remain crystal clear at refrigerator temperatures, otherwise they must be winterized to meet that criteria.

Dry fractionation or "pressing" is used for the production of hard butters by pressing the liquid oil out of the solid fat from oils such as palm kernel and coconut by means of hydraulic pressure. If a suitable solvent is used to dissolve the triglycerides selectively, the process is called "solvent fractionation". The process depends upon the fact that ordinary liquid fatty materials become increasingly soluble in organic solvents as they become more unsaturated or as their molecular weight decreases. It is used commercially to produce hard butters, specialty oils and some salad oils from a wide variety of edible oils.

2. Interesterification.

This is an important process used in the production of plastic shortenings and specialty products, in which the fatty acids redistribute or rearrange themselves on the glycerine molecule in a random fashion, if the reaction is permitted to come to complete equilibrium. The reaction is carried out under vacuum in an agitated stainless steel vessel at an elevated temperature. The reaction is aided by the presence of an appropriate catalyst and it is essential that no water be present to form soap, that the fat free of be acid and peroxide, and that the catalyst be rapidly dispersed through the reaction mixture immediately after it is added.

In directed or non-random interesterification, other conditions permit the rearrangement process and the simultaneous crystallization of some of the triglycerides to take place, which allows further modifications of the shortening's physical and plastic properties. It is normally carried out at a temperature below the melting point of the triglycerides to be removed. The preparation of fat resembling cocoa butter, from completely hydrogenated cottonseed oil, by solvent crystallization is an example.

Interesterification was initially used to improve the poor creaming properties of lard due to the formation of the large beta crystals. The formation of the large crystals in lard resulted from the uniform nature of triglycerides, in which the 2-position was occupied by palmitic acid. By interesterification, molecular rearrangement or randomization of this fatty acid occurs causing the formation of the more desirable beta prime crystals. The result is a smoother shortening with excellent creaming properties.

The rearrangement process does not change the degree of unsaturation or the isomeric state of the fatty acids as they transfer from one position to another.

F. COMMERCIAL USES OF FATS AND OILS

Any refinery will have on hand a variety of properly refined, bleached and deodorized (RBD) oils as well as refined and bleached, partially hydrogenated base stocks for further blending and deodorization which they can sell in bulk to other processors who can use them as they are or process them into other fat containing foods for the consuming public.

Salad and cooking oils, margarines, shortenings, salad dressings, and confectioner's coatings are some of the wide variety of products based entirely on fats and oils or containing fats and oils as a major portion of their composition.

The significance of any food product to our diet depends on its relationship to the total energy consumption. Hence, fat is popular in the diet not only for the sensory values of eating pleasure and satiety, but its prime nutritional advantage lies in its high caloric density: one gram of fat will supply about 9 Kcal whereas one gram of either protein or carbohydrate will supply about 4 Kcal each. Dietary fats have been categorized into "visible" and "invisible" sources of fat. The former category comprises the fats that have been isolated from animal tissues, oilseeds, or vegetable sources, such as salad oil, margarines and shortenings. The latter category are those that have not been isolated from the above mentioned sources but consumed as part of the animal tissues or the vegetables in our diet.

1. Salad and Cooking Oils.

Edible fats and oils intended for human consumption fall into one of the following two categories:

- Liquid oils, prepared from vegetable oils that are refined, bleached, and deodorized, such as corn, canola, soybean, sunflower and cottonseed. Sometimes they are lightly hydrogenated and winterized.
- Plastic fats, such as butter, lard, shortenings and margarines.

The difference between salad and cooking oils is due the fact that the former will be substantially liquid and clear when kept in a refrigerator at 4° to 8° C. Also, they are generally suitable for all classes of cooking except those which require the production of a highly developed dough strength. They are also used by the packing industry for packing certain canned meats, sausages, fish, sardines, anchovies and tuna.

On the other hand, cooking oils are in demand for deep frying of products such as french fried potatos or doughnuts, which are consumed reasonably fresh soon after production.

It must be born in mind that in the Orient the common cooking oils such as peanut, rapeseed, sesame, soybean and sunflower are consumed in their crude form.

2. Plastic Shortenings.

The term plastic is applied to pure fats of such consistency that they are readily mixed, worked or spreadable. The term "shortening" refers to the ability of a fat to lubricate, weaken or short the structure of a baked product. Without shortening the gluten particles will adhere to each other and give the sensation of toughness when chewed. If shortening is present, the gluten particles slip by each other more readily and produce tenderness.

For many years animal fats, particularly lard and marine oils, were the principle edible fats used in shortenings. For the record, compounded plastic shortening is an American invention, growing out of the cotton-raising industry. They were first prepared by the blending of hard and soft fats and called "lard compounds" or simply "compounds". With the introduction of the catalytic hydrogenation process shortening manufacturers were able to produce plastic shortenings made entirely from vegetable oil. These shortenings have superior physical properties such as good mixing and creaming qualities, high stability and uniformity, as compared to lard.

3. Types of Shortening.

Shortenings fall into a number of categories, determined by the functional requirements of the product. They are formulated from one or more of the following ingredients: an oil, a base oil, a plasticizer and an emulsifier. The most common types are briefly discussed below.

All-purpose shortening.

This shortening may be prepared from a single base oil that has been partially hydrogenated to an iodine value of between 65 and 80, or a blend of oils that have been hydrogenated to a specific plasticity or consistency plus 8 to 10% of stearins or flakes (highly hydrogenated base stock, 5 IV maximum). In the case of an 100% vegetable all purpose soybean shortening, the hard stock must be a beta prime oil such as cottonseed or palm oil.

Table 8.
EFFECT OF HYDROGENATION CONDITIONS ON BASESTOCK CHARACTERISTICS

	Soybean Oil			Cottonseed Oil		
	Original Oil	Selective Conditions	Non-selective Conditions	Original Oil	Selective Conditions	Non-selective Conditions
Fatty Acid	Percentage Composition					
Palmitic	11.5	12.2	11.7	25.3	25.3	25.6
Stearic	4.3	7.9	15.2	3.1	3.8	10.8
Palmitoleic	0.0	0.0	0.0	0.7	0.7	0.9
Oleic	25.2	72.8	57.7	20.4	55.1	44.9
Linoleic	50.0	7.1	15.4	49.7	14.1	16.6
Linolenic	8.5	0.0	0.0	0.0	0.0	0.0
trans, %	0.0	38.9	33.3	0.0	36.5	35.5
Iodine Value	130	80	79	105	78	75
MP, °C	--	35	51	--	35	45
Temp., °C	Solid Fat Index					
10.0	--	22.6	34.5	--	28.0	39.0
21.1	--	11.5	26.0	--	15.0	29.6
26.7	--	6.3	23.6	--	9.7	26.3
33.3	--	0.6	15.5	--	1.4	16.4
37.8	--	0.0	10.5	--	0.0	9.3

Also, it must be born in mind that formulation of a product with good shelf life stability will require the use of non-selective hydrogenation of the base stock. With beta prime oils such as cottonseed it is possible to partially hydrogenate the base stock to provide good body at high temperature without the addition of hard stock, as shown in Table 8. However, the blending method is generally preferred because it produces a more stable shortening and is easier to control.

Frying shortenings.

The major criteria for frying fat include a low level of unsaturation to assure superior flavor stability, a high smoke point, and a bland flavor. Frying fats are used at temperatures ranging from 180° to 190°C, so it is essential that they have as much heat stability as possible. The ability of frying fats to withstand oxidation is not a function of its overall degree of unsaturation, but rather is determined predominantly by its content of polyunsaturated fatty acids, or more accurately, by its concentration of the active methylene groups (linoleic and linolenic acids).

Component oils vary in their ability to withstand the rigors of frying conditions, and a shortening which gives good results in baking will not necessarily be a satisfactory frying fat. Also, in producing frying fats the choice of the proper base stock is not the only important objective, as it is also important that they are properly refined and the trace quantities of iron and copper which are always found in the crude oil are neutralized by the use of the proper chelating agent. A frying fat with high oxidative stability does not have a long plastic working range. It will tend to be relatively brittle at temperatures below 36°C and soft at temperatures above 50°C.

Because deep frying shortenings are present on the surface of foods, a high melting point can cause a greasy or waxy taste in the food. To avoid this, hydrogenation conditions of the oil must be carefully chosen in order to obtain maximum oxidative stability with the lowest possible melting point.

Cake and icing shortenings.

These shortenings are made by combining an appropriate amount of the selected emulsifier with a base similar to an all purpose shortening described above since the same consideration for crystal habit and form, texture, plastic range and mixing are important.

Mono- and diglycerides possess marked surface activity due to their content of both oil loving (lipophilic) and water loving (hydrophilic) groups, and are extremely effective in promoting dispersion of the shortening in the doughs as well as giving it more strength, thus allowing the baker to use a higher ratio of sugar to flour and other ingredients (water and milk, etc.) in the recipe, while still obtaining adequate aeration of the batter during mixing. The result is a sweeter, more moist, lighter and finer textured cake.

The choice of mono- and diglycerides will depend upon the ultimate purpose of the product. Generally speaking, a higher melting point one is preferred for cakes and a lower melting for icings. However, almost all cake and icing shortenings on the market contain an intermediate melting one. The traditional and most widely distributed cake and icing shortenings are formulated for dual purpose use, either cake or icing. Typically, these shortenings will contain a mono- and diglyceride emulsifier at a level of 2.5 to 3.0% as alpha monoglyceride.

Biscuit and cracker shortenings.

These are high stability type shortenings used in the manufacture of crackers and sweet biscuits which are sold in consumer packs nationally or regionally in supermarkets and grocery stores. They all require long shelf life stability since prolonged periods of time intervene between their time of manufacture and consumption. Shortenings are a major ingredient in the recipe of these products and may account for as much as one-third of the formula. Also, most of these products are manufactured in large factories which use complicated high speed production and packaging lines to produce a variety of items simultaneously. As a result, the shortening must be precisely tailored to meet the following objectives:

- It must provide the desired esthetic properties to the finished product.
- It must have the physical properties required for high speed mixing and processing equipment.
- It must have high oxidative stability for long shelf life storage.

Most manufacturers of shortenings make special products for biscuits and crackers in which the plastic range is sacrificed to some extent in favor of stability or to meet customer's specifications. One specification common to all is a high AOM stability, usually 100 hours.

Filler fat shortenings.

The manufacture of sandwich cookies and wafers requires the presence of a filler mixture between the cookies or the wafers. This mixture is composed of one-third shortening and two-thirds finely ground sugar with suitable flavors added. It is applied to the cookies or wafers when sufficiently fluid, but sets up due to the thixotropic properties of the base fat which allows its consistency to decrease while the mixture is being stirred, returning slowly to its original value when stirring stops and the material is allowed to rest. Wafer filler fat is quite firm since the filling must provide support for the fragile wafers.

Snack spray fats.

This is a very popular type of fat used by the snack industry for spraying snack crackers with as much as 25% of oil, in order to improve their eating quality and give them a glossy surface appearance. The oil must possess two important qualities: good oxidative stability because of the large food surface area covered; and a low melting point to avoid a waxy or greasy mouth feel and a dull surface appearance. These qualities were first found in coconut oil but partially hydrogenated soybean oil is on the market as a replacement.

Coating fats.

These are hard butter replacements or substitutes for cocoa butter in confectionary and immitation dairy products. Today such product is on the market and is made from a combination of soybean and a small quantity of cottonseed oil through the utilization of special hydrogenation techniques. This product has excellent appearance and is sometimes preferred over coconut and palm kernel hard butters.

Fluid shortenings.

These cover the latest arrival on the market for frying and baking and are far removed from the traditional plastic or semi-solid products. They consist basically of either RBD or lightly hydrogenated soybean oil to which is added either hard fat (stearins) and/or hard emulsifiers. These are then processed in such a manner to incorporate these additives in finely divided crystals which will remain in suspension. A typical fluid shortening formula is formulated with 102 to 110 IV partially hydrogenated soybean oil with from 2 to 8% of soybean hard stock added, plus proper amounts of antioxidant and anti-foaming agent. These fluid shortenings have the distinct advantage of being pumpable or pourable at room temperature and can be used either for frying, or for bread baking in the continuous mixing process.

II. MARGARINE AND SHORTENING PRODUCTION

Production of plastic shortenings and table grade margarines utilize the same equipment, and the same principles apply to both products with one exception. Since margarine contains at least 17% aqueous phase, all processing equipment must be constructed of stainless steel, whereas shortening production may utilize heat exchangers constructed of carbon steel. However, new installations are using stainless steel units.

Crystallization of the fat or emulsion phases has undergone many changes over the years. Early crystallization was done by running the emulsion in a wooden gutter through which, at the same time, a current of water was flowing in the opposite direction. With the perfection of mechanical refrigeration the use of a sheet of ice-cold water replaced plain water to solidify the fat phase. This gave way to the use of a spray of ice-cold water, that in turn was replaced by milk, followed by the use of cold skimmilk or buttermilk to accomplish the same purpose.

The development in the U.S.A. of the brine cooled revolving drum for the rapid chilling of pure lard was accomplished in 1883 and adapted for margarine in 1907 in England.

Modern technology for the plasticization of shortening began about sixty years ago when the Girdler Corporation developed the closed, continuous, internally chilled plasticizer, using a scraped-wall heat transfer unit which became known throughout the world as the Votator in 1931, and was later adopted for the production of margarine in 1937. Since that time, the original unit has undergone several modifications, but the principle has remained the same. In the ensuing years, other manufacturers have developed similar systems which embody the same heat transfer concept. The main differences lie in the treatment of the crystallized fat phase after the initial, rapid, shock-cooling step.

The old fashioned drum crystallizer is still in use for the production of puff pastry margarines in Europe. It is a large, horizontal stainless steel drum which revolves rather slowly, refrigerated internally by expanding ammonia or Freon in order to bring the temperature of the outer surface to -20°C. A very thin film of the margarine emulsion is spread onto it from a trough mounted horizontally as shown in Figure 6. The fat crystallizes rapidly and is removed by a sharp scraper blade mounted just below the feeding trough. The flaked margarine is allowed to fall into specially constructed dumpsters where it is allowed to rest at room temperature for at least four hours before being kneaded and extruded for packaging.

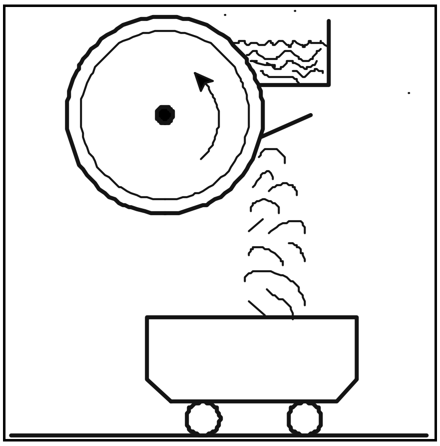


Figure 6. Drum processing of puff pastry margarine.

A. HISTORY OF MARGARINE PRODUCTION

Attempts to produce a substitute for butter started in Europe during the middle of the nineteenth century, due mainly to the increasing pressure of the population on the food supply which led to high prices for butter and other foods. The invention of margarine occurred, then, at a time of definite need in Europe for a cheap substitute for butter.

The first acceptable butter substitute was produced by the French chemist Mege Mouries in 1869. He had been commissioned by Emperor Napoleon III, in 1867, to produce a butter substitute for the armed forces and the needy classes of the population, which would be cheaper and of better keeping quality than the natural product. For his outstanding accomplishment he was rewarded a handsome prize.

His observation that cows on reduced rations produced milk containing reduced amounts of fat led to the conclusion that the origin of this fat must come from the cow's body reserve. Hence, in his process he washed heated tallow with warm water containing potassium carbonate, pepsin, and salt. This step contributed to improving the flavor of the fat by removing non-fatty contaminations. The separated fat was drawn off, washed with water and left to crystallize in shallow trays. This was followed by the separation of the softer portion of the fat, called "oleo", from the harder fraction. This oleo fat had a chemical composition different from that of whole tallow, resembling butter in melting point and to some degree in consistency. This purified fat was the raw material used in the first successful production of margarine.

The word margarine is an invention, like the food it represents. Its root is found in the classical languages. It originated from the observation that the solidified mixture of ingredients of this new product had a pearly appearance, that reminded him of the Greek word for pearl (*margaron*) and pearly (*margarites*). Also, the originator recognized the need for a name for the new food to separate it from butter which it closely resembled, so he called it "margarine". The prefix "oleo" (originating from the latin word "oleum" for beef tallow) was added, referring to the origin of the fat used. The name "oleomargarine" became fixed in the USA until the advent of the all-vegetable margarines in the 1930's. In the meantime the consumer referred to the product only by the prefix "oleo". Gradually the name "margarine", which had already achieved legal recognition in Europe, became the favored word. However, to some the word "oleomargarine" means margarine containing animal fats.

B. MANUFACTURE OF MARGARINE

The first method used for the production of magarine provided for churning the emulsion, which to some extent texturized a product that must have been very grainy. However, this was remedied by quickly chilling the emulsion of fat and milk in a tub of cracked ice where it stayed in contact with the ice for two to three hours, after which the solidified oil was churned with additional sour milk and salted much like butter. With the perfection of mechanical refrigeration, ice cold water replaced the ice and later the fat was sprayed into a sluice where it met a spray of cold water which crystallized the fat and washed it down into a truck for draining.

With the application of the brine-cooled revolving drum to crystallize the emulsion on its outside suface, the solidifying medium was never in contact with the emulsion. This practice is still popular in Europe for the production of puff pastry margarines.

Regardless of the method of crystallization the solidified material appears as a mass of crystals or plates which do not adhere together. In order to produce a smooth homogeneous mass the crystals must be kneaded or worked until they join together and become homogeneous using any suitable kneader.

All the above methods were inefficient and subjected the margarine to serious microbiological problems emanating from contaminated water or from airborne organisms. Also, the subsequent handling and working were costly in labor and could lead to further contamination. It was not until 1937 when the closed, continuous Votator system method became available, that chilling and working the product under conditions of maximum sanitation and efficiency was introduced to the industry. Essentially the apparatus consists of a scraped-surface heat exchanger chilling unit, or "A" unit jacketed for a direct expansion refrigerant system such as ammonia or Freon, and an unagitated tempering zone or "B" unit where the margarine undergoes further crystallization and sets with the minimum of work as shown in Figure 7.

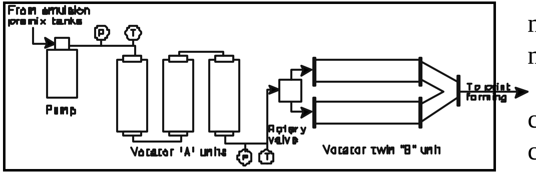


Figure 7. Flow diagram of the Votator margarine process.

The heat transfer tubes are 10.15 cm (4 in.) in diameter, constructed of pure nickel and chrome plated to minimize cylinder wear and prolong the life of the scraper blades; all other parts coming in contact with the product are of stainless steel. The shafts are 8.25 cm (3 1/4 in.) in diameter, leaving an annular distance of 0.95 cm (3/8 in.). On the larger shortening units the cylinders are 25.4 cm (10 in.) and the shafts are approximately 22.9 cm (9 in.) in diameter, made of carbon steel which is chrome plated to minimize wear and prolong the life of the scraper blades. The shaft has two rows of scraper blades that are not rigidly mounted, but are thrust against the cylinder wall by pressure, centrifugal force, and the viscosity of the plasticized shortening or margarine emulsion.

In general, shaft speed is in the range of 400 to 700 rpm depending upon the size of the unit, which allows the blade to travel upwards of 215.4 meters (700 feet) per minute, and the two rows of blades to scrape the surface clean about 1500 times per minute. The action of these blades provides the violent agitation so necessary to the formation of a fine, uniform crystal structure. Almost all margarine manufacturers in the USA are owned and operated independently of refineries. They have tank farm limitations. Consequently, they purchase their oil requirements according to certain agreed to and written specifications. They also make sure that the residence time of any oil within their plant is as short as possible, in order to minimize any flavor deterioration to that oil.

The method by which the different ingredients are added or blended together will depend to a great extent upon the tonnage needed, the formula variations, and, most importantly, how close the final fat content of the margarine is compared to the standards set by the law. Since fat constitutes 80% of a standard package of margarine, it is the most expensive ingredient to monitor, and serious consideration must be given to its batching method.

In all modern margarine processing plants there are essentially six steps, regardless of the type of equipment used. These are:

1 Mixing of oil(s) with oil soluble ingredients.
2 Mixing milk phase or water phase with salt and other water soluble ingredients.
3 Mixing of phase (1) and (2) to form the emulsion.
4 Chilling and plasticizing the above formed emulsion.
5 Forming the plastic margarine into prints or filling it into plastic tubs or bulk containers.
6 Wrapping, cartoning, packaging and cold storage of the finished product.

In the first step, the most reliable method is weighing the different oils to be used one at a time in a stainless steel beam or load cell scale tank of an appropriate size, normally 500-gallon capacity. The weighed oils are either dropped or pumped to another tank slightly larger than the scale tank, or about 600-gallon capacity, equipped with an efficient agitator as well as provision for heating and cooling, with upper and lower control limits. The temperature of all partially hydrogenated oils must be maintained about 5.5°C (10°F) above their melting points during storage. They should be kept mildly agitated to prevent stratification, preferably under an atmosphere of nitrogen in order to prevent oxidation and flavor deterioration during storage.

With the agitator running, the proper amount of emulsifier is added. This could be in the form of any federally approved emulsifier such as lecithin, mono- and diglyceride or a combination of the two. Also, Vitamins A, D, or E, are added, as well as colorants such as beta-carotene or annatto and oil-soluble artificial flavors. Because these additives are normally concentrated, viscous, and expensive, it is always advisable to dilute them with with several times their weight of margarine oil. Diluted lecithin mixes should be kept at temperatures no higher than 49°C (120°F) in order to prevent darkening. Also, dilution of mono- and diglycerides should be done in stainless steel containers, and the solution kept at 60-63°C (140-145°F). As far as vitamins and color are concerned, they are delivered in pre-batched cans ready to add per formula or batch which is normally referred to as a "churn", a term adopted from butter churning in the dairy industry.

When the oil-soluble ingredients are thoroughly mixed, the proper amounts of the water phase components are added. They could be whole milk, skimmilk, reconstituted nonfat dry milk solids and water, cream or water with salt dissolved in it. Also, the water soluble bacteriostat sodium benzoate or the fungistat potassium sorbate and/or the heavy metal chelating agents citric acid and EDTA are added if needed and if the law allows it. Water soluble flavors such as diacetyl and starter distillate are added to the water phase at this stage. However, some manufacturers still develop their butter flavor by fermenting part of the pasteurized milk phase using special lactic bacteria cultures.

It is very important that the water phase is added to the oil phase in order to promote the formation of the water-in-oil emulsion. In the standard 80% fat margarine the rate of water addition has little effect on the outcome of the nature of the product. However, as the proportion of water phase increases it is essential that the rate be reduced, especially in the early stages of emulsion formation otherwise the emulsion will invert.

In some installations the formulated margarine emulsion is pasteurized at 73°C (165°F) for 16 seconds before chilling in the Votator, in order to ensure its wholesomeness and freedom from pathogenic bacteria. After the water phase is added the emulsion is kept under constant agitation to prevent it from separating. On the other hand, margarine is a stable emulsion because that the congealed oil contains the dispersed aqueous phase in droplets ranging in size from 2 to 20 microns diameter, with the majority about 5 microns. It must be born in mind that in the Votator process violent agitation and kneading in the "A" unit produces this extremely fine dispersion of the water phase droplets in the fat phase. While this tight emulsion is effective in preventing leakage of the water phase from the margarine, it contributes to the slow release of the milk and water soluble flavors in the mouth, because the surrounding fat must melt to allow the small water phase droplets to coalesce enough to become perceptible to the tongue taste buds. Also, crystallization with minimum agitation produces a less plastic less spreadable product. Modifications of the original Votator process took place to overcome this problem by placing perforated stainless steel plates, "texturizing plates", in the resting tube or "B" unit in order to increase the plasticity of the product.

Most margarine manufacturers in the USA prefer to batch all the major ingredients such as the oil and water phases and dose the rest using stainless steel, calibrated, positive displacement pumps. However, the use of proportioning pumps for the entire operation was practiced in Europe for a long time. It required very accurate temperature controls on all major ingredients in order to deliver the exact amounts at all times, and added considerably to the cost of quality control and fat analysis as well as mechanical maintenance of any worn pump gears.

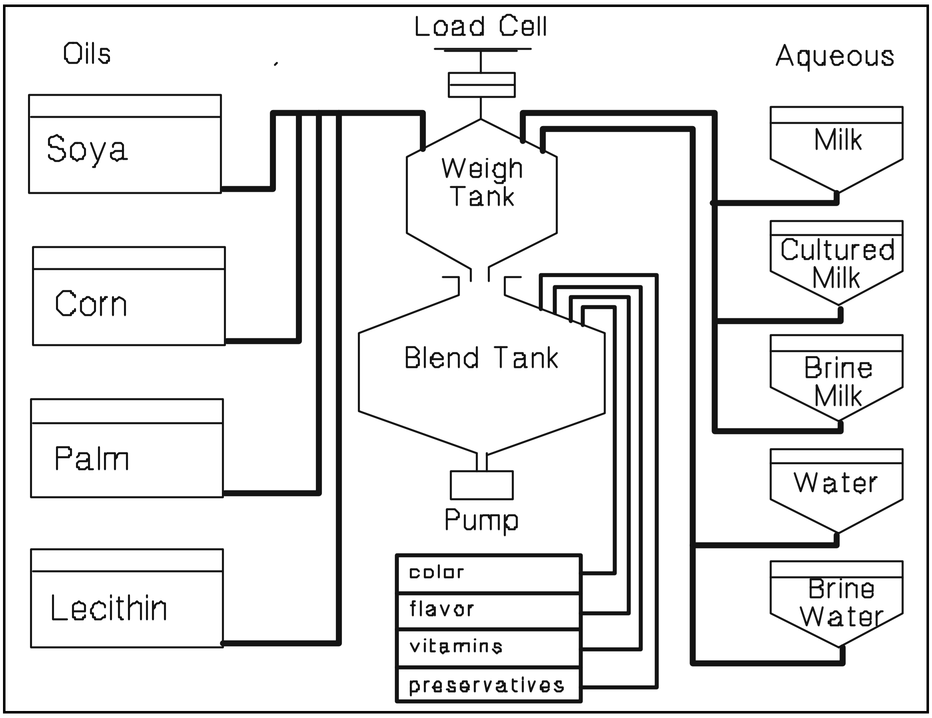


Figure 8. Automatic batching of margarine components.

The most advanced and fully computerized in-plant batching system for margarine manufacture was installed in 1965 by an American manufacturer. It depended on the accuracy of a load cell in weighing the major ingredients, and dosing the diluted minor ones using pre-calibrated stainless steel positive displacement pumps (Figure 8). Its speed and accuracy allows it to be used in either a batch, semi-continuous or fully continuous modes. Today, many major manufacturers on both continents have converted to this system.

Today, margarine is a household food item used by everyone as a spread or in baking and cooking. However, since it is made to resemble butter and has been fortified with vitamin A, its composition is governed by laws and standards of identity in almost every country including the USA. According to the US Standard of Identity for margarine all consumer packs must be sold in one pound units regardless of container shape. Hence, a housewife shopping for margarine in the neighborhood grocery store or supermarket will find the following categories of margarine in the display case:

1 Regular stick margarine - containing a minimum of 80% fat (to be referred to as standard), usually available in four 4-ounce (113.5 g) parchment or foil wrapped sticks, cartoned in either foil or lacquered carton.
2 Soft margarine - containing 80% fat (to be referred to as standard), is sold in either two 8-ounce (227 g) plastic tubs cartoned in a sleeve package, or in a one-pound plastic bowl or tub, either cartoned or not.
3 Diet margarine - containing a maximum of 40% fat is sold in a similar type of package as the soft margarine.
4 Whipped stick margarine - with as much as 50% injected air, found in six foil wrapped sticks to a pound, and over-wrapped in a sealed foil laminated carton.
5 Spreads - which are not governed by the standard for regular or diet margarines, contain from 72% to

52.5% fat, found in either stick or tub forms. The stick is wrapped and cartoned similar to regular margarine #1. On the other hand, the soft form can be sold in either one, two or three pound plastic tubs.

6 Liquid form margarine - containing 80% fat, is sold in one-pound squeezable plastic bottles.

To satisfy the requirements of institutional and commercial bakers, special purpose margarines are manufactured to meet their needs. These are formulated to give the baker a product with a long plastic working range, or a super-glycerinated product (high ratio type) with strong dairy flavors. To a baker, the main objective of using margarine in baking and icings is to impart the buttery taste and smell to the finished products. These margarines are normally sold in 22.2 Kg (50 pounds) polyethylene-lined cardboard boxes, or 177.8 Kg (400 pounds) polyethylene-lined fiber drums.

Another product that may be classified as a margarine is the so-called "puff-paste margarine", because it contains between 6 and 8% of either water or milk. This is used as a roll-in fat for puff pastry, because the water expands during baking to give the flaky texture characteristic of this type of baked good. It is very popular in Europe and is manufactured on the drum crystallizer. However, there are some installations that are producing it with special closed continuous crystallizers such as Schroeder or Gerstenberg.

Table 9.
SOY OIL BASE STOCK PROGRAM FOR SHORTENING AND MARGARINE

Base No.	1	2	3	4	5	6
Hydrogenation Conditions for Making the Base Stocks						
Initial °C	150	150	150	150-163	150-163	140
Final °C	165	165	165	218	218	140
Pressure (Bars)	1.0	1.0	1.0	0.3	0.6	2.7
Ni catalyst (% of oil)	0.02	0.02	0.02	0.05 (Selective)	0.02 (Selective)	0.02
Final IV	83-86	80-82	70-72	64-68	73-76	104-106
Congeal	--	--	25.5-26.0	33-33.5	24-24.5	--
Solid Fat Index of the Base Stocks						
10.0 °C	16-18	19-21	40-43	58-61	36-38	4 max
21.1 °C	7-9	11-13	27-29	42-46	19-21	2 max
33.3 °C	0	0	9-11	21 max	2 max	0

As previously mentioned, margarine manufacturers in the USA are owned and operated independently of refineries, and must purchase their oil requirements either already pre-blended to their specifications, or purchase base stocks and blend them in-plant, depending upon their method of margarine batching. In either case, to enable the formulating chemist to make the widest possible variety of products, while keeping the number of base stocks as low as possible, six partially hydrogenated soybean oil base stocks will suffice, as shown in Table 9.

Table 10 gives the ratios of the above bases to use for the production of different margarines, and the Solid Fat Index specifications for each oil blend.

All the above formulations are based on 100% soybean oil for refrigerated products. Consistency problems in the finished margarines, caused by polymorphism and crystal habit characteristices of the oil blend, may require the addition of 5 to 10 per cent of a beta prime fat. The ones used most often are partially hydrogenated cottonseed or palm oil with an SFI curve similar to stock #4. This addition gives maximum resistance to thermal shock and conversion to beta phase crystals, in case inadequate refrigeration after production is not available. The crystal habit tendencies of pertinent fats and oils are shown in Table 11.

Table 10.
BLENDS FOR MARGARINE STYLES

	Margarine Style			
Base Stock	Regular Stick	Soft Stick	Tub #1	Tub #2
3	--	--	25 ± 5	--
4	38 ± 5	50 ± 5	--	27 ± 2
5	20 ± 5	--	--	--
6*	42 ± 5	50 ± 5	75 ± 5	73 ± 5

*RBD Soy Oil may be used for Soft Stick and Tub Margarines

Solid Fat Index of the Margarine Oil Blends				
10.0°C	25-30	16-24	8-14	8-14
21.1°C	14-18	10-15	5-8	5-8
33.3°C	2-4	1.5-4	0.5-2.5	0.5-2.5

C. QUALITY CONTROL

The integrity and reputation of any shortening and margarine producer depends upon his ability to supply his customers with the same quality products all year long. This is not an easy task. It requires an outlay of capital to build and equip a proper laboratory, and then to staff this laboratory with personnel who are competent to monitor all production steps, in accordance with a quality control and quality assurance program which is agreed upon and understood by everyone.

Table 11.
CRYSTAL HABITS OF FATS AND OILS

Beta Type	Beta Prime Type
Canola (LEAR)	Cottonseed
Coconut	Palm
Cocoa Butter	Rapeseed (HEAR)
Corn (Maize)	
Palm Kernel	Herring
Olive	Menhaden
Peanut	Whale
Safflower	
Sesame	Butterfat
Soybean	
Sunflower	Tallow
Lard	Modified Lard

The nutrient content of any food is a basic quality consideration. Shortenings and margarines may be considered as food commodities whose nutrient qualities are recognized and understood by almost all consumers. Nevertheless, those consumers are becoming increasingly interested in the relationship between the source of fat in the shortening or margarine, its fatty acid composition, and their health.

Assurance of product quality of either margarine or shortening is based on an understanding of, and adherence to, the underlying principles of shortening or margarine formulation, as well as processing technology. Such principles provide for acceptable standards and limits which should not be exceeded by formulation, comingling, or unit process control.

The most critical areas of shortening quality control relate to those factors affecting oxidative stability, consistency, texture and color, emulsifier level, and functionality. Refractive index, iodine value, AOM stability, and peroxide value provide standardized methodology for those factors affecting oxidative stability.

Solid fat index (SFI) as determined by dilatometry or solid fat content (SFC) as determined by nuclear magnetic resonance (MNR), Wiley or capillary melting point, Mettler dropping point, penetration, and viscosity are factors customarily used to measure consistency and texture.

Color is most frequently measured by the Lovibond tintometer procedure. Color is determined visually or instrumentally on the final product to match a standard agreed to internally, or one specified by the customer.

Critical areas of control of margarine quality relate to those factors affecting oxidative stability of the base stock oils and blends thereof, which can be expressed by the determination of the refractive index, iodine value, AOM stability, and peroxide value, as well as tasting all incoming oils and final blends.

Plasticity and spreadability are determined by either SFI or SFC determinations, and Wiley or capillary melting point. At times a manufacturer may use penetration on the final product as a quality control method. However, spreading the margarine on a piece of bread or a piece of cardboard may suffice.

Most of the above mentioned tests are standard tests published by The American Oil Chemists' Society, and must be followed without any changes or modifications. This is an essential requirement in establishing and performing any quality assurance program, since it provides the manufacturer, the customer and the user with standardized methodology to be followed by all concerned, regardless of where the test is performed, or by whom. Management support and dedication to product quality and technical training of production supervisory personnel is key to any quality assurance program, and essential to the production of high quality shortenings or margarines.

III. USE OF SHORTENINGS IN BAKERY FOODS

Shortenings (fats and oils) perform a number of desirable functions in bakery foods. These include:

- Imparting tenderness
- Moister mouthfeel
- Structural contribution
- Lubrication
- Air incorporation
- Heat transfer

The factors which determine the ability of a particular fat or oil to perform one or more of these functions are: the ratio of solid to liquid phase; the plasticity of a solid shortening; and the oxidative stability of the fat or oil. These factors are discussed in more detail in the next chapter. In this chapter the contributions of shortening to the quality of a number of different bakery products are considered. The specific functions of importance to each particular bakery product are discussed.

A. USES IN YEAST-LEAVENED PRODUCTS.

1. Bread.

The inclusion of fat in bread dough has several consequences. The final loaf volume is larger (improved ovenspring), the crumb is softer, and the keeping quality of the bread is better.

Up to 5% fat (flour weight basis) may be used in bread, although the usual level is 3% to 4% of a plastic fat such as all-purpose shortening or lard, or 2½% to 3% of vegetable oil. These amounts produce the optimum effect in the bread. The shortening is simply added to the mixer at the beginning of dough mixing.

The tenderizing effect of shortening is due to the liquid phase. Since all-purpose shortening contains about 25% solid fat at room temperature, 3 kg of vegetable oil is equivalent to 4 kg of plastic fat, in softening bread crumb. This tenderizing effect also slows down the staling process, so the bread with shortening is more palatable after storage for several days, than the same formula without fat in the dough.

The solid phase of shortening contributes to loaf volume, and when a switch is made from plastic fat to oil, it is also necessary to use a dough strengthener such as sodium stearoyl lactylate (SSL) or diacetyl tartrate esters of monoglyceride (DATEM) to get good volume. Loaf volume increases as the amount of plastic shortening increases, up to about 5% (flour basis), then remains roughly constant (Figure 9). This is because the dough expands, in the oven, for a longer time when shortening is present, as compared to a dough made without added fat. In other words, in bakery terminology, the addition of shortening increases the ovenspring of the bread.

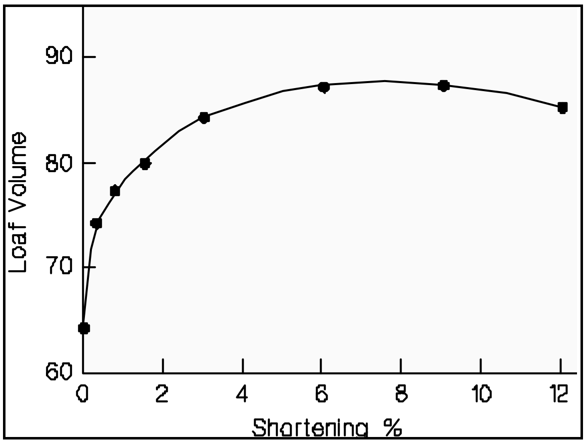


Figure 9. Increase in loaf volume with increasing shortening in bread dough.

If bread is being baked for conversion into toasts (Zwieback) or croutons, the oil used should have better oxidative stability than simple vegetable oil. The final product is expected to have a shelf life of weeks to months, rather than the few days for fresh bread, and possible oxidative rancidity must be considered. Vegetable oils may be lightly hydrogenated, which markedly increases their resistance to oxidation, but does not produce any appreciable amount of solid fat at room temperature. These give all the tenderizing effects of simple vegetable oils, but have a longer shelf life.

2. Danish, Puff Pastry.

In many bakery products, fat is layered between sheets and dough, and this is manipulated to make a dough sheet consisting of up to 100 alternating layers of dough and fat. Such roll-in doughs include Danish pastry, puff pastry, brioche, and croissants. The dough is mixed, divided into pieces of about ten kilograms each, then cooled to 5-10°C in a retarder. The cooled dough is rolled out, two to three kilograms of fat is spread over part of the sheet, and the dough is folded over to cover the fat. The "sandwich" is then rolled out and folded; this is repeated several times, often with a retarding step included to keep the dough/fat mass cool.

The primary goal during the roll-in process is to preserve the structure of alternate layers of dough and fat. There are several important factors to consider in selecting the correct shortening or margarine for such a process. Some of them are: SFI and plasticity of the fat; complete melting point of the fat; consistency (softness) of the dough; retarder temperature; number of folds given the dough before returning it to the retarder; and proofing temperature. Many of these factors are unique to a given product in a particular bakery, and they influence the specification for the roll-in fat which gives the best final product in that bakery.

The plastic range of the fat must be rather broad. The consistency of the fat should nearly match that of the dough across the temperature range, which usually includes the temperature of the retarder (on the cool end) to room temperature or above. If the fat is significantly harder than the dough at the cool temperature, then when a retarded dough is rolled out, the fat does not spread into a uniform layer between the dough layers, but is likely to tear holes in the dough sheet. If the fat is softer than the dough at room temperature, then as the dough mass warms up (during rolling and folding) the shortening soaks into the dough, the adjacent dough layers knit together, and the layering effect is lost.

The proper plasticity of roll-in fat requires a relatively shallow SFI profile, and stabilization in the â′ crystal phase. The contribution of these factors to plasticity is discussed in the next chapter.

The melting point of the fat must be higher than the temperature at which Danish or croissants is proofed. If the proof box temperature is above the fat melting point, the fat layers turn to oil. This allows the dough layers to knit together to some extent during proofing, and the final product is less flaky than desired. As a general rule, the complete melting point should be at least 5°C higher than proof box temperatures.

Rolled-in doughs that contain no yeast (puff pastry, brioche) depend upon steam generation in the oven for their leavening. Usually margarine (which contains about 17-20% water) is used for the roll-in fat for these doughs. The water is trapped and held in the fat layers in the dough. It evaporates and expands in the oven, giving an expanded structure to the final product. If the fat portion of the margarine is too soft, the water migrates into the dough during the roll-in step, and the leavening action in the oven is decreased.

Sometimes baking soda (sodium bicarbonate) is added to the dough, for leavening. In this case a regular shortening (100% fat) having the proper plasticity may be used. This is less expensive than margarine, on an equal fat basis, and the final product will be more economical.

B. USES IN CHEMICALLY-LEAVENED PRODUCTS

1. Cakes, Muffins.

In layer cakes and related items (for example, Madalenas), the closeness of the internal grain, and to some extent the final volume, are strongly influenced by the characteristics of the shortening used. In the finished cake a high percentage of the total volume is open space, present as finally divided cells. These spaces are created by carbon dioxide (from the leavening system) and steam, formed during baking. When these gases are generated, by heat, they migrate to the nearest air bubbles, that have been incorporated into the cake batter during mixing. If there are many small air bubbles in the batter the leavening gases are distributed widely. Each of the bubbles is small, and does not rise rapidly to the surface of the cake. The leavening gases are retained in the cake and contribute to final volume. If the air incorporated during mixing is present as relatively few, larger, bubbles, then during baking the bubbles are expanded by the leavening gases, and many of them are large enough that they rise to the surface, escaping and yielding a lower final cake volume.

If the original batter contains many small air cells, the final cake will have larger volume and a fine (close) grain. If the original air bubbles are fewer and larger, the final cake will have less volume and a coarse (open) grain. The shortening used plays a large role in determining the degree of subdivision of the air.

In the usual two-stage process of cake production, the shortening and sugar are combined and mixed. During this step the air is dispersed into the solid phase. Then the eggs are incorporated, followed by the flour, liquids, and other ingredients. During the first creaming step, the plastic shortening entraps air bubbles. In the presence of an emulsifier such as 4% monoglyceride, these bubbles are divided into numerous small air cells, by the action of the beater. The shortening must be solid (so the bubbles don't escape), but also plastic so it can fold around each air pocket. This is best accomplished by a plastic shortening, crystallized in the â′ phase. If the shortening has transformed into the â phase, the large plates of solid fat are much less effective in entrapping the fat. A good shortening for this type of cake batter production has the SFI profile of all-purpose shortening, containing added monoglyceride.

It is also possible to make cakes in a one-stage production process, in which all the ingredients are added at the beginning and the batter is mixed. In this case the air is entrapped in the water phase rather than in the shortening. In order to form the air-in-water foam, which is stabilized by proteins contributed from flour and eggs, it is necessary to prevent the defoaming action usually associated with fats and oils. This is accomplished by including an á-tending emulsifier in the shortening; typical ones used are propylene glycol monoesters (PGME) or acetylated monoglyceride (AcMG). At high enough concentrations these emulsifiers form a solid film at the oil/water interface. This solid interfacial film segregates the fat from the water phase, so it cannot destabilize the protein foam.

The film-forming tendencies of á-emulsifiers enable the use of liquid oil as the shortening in a cake or muffin batter. Cakes made with oil shortening are more tender than when they are made with a plastic shortening. The cake gives an impression of moistness when eaten, even after storage for a week or longer. Packaged dry cake mixes, for use by the housewife, are usually made with oil as the shortening.

2. Cookies.

Fats and oils are used for several different parts of cookie products. The functionality and requirements are different for each application, and will be discussed separately.

Dough.

For wirecut cookies, where the dough is extruded through a die and portions are cut and dropped onto the baking band, the main dough function is incorporation of finely-divided air bubbles. The rational is the same as that discussed above, for cake batters. As the cookies bake, leavening gases (steam, carbon dioxide) collect in the air bubble nuclei. If the air cells are few and large, the grain of the resulting cookie will be open, while if the air nuclei are many and small, the cookie will have a finer grain.

In rotary-molded cookies, air incorporation is important, but shortening also makes a structural contribution to cookie processing and quality. The solid phase of the shortening influences the consistency of the dough; if the fat is too soft (the SFI profile is too low) the dough will be soft, and not machine properly at the molder. Also, oil will tend to leak from the shaped pieces, and saturate the cloth takeaway belt, causing problems. If the SFI profile is too high, the dough will be stiff, it will not fill the mold properly, and it will not release cleanly from the die. In the former case the shortening is making an inadequate contribution to dough structure, while in the latter case lubrication by the shortening is lacking. It is necessary to maintain the proper balance between the solid and liquid phase in the shortening, to have good machinability.

For sheeted cookies, such as Marias biscuits, dough structure is primarily due to a modest amount of gluten development, and the grain of the final product depends upon proper extrusion and sheeting. The main contribution of shortening in these items is tender eating quality in the finished product. This is an attribute of the oil phase, and a liquid oil shortening should give good results, when used at about 75% of the amount of plastic fat in the formula. Cookies are a long shelf life item, and they must be acceptable to the consumer for up to six months or more. If oil is used in the dough, it should have good oxidative stability, so rancidity does not develop in the product during storage.

Wafer batter does not ordinarily contain fat or oil. However, on occasion a small amount of oil is included in the batter, to facilitate release of the baked wafer from the griddle. The amount used is just enough to effect release (perhaps 0.5% of total batter weight). An oil with high oxidative stability would give the best lubrication in this application.

Filling fat.

Fillings for sugar wafers or sandwich cookies consist of fat and sugar, with flavor and color added as desired. The consistency of the filling is determined to a large extent by the SFI profile of the fat used. This profile must meet three requirements:

1) The blend must have a soft consistency, so it can be extruded onto the basecake or wafer;
2) The extruded filling must be firm at room temperature and below, so that it does not slide when the cookie is eaten;
3) The fat must melt almost completely at mouth temperature, so it does not have a waxy mouthfeel.

To achieve these goals, the SFI profile of a filler fat is rather steep, higher than that for all-purpose shortening at low temperatures, and lower at high temperatures (Figure 10). The plastic range is much narrower, and better temperature control at the mixer and extruder is necessary than for the dough mixer, for example. Filler fats with a wide range of SFIs are available (see Appendix A for two suggested specifications), and individual plants may want to develop their own specification, to fit their equipment and processing conditions.

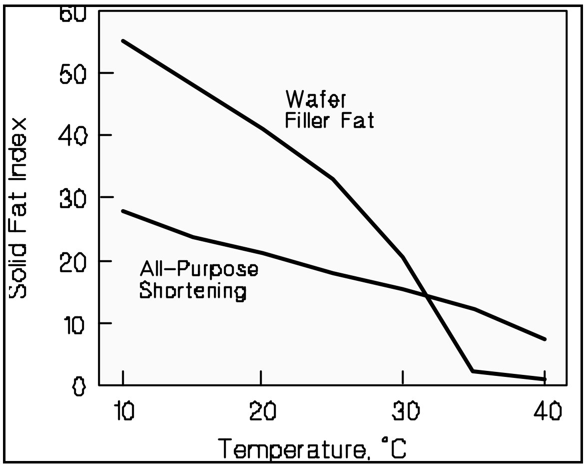


Figure 10. Solid Fat Index profiles for all-purpose shortening and filler fat for wafers.

Coating fat.

Cookies and other snack items are frequently coated with chocolate. The SFI profile of cocoa butter is unique among natural fats, being very high at room temperature and below, but melting rather sharply and completely at about 32-35°C. This characteristic is accepted as the norm for coating fats. A number of substitutes for cocoa butter have been sold. These are based upon shea butter, fractionated palm kernel oil, or soy and similar vegetable oils which have been hydrogenated in a special fashion. Such a fat is called a "hard butter".

Hard butters do not have such a sharp SFI profile as cocoa butter (Figure 11), and their melting point is generally slightly higher, around 38-42°C (the melting point is adjustable, by making slight changes in process parameters). When used to make a coating for a cookie or wafer, they are blended with cocoa powder, sugar, and milk solids. While the fat does not melt completely at mouth temperature, this is not a problem, because it is chewed along with the other, non-melting parts of the cookie, and the slight residual solid fat is not noticed. The confectionery coating has an advantage over chocolate; it does not melt as readily when held in the fingers, or in warm summer temperatures.

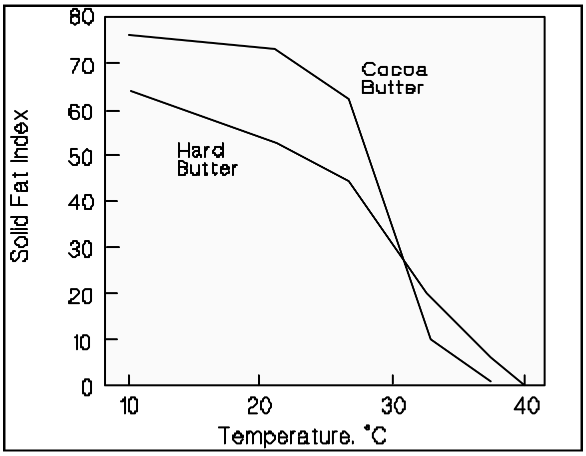


Figure 11. Solid Fat Index profiles for cocoa butter and a hard butter made from soy oil.

The crystallization behavior of cocoa butter is complex. Careful tempering of the chocolate is necessary, to obtain a covering which is smooth, glossy, and stable. If the cocoa butter in the covering undergoes crystal transformation, because of temperature fluctuations or a variety of other reasons, it takes on a dusty look, referred to as chocolate "bloom". Hard butters are generally less complex in their crystal habit, tempering is easier, and bloom formation less likely to be a problem. The two kinds of fat generally are not compatible, and a coating made with hard butter should not contain any more cocoa butter than the few percent that is present in the cocoa powder, used for flavor and color. Likewise, trying to extend chocolate by adding hard butter enhances the tendency for bloom formation.

3. Crackers.

Shortening is used in a cracker dough, primarily for its tenderizing effect in the finished product. As such, it may be either a plastic all-purpose shortening, or an oil. Presumably it helps the ovenspring of the cracker, by the same mechanism as in bread.

Snack crackers are sprayed with oil as they exit the oven. This oil soaks in as the crackers cool, and give them a more tender bite, as well as a moister impression as they are chewed. The amount of spray oil may be as much as 17% of the weight of the cracker itself, although 10-12% is more usual. Because the oil is on and near the surface of the cracker, and because the cracker should have a shelf life of up to six months, the spray oil must have good oxidative stability.

The choice of oil depends in part upon the desired appearance. If the baker wants a dry appearance, then an oil with appreciable solids at room temperature is used. If a shiny surface is preferred, an oil with a lower SFI profile is chosen. In terms of soy oils, the former oil might be a selectively hydrogenated one with an iodine value around 70 (see Appendix A), while the latter oil might have an iodine value around 92. In either case, oxidative stability should be good (AOM of 50 hours or more).

Spray oil might also be used with other items (for example, Marias cookies), in which a shiny surface and moister mouthfeel is desired.

4. Deep-fried Snacks, Donuts.

Fat is a good heat-transfer medium for cooking foods. The uncooked food contains water, and as this is expelled from the food, it is replaced by the frying fat. A cake donut, for instance, weighs the same before and after frying; the water loss is exactly counterbalanced by fat absorption. While the balance is not so exact with potato slices or corn chip masa, the general principle still holds. The absorbed fat imparts flavor, and tenderizes the finished snack.

Fat for frying is usually at a temperature of around 180-190°C, and a number of unwanted chemical reactions can occur. The water leaving the food causes some hydrolysis of the fat, and the free fatty acid (FFA) level increases. In commercial donut frying operations, the quality control department periodically checks the fat in the fryer for FFA, and if it is greater than 1%, the fat is discarded. Normally, fat turnover (absorption by donuts being fried, and addition of fresh shortening) keeps FFA around 0.5%. The significance of FFA level in frying fat is two-fold. For every increase of 0.1% in FFA the smoke point of the fat will decrease by approximately 5°C. Also, free fatty acids increase the amount of fat absorption by donuts or snacks, and the composition of the finished product may be greater than the established specifications.

Another group of undesirable reactions are connected with oxidation of the fat. The rate of oxidation doubles for every increase in temperature of 10°C. Oxidation forms hydroperoxides and epoxides at the unsaturated double bonds in the fatty acid chains. These can break down to the odoriferous compounds noted in rancid fat (see the next chapter), but these compounds are volatile at frying temperatures, and are not detected in the fresh finished product. The oxidized fatty acids also polymerize. The first sign of polymerization is a darkening of the frying fat. The polymers promote the formation of foam on the surface of the fat. If polymerization is far advanced, a dark varnish is noted on the walls of the fryer. Metal ions catalyze the autoxidation of fats; traces of copper or iron in any part of the equipment that is in contact with the fat speeds up fat breakdown. Never use any kind of braze or solder containing copper to repair such equipment, for example, baskets containing the food to be fried.

Because of the high temperature involved, a prime factor in choosing a fat or oil for deep fat frying is oxidative stability. A high stability oil, with an AOM of 200 hours, is excellent for snack frying. All-purpose shortening, with an AOM of 75 hours, works well in cake donut fryers, where fat turnover is quite rapid. Lightly hydrogenated soy oil (AOM of 25 hours) is used for light-duty frying, where the oil is heated, the food is cooked, and then the oil is cooled, rather than being held at the high frying temperatures.

IV. FACTORS IN SHORTENING FUNCTIONALITY

Certain properties of shortening are of particular importance to bakers. The solid fat index, plasticity, and oxidative stability of shortening are determined by the supplier's production process. The source of the starting oils, the conditions and extent of hydrogenation, the blending and crystallization of various basestocks, the storage conditions after packaging - these production variables determine the factors which influence shortening functionality. Some understanding of the nature of the three factors mentioned above clarifies their role in the bakery production process, and contributes to improved selection of shortenings for different bakery products.

A. SOLID FAT INDEX/CONTENT

The Solid Fat Index (SFI) relates to the percent of shortening which is solid at various temperatures (Figure 12). This curve can have a variety of shapes, being rather humped like cocoa butter, or almost straight over most of the range, with a steeper or shallower slope. The whole curve cannot be predicted from a determination made at just one temperature. Curves for different fats may cross; the whole SFI curve is required in order to understand the properties of the shortening at different temperatures.

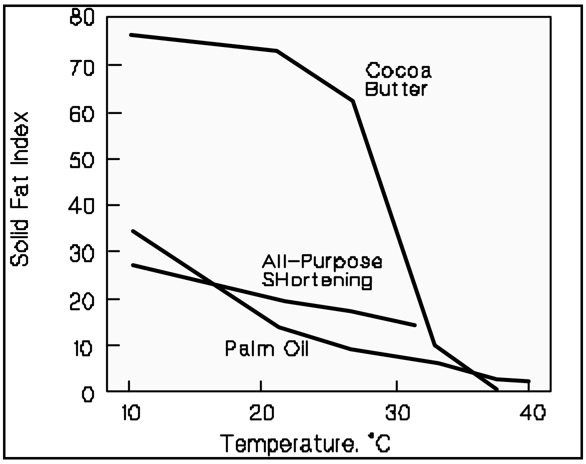


Figure 12. SFI curves for various fats.

Solid Fat Index is measured by placing a sample of the fat in a dilatometer and measuring the volume at various temperatures. When a solid fat melts it expands (Figure 13a). A solid triglyceride has a coefficient of expansion of about 0.00040 ml/g/°C, while a liquid triglyceride has a coefficient of expansion of about 0.00084 ml/g/°C. The slope of the line above and below the hypothetical melting point shown in Figure 13a is different.

A shortening is a mixture of triglycerides that melt over a range of temperatures, and the actual volume change is more like the solid line shown in Figure 13b. In this hypothetical example, the actual percent of solids in the fat at 20°C is S/T, or about 47%. While the specific volume line for oil is easy to determine, the corresponding line for fully solid fat is difficult to define. The standard SFI method (AOCS Method Cd 10-57) circumvents this difficulty by adopting a convention: the lower reference line is given the same slope as the line for the liquid, and is located 0.100 units below it. (This is the dotted line in Figure 13b.) For the example the SFI value is S/T′, or about 40%.

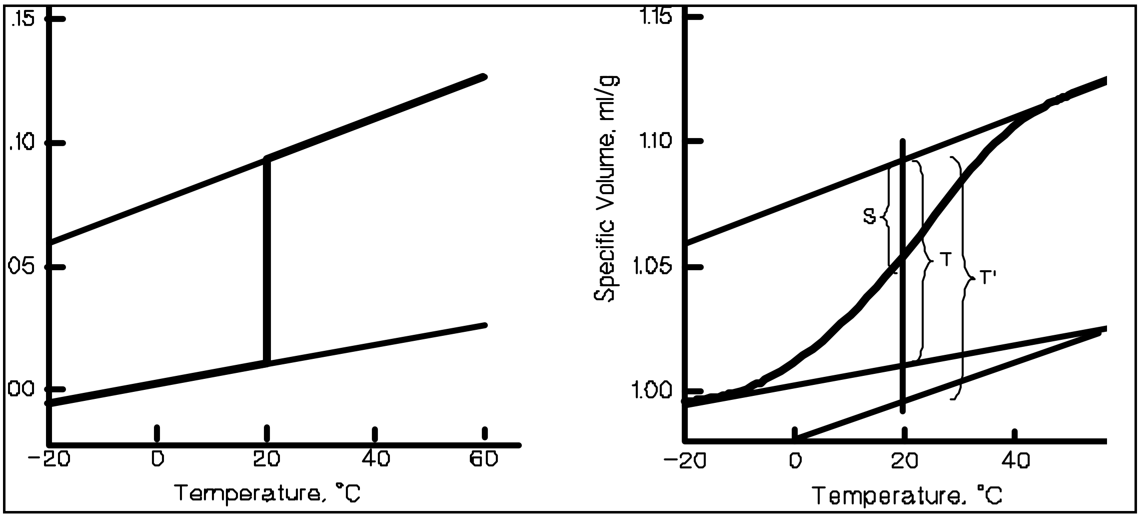


Figure 13. Specific volume of fat and its relationship to measuring SFI. a. Changes in specific volume when a pure triglyceride melts. b. Changes in specific volume when a shortening or margarine oil melts.

The dilatometric method is time-consuming and subject to the bias introduced by the convention described.

More recently pulsed Nuclear Magnetic Resonance (pNMR) has been used to measure the relative amounts of liquid and solid fat in a sample, based upon the difference in rates of relaxation of protons in the two phases after the sample has been pulsed (AOCS Method Cd 16-81). With proper calibration this gives a direct determination of the percentage of solid fat, and the results are termed Solid Fat Content (SFC). The analysis takes less time than dilatometry, but the equipment is more expensive.

The relationship between SFI and SFC is a complex function of both temperature and the level of SFI (Figures 14, 15). A comprehensive study of 46 shortenings across the temperature range of 10°-45°C provided data for deriving equations relating the two values.

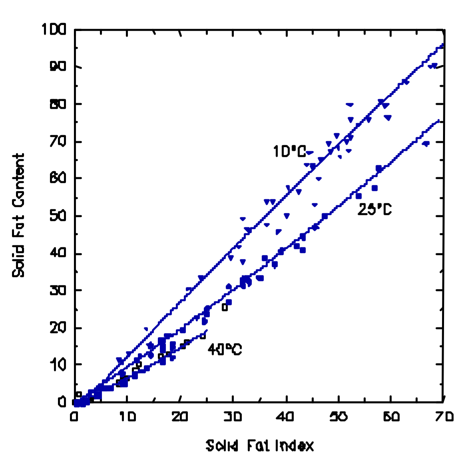


Figure 14. Relationship between SFI and SFC at three temperatures.

Analytical measurements of SFI and SFC are relatively precise; duplicate determinations should agree within ± 1 unit. The suggested values given in Appendix C for SFI and SFC have rather large tolerances specified, because it is difficult to control the steps in shortening production to closer tolerances than those given.

$$SFC = +\ 5.65 - 0.496 \times T + 0.0083 \times T^2 + SFI \times (1.406 - 1.586 \times T) + 0.00128 \times SFI^2$$

$$SFI = +\ 1.169 + 0.6293 \times SFC + 0.01415 \times SFC \times T - 0.000758 \times SFC^2$$

Figure 15. Equations relating Solid Fat Content (SFC), Solid Fat Index (SFI), and temperature in °C (T).

Functionality of a plastic fat in the bakery depends not only on solids content, but also on the slope of the SFI curve. Meeting an SFI specification implies that the values for a particular batch lie within the specified ranges, and also that deviations from the target values are all on the same side, either higher or lower. This is particularly important in producing basestocks for blending for margarine and shortening production.

B. PLASTICITY

The plasticity of a fat is defined operationally; the shortening is smooth, not grainy, deforming readily when squeezed but holding its shape when set on a flat surface. No precise method of measuring these characteristics objectively has been developed to date. Various sorts of penetration tests give approximate results which are useful, although they must be used with some caution. One such test is the cone penetrometer method (AOCS Method Cc 16-60). A metal cone is set on the top surface of the fat, and the depth of penetration after a fixed time period is determined. The extent of penetration is larger for a soft fat than for a hard fat. A second method which is of value on the shortening production line employs a thick needle. A tube is held vertically on the surface of the fat, and the needle is dropped from the top of the tube. The depth of penetration is read from markings on the needle. Some of the factors which must be considered in instrumental measurements of fat consistency have been reviewed.

The plastic range refers to the range of temperatures over which a shortening will have the properties listed above. Plasticity is a function of two factors: SFI and crystal structure. Assuming the shortening has the proper â′ crystal structure then it will be plastic over a range of about 10 to 25 SFI units (Figure 16). The choice of upper and lower limits of plasticity depend upon the experience of the individual choosing them, and the application; they are broader for bakery shortening than for margarine for use in the home.

Triglyceride fats crystallize in three different crystal forms. Rapid cooling of melted fat forms a waxy solid called the alpha (á) form (Figure 17a). This is a rather unstable crystal which quickly changes into long needle-like clusters of beta prime (â′) crystals (Figure 17b). This is the preferred crystal form for plastic shortenings. The long, thin crystals join together into a "brush heap" which immobilizes several times its own weight in liquid oil. The thin needles are readily broken when squeezed (and reform when deformation ceases) so the overall feeling is one of a very smooth, creamy solid.

If this crystal phase isn't stabilized by proper tempering at the time of manufacture, or if the shortening is stored at too warm a temperature, the solid phase reorganizes into the most stable structure, beta (â) crystals (Figure 17c). These are platelike, firm structures. Because there is less surface area per gram than in the case of â′, the â crystals immobilize less liquid. A fat which has converted to the â form feels grainy or sandy, and also oily. A shortening which has "gone beta" has lower plasticity than the same shortening stabilized in the â′ phase.

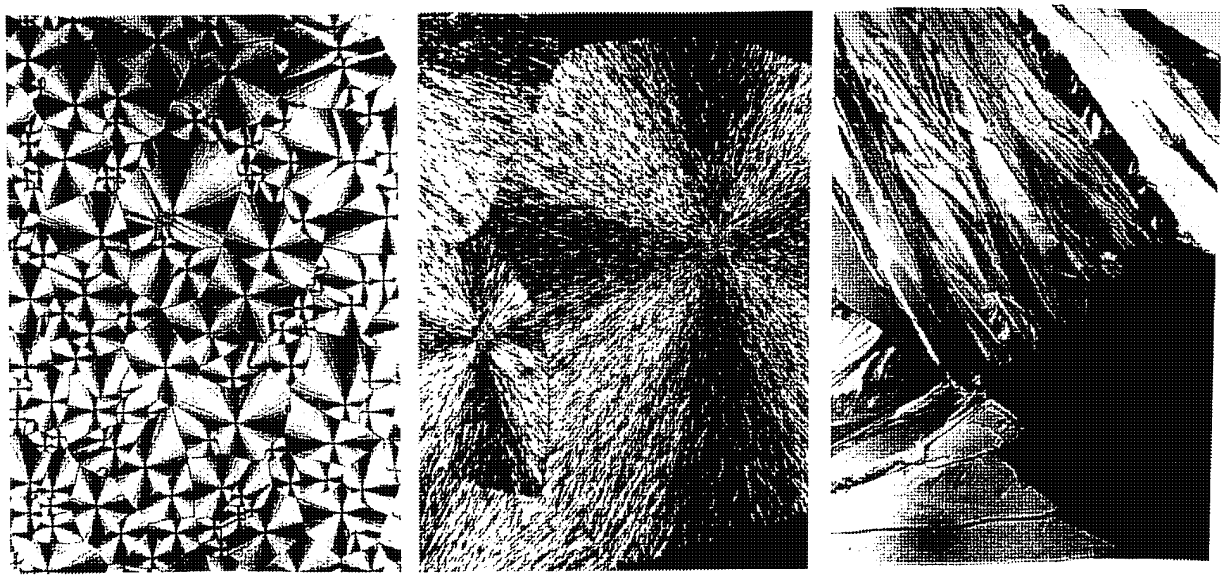


Figure 17. Microphotographs of fat crystals, taken in polarized light. From left to right: á crystals; â′ crystals; â crystals.

Shortening made from 100% hydrogenated soy or sunflower oil converts to β crystals rather readily, but the addition of 5% to 7% hydrogenated palm or cottonseed oil stabilizes the β′ phase. Most plastic shortening used in the United States today is made from partially hydrogenated soy oil plus a small amount of palm or cottonseed hard flakes (iodine value of 5). There are a few shortenings for which some β crystals are preferred, mainly in fluid shortenings.

The function of plasticity in various bakery products was discussed in a previous section. In ordinary cookie production the plastic shortening is combined with sugar and then mixed, or creamed, to incorporate air bubbles. These air bubbles are the nuclei for gas expansion during baking, that creates the internal structure giving desirable eating quality in the cookie. The air is physically trapped, and the brush heap structure of β′ shortening is better able to do this than the plates of β crystals. The air is actually in the liquid oil, so if SFI is too high there is not enough oil volume for adequate aeration. On the other hand, if SFI is too low the air is not trapped, and it escapes before dough mixing is complete. There is a range of SFI values giving optimum aeration of the creamed shortening, corresponding to the plastic range.

The machining of doughs, preparatory to baking, often causes some warming. If the SFI gets too low oiling out may be observed. The plasticity is suitable for the temperatures experienced in mixer operation, but because of warming during machining the shortening causes problems at the front of the oven. The plastic range of the shortening is too short to accomodate both the mixing and the forming operations. This is most often seen when a simple shortening (eg palm oil, as depicted in Figure 16) is used. Switching to a shortening with a broader plastic range will usually solve the problem.

Filling fat for wafers and sandwich cookies must meet a different set of requirements. If the fat is plastic at room temperature the wafers will tend to slide. The plastic range of filler fat is narrower, with less temperature tolerance at the mixer. When the wafer is cooled to room temperature the cream sets up to the firm consistency needed. In the production of filled wafers it is crucial that the crystal structure be β′. If the shortening has started to go beta, the resulting oiliness makes the wafer sheets slide during the transport and cutting operation. Also, β crystals set up slower than β′ crystals, causing delays between the extruder and the cutting operations.

C. OXIDATIVE STABILITY

An important consideration with respect to fats and oils is oxidative stability. The degree of importance depends, of course, upon the intended use of the oil, in particular, the temperature at which it is used, and the length of time of storage of the finished product. Two extremes are bread and a deep-fat fried snack. In bread the maximum temperature to which fat is exposed is 95°C (the final internal temperature during baking) and the storage time is at most 7 days; the least stable shortening, RBD oil, can be used for this application without danger of rancidity developing. The oil for deep-fat frying is heated to about 190°C, exposed to air while the frying operation proceeds, and the fried snack may have a shelf life of up to 1 year; a fat having high resistance to autoxidation is needed, so that rancidity does not make the snack prematurely unacceptable.

Autoxidation of fats occurs with unsaturated fatty acid chains. The relative rates of oxidation of oleic, linoleic, linolenic, and arachidonic acids (one, two, three, and four double bonds, respectively) are 1, 12, 25, and 50. The double bonds in the polyunsaturated acids are separated by methylene groups, and are *cis* in their configuration. The hydrogenation process moves some of the double bonds into the conjugated positions, and also converts some percentage into *trans* bonds, as discussed earlier. These structural alterations change the susceptibility of the side chains to oxidation.

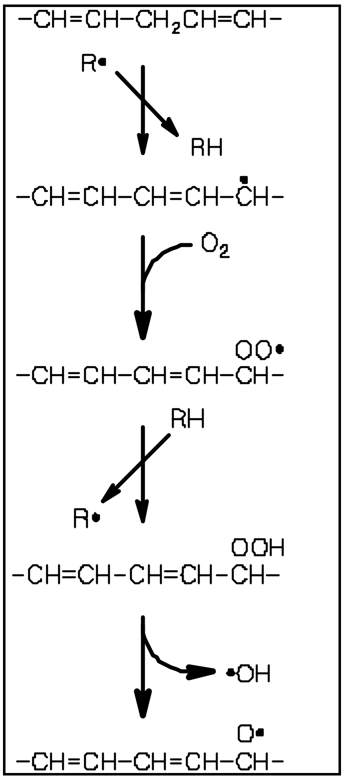


Figure 18. Reactions occurring during autoxidation of fat.

Autoxidation is a free radical reaction, initiated and propagated by free radicals reacting with methylene -CH_2 - groups which are adjacent to double bonds (Figure 18). A hydrogen radical is extracted, one of the double bonds migrates into a conjugated position (in the case of the natural methylene-interrupted system), moving the radical site to the outer carbon. Dissolved oxygen adds to this site generating a peroxyl radical; this abstracts a hydrogen from a donor - perhaps another methylene group - making a hydroperoxide. The hydroperoxide splits to generate two free radicals, a hydroxyl and an alkoxyl radical. This cleavage is catalyzed by traces of metal ion such as copper or iron. The net result is three free radicals, each of which can initiate another chain of reactions. The rate of reaction is self-enhancing, ie it is an *autocatalytic* reaction.

The signs of rancidity (musty odors; bitter, disagreeable flavors) are due to breakdown products of the alkoxyl radical structure. These are a variety of aldehydes and ketones derived from breaking the fatty acid carbon chain at the point where it is oxidized. Common ones are heptanal, ethyl hexyl ketone, and the ù-aldehyde of nonanoic acid.

The reactions detailed above can occur in the dark, as long as molecular oxygen and an initiating free radical species is present. If the oil is exposed to light, oxygen may be photoactivated to singlet oxygen, which can initiate the chain at the second step shown in Figure 18.

Four main factors contribute to autocatalytic rancidity:

1) Chain initiation by trace free radicals;
2) Chain propagation by molecular oxygen;
3) Hydroperoxide cleavage catalyzed by metal ions;
4) Chain initiation by photoactivated oxygen.

These factors can be minimized by good manufacturing practices. The trace free radicals arise from peroxides which are not removed during refining and deodorization. Oil should be processed, transported and stored under a nitrogen atmosphere. Metal ions can be kept out of the oil by having properly designed and maintained equipment, and traces of metal in the oil can be inactivated by chelation with citric acid. Finally, the exposure of oil to light should be minimal. With these precautions, oil oxidative stability can be increased several fold.

Antioxidants can also increase oxidative stability. These react with the active free radicals, giving a stable form, and transferring the radical function to the antioxidant (Figure 19). Because of the ring structure this radical has a low reactivity, and does not initiate new reaction chains. If free radicals continue to form, due to the presence of oxygen and trace metals, eventually all the antioxidant will react, and the autocatalytic sequence will develop without hindrance.

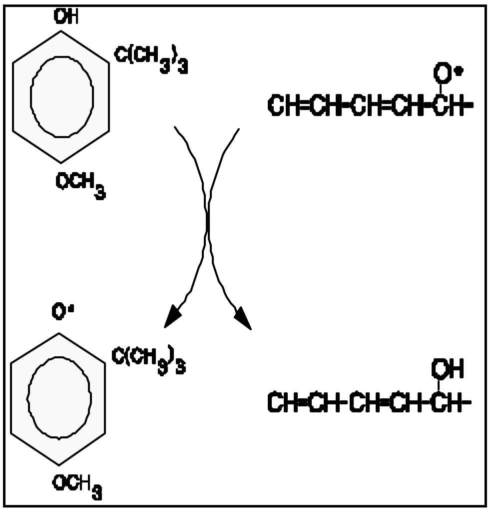


Figure 19. Termination of the chain of autoxidation reactions by antioxidants.

Fat oxidative stability is measured by the Active Oxygen Method (AOM, AOCS Method 12-57). Twenty milliliters of oil or fat is held at 97.8°C while air is bubbled through it at a rate of 2.33 ml/sec. The time required to develop a peroxide concentration of 100 meq/kg is the AOM stability of the sample. A closely related method, the Rancimat method, also bubbles air through hot oil. One of the breakdown products is formic acid, which is trapped in a water cell. The machine continuously monitors conductivity of the water, and records the time when it rises sharply. Rancimat results correlate well with AOM values; results obtained at 110°C are 40-45% of the AOM numbers.

Oxidative stability is important for obvious reasons. The food manufacturer does not want the shortening or oil to develop rancidity in storage before use, and wants to avoid rancidity in the finished product as long as possible. The best way to achieve this goal is to insist that the fat or oil upon delivery to the food plant has a low peroxide value, preferably below 1 meq/kg. The lower the initial PV, the longer the time before noticeable rancidity develops. A shortening that already has a PV greater than 1 meq/kg cannot be "fixed" by adding antioxidant. That expedient may delay oxidation slightly, but does not correct the underlying problem. If the amounts used are large enough, the food processor may consider blanketing his oil storage tanks with nitrogen to extend the storage stability of the oil before it is used in the manufacturing process.

V. SPECIFICATIONS AND QUALITY CONTROL

The purpose of specifications is COMMUNICATION. The purpose of Quality Control is FACILITATION of the use of specifications. Thus, the two topics can reasonably be considered together. In this chapter `Quality Control' is used in a rather narrow sense, and is only a part of the larger subject of Quality Assurance; space is too limited for a full consideration of quality assurance programs in a vegetable oil refinery, a margarine manufacturing plant, or a bakery.

A. SPECIFICATIONS

1. Communications of Needs and Capabilities.

In their simplest form, ingredient specifications are a way for a customer to tell the supplier his *need*, and for the supplier to inform the customer of his *capability* for meeting that need. The supplier's Finished Product Specification (his capability) should match the customer's Raw Material Specification (his need).

To arrive at this point may be simple, or it might require extensive experimentation. A simple case is that of a shortening manufacturer who *needs* a high-quality RBD soy oil for blending with other basestocks. He writes a specification in terms of maximum acceptable levels of free fatty acids, peroxide, phosphorus, and color. A potential oil supplier compares this with the specification for RBD oil produced in his plant, and demonstrates the *capability* of meeting this specification (through a history of analytical tests on routine production).

A more complex case is that of a manufacturer of sandwich cookies who *needs* a shortening for making the filling that goes into the cookies. He may not know what the best solid fat content profile is for his process, but (based on information from outside sources) he has a rough idea of what this curve should be. In consultation with suppliers of such shortenings, two possible shortenings are selected, and plant trial runs are made. Based on the results of these runs, one of the shortenings may be selected, or one with a slightly different SFC profile may seem more suitable. After a time of this kind of experimentation the baker will be able to establish the SFC profile specification which meets the requirements of his particular production needs; he can then show this specification to various suppliers, and those suppliers who possess the *capability* of manufacturing shortening to these specifications can bid for the business. The existence of, and mutual agreement to, the specification enhances the chances that filling shortening will not be a problem point for the cookie manufacturer as he operates his plant.

2. Characteristics of a Good Specification.

In both cases, the important point is that the need of the ingredient buyer can be expressed in objective, measurable, realistic criteria which can be communicated in writing. In the former case these criteria relate to chemical purity of the RBD oil, while in the latter instance they address the solidity and plasticity of the shortening at various temperatures. The communication has to be in objective terms so that if any question arises at a later date, both parties, the supplier and the purchaser, can discuss it in mutually understandable language.

Usually, the test for measuring the criterion should be included as part of the specification. Thus, a typical free fatty acid specification might be "0.05% maximum (as oleic acid)", and the test method is "AOCS Method Ca 5a-40". In the case of items such as stability several different methods are used, and designation of the test is imperative. Sometimes a test is not a standard one, and plant personnel use a method which has been developed in-house, for example, testing for bad odors. This method should be written down and shared with suppliers or customers. Certain important shortening properties (for example, plasticity) are difficult to measurable objectively, and in this instance good communication between vendor and purchaser is imperative to prevent misunderstandings and problems.

The specification must also be realistic, taking into account the production capabilities of the supplier, the actual needs of the purchaser, and the precision of the analytical tests. For example, a specification for Iodine Value of a lightly hydrogenated soy oil could be written as 112 ± 0.5, realizing that this is about the limit of analytical accuracy. It is difficult to control hydrogenation this closely, and imposes extra production costs on the supplier. The production people who will be using this ingredient should be consulted, to determine the actual functionality that they need. It is quite likely that they can operate equally well with an oil of IV 110 or 114. An iodine value specification of 112 ± 2 will serve the plant just as well, and decrease the cost of the raw ingredient. However, do not take this idea too far: a specification of 112 ± 10 will almost certainly be too broad, and raw materials at one end or the other of such a wide range would probably cause problems somewhere along the line.

3. Writing a Good Specification.

Developing a specification is a process of communication - the exchange of pertinent data between the supplier and the purchaser. The supplier must understand the ability of his plant to produce certain kinds of oils and shortenings. The purchaser must know accurately what properties are needed to make his production process operate smoothly. Referring back to the example of a filler fat for sandwich cookies, several rounds of information transfer may be needed, involving experimental runs by the production department of both the supplier and the purchaser, before the final specification can be written. This communication must be open, with vital information shared between the vendor and the customer. Confidentiality must be respected, but an attitude of trust is also important.

Finally, the written specification must be broadly available to everyone who has any responsibility for the material - the purchasing department, the technical group, and the production personnel. A specification which exists only as one copy, filed on a shelf in the main office, does not serve its purpose. A supplier's Finished Product Specification should be available to any potential purchaser, and likewise a customer's Ingredient Specification should be shared with any potential supplier. This sharing of information is *communication* - the main purpose for having the specification.

Appendix C lists typical specifications for a wide variety of industrial shortenings and margarines manufactured from soybean oil, representative of the products presently offered for sale in the United States. They are meant to be used as guidelines for beginning the process of establishing specifications, outlined above. The actual numbers, particularly the SFC/Temperature profile, may be adjusted to fit the production equipment and requirements of a specific operation.

B. QUALITY CONTROL

1. Responsibility for Quality Control.

The best form of quality control occurs when a mistake is recognized early, so that it can be corrected with little or no product loss. Mistakes are deviations from what is desired: a raw material is not correct, or a product being processed is not meeting standards. The best quality control methods are quick and involve little more than ordinary senses - sight, feel, taste, smell - but people must be trained to know what it is they should be seeing (feeling, etc.). Laboratory testing usually takes more time, but is necessary on occasion to detect more subtle but still important deviations.

The most important key to an effective quality control program is the recognition of who is responsible for it. The answer is "Everyone":

The personnel who receive and unload raw materials;
The shipping workers who send out finished product;
The purchasing agent who chooses the supplier;
The production supervisor who sends substandard product to rework;
The laboratory technician who responds quickly to questions;
The top managers who insist quality is more important than a short-term cost saving.

All of these people have a role to play in a good quality control program. Understanding and commitment by top management are crucial to making it work in a successful operation.

2. Quick Quality Control Tests.

There are several simple tests which can be applied to oils and fats that give a good idea about the quality of the product. These use the senses of sight or touch, or simple instrumentation.

Oil color.

RBD oil specifications include a Lovibond color, which is measured using a laboratory instrument. However, color can be quickly checked by keeping a bottle of oil (known to meet the specifications) on hand at the shipping or receiving dock. A sample of oil from the truckload being handled is put in a similar bottle and compared visually to the standard sample. If the sample oil is off-color the load should be held until this result is confirmed by a laboratory check, then a proper disposition should be made. Note that the standard sample should be kept tightly sealed and in a dark place (except when needed), and replaced periodically, to prevent a slow intensification of the color due to oxidation.

Degumming of oil.

When a properly degummed oil is shaken with water, the emulsion should break quickly and cleanly, leaving a clear oil layer. If all the gums (lecithins) are not removed, the emulsion takes longer to break and the oil layer remains hazy. The operator takes a sample of oil, shakes it with some water in a closed bottle, then lets it set for a short period of time (say, one minute) and holds it up to the light. After a little practice with oils which have various levels of gums, an experienced operator can tell whether the refining (degumming) process is running correctly. If there is any question, the sample should go to the laboratory, where the same principle may be used to accurately determine the amount of gum in the oil, using a turbidimeter, an instrument for measuring the degree of haziness.

Refractive index.

During hydrogenation oil samples should be taken periodically and the refractive index (RI) measured by the operator, using a simple hand-held refractometer. As unsaturation decreases, RI increases. If the hydrogenation process is carried out for a set period of time, then any unexpected changes in oil properties or catalyst efficiency will give a final product which is outside the finished product specification range. Measuring RI monitors the course of the reaction, and deviations from normal plant experience alert the operator to a potential problem. The cause for the deviation should be determined and corrected before it causes an actual problem.

Shortening plasticity.

Partially hydrogenated plastic shortening for bakery use must be stabilized in the â′ crystalline phase. If, through improper manufacture or storage, it has started to convert to â phase crystals, the shortening will not function correctly in the intended bakery application. This situation is easily detected by sight and touch. The agent at the bakery receiving dock should open a cube of shortening, look at it, and squeeze some through his fingers. Shortening which has "gone beta" will usually have a thin film of free oil on the surface (sight) and it will feel grainy (touch). If either of these conditions exist the load should be returned to the supplier, rather than accepting it and dealing with the problems it will cause in production.

3. Laboratory Quality Control Tests.

There are numerous laboratory tests for various properties of oil and fat. These can be found in publications such as the "Official Methods and Recommended Practices of the American Oil Chemists Society", and should be familiar to any laboratory technician who is connected with the fats and oils industry. Some tests can be run rather easily, and give a relatively quick indication of the quality of the oil or fat being examined.

Free fatty acid.

The determination of free fatty acid (FFA) content is quick, but requires an analytical balance, burettes, and similar equipment which is not suited for the plant floor or receiving dock. Every load of oil or fat being received should be checked for FFA, because a high level indicates that the oil has not been stored properly. Monitoring FFA during deodorization is one way to check on the operation of the equipment. As with the measurement of RI during hydrogenation, an expected curve for the decrease in FFA during a good, routine run is established. Any deviation from this curve alerts the plant personnel to alterations in deodorizer operation which should be corrected immediately.

Peroxide value.

As with FFA measurement, the determination of peroxide value (PV) requires an analytical balance and burettes. This analysis is rather more exacting than simple FFA titration, and operator experience contributes greatly to accuracy. Oxidation, leading to the formation of peroxides, is the main reason for short shelf life of food fats and oils, and since oxidation is an autocatalytic process, the lowest possible PV should be sought in an oil being shipped to, or accepted by, a food processor. A PV value at or above the specification maximum indicates that the supplier has not taken as much care in storing and handling the oil as he should, and should be discussed with the vendor by the purchaser.

Odors in oil.

This test usually requires that the oil be heated on a boiling water bath for a few minutes, to release any off-odors it might have. For safety reasons, it is obvious that this should only be done in a laboratory environment. Laboratory personnel need prior training to know how to run this test safely and reliably.

Other key tests.

There are several other key properties of fats and oils - Solid Fat Content, Iodine Value, Oxidative Stability, Cold Test, Fatty Acid Composition - which take from 1 to as long as 25 hours to run, requiring hazardous laboratory chemicals or expensive equipment. A supplier of shortening and margarine should have the laboratory capability to make these tests. A purchaser will probably not want to invest the money and time to run these tests on every shipment received, relying on the simpler tests outlined above to indicate that a raw material is probably within specifications. However, it is a good idea to take samples from time to time and send them to an independent testing laboratory, just to make sure that specifications are being met. If there is ever a question about a particular shipment of oil or shortening this sort of laboratory analysis is important for both parties, the supplier and the purchaser.

4. Feedback and Action.

The whole reason for having quality control testing based on specifications is to detect mistakes (deviations from specifications) before they turn into problems. So, when a mistake is found, what should be done with it?

Report it!

Production supervisors and plant managers do not like to hear that there is a problem; life is easier when everything runs smoothly. Management must make it clear to the employees that reporting out-of-specification ingredients or products is part of the job. It takes a while to build an attitude of trust which allows a young, relatively inexperienced employee to go to the supervisor and say "I think there is something wrong here." But management must support this level of trust if it wants to get quality-conscious performance from its personnel. Every out-of-specification occurrence must be reported.

Find the cause!

Usually the cause of a problem is apparent and can be fixed quickly. Sometimes it takes more work to track it down. The dangerous problems are those which seem to go away by themselves. If the cause of the problem is not located, it will surely occur again, and perhaps at a time when it is even more costly. In the record of problems reported and corrective actions take, it should be unacceptable to close an out-of-specification incident with the notation "problem disappeared - reason unknown".

Correct the problem!

It is amazing how often, in production facilities, problems are not corrected, but the symptoms are simply covered up. Again, management must be adamant in its policy that problems are to be corrected. While it may be necessary to compensate for symptoms for the time being (say, until the end of the shift) in order to meet productions delivery schedules, this should never be accepted for longer than absolutely necessary.

5. Quality Control Starts with Top Management.

For a program of specification-writing and product/ingredient quality control to be effective, company management must make its position clear. It must be fully committed to spend the time, effort, and money to achieve a high quality finished product, and recognize that the use of specifications and quality control methods is one tool in achieving that goal. Another tool is acceptance by everyone in the plant - from the plant supervisor down to the newest hourly employee - of appropriate responsibility for the quality of the finished product. That acceptance is only possible when every employee is convinced that top management really means it when it declares that quality control is important.

Appendices

Appendix A

COMPOSITION OF FATS AND OILS

	IV	C8:0	C10:0	C12:0	C14:0	C16:0	C17:0	C18:0	C20:0	C22:0	C16:1	C18:1	C20:1	C18:2	C18:3
LAURIC FATS															
Babassu	13-18	6.0	5.1	42.4	16.8	9.3	--	3.5	0.1	--	--	14.2	--	2.4	--
Coconut	7-12	7.1	6.0	47.1	18.5	9.1	--	2.8	0.1	--	--	6.8	--	1.9	0.1
Palm kernel	14-19	3.3	3.4	48.2	16.2	8.4	--	2.5	0.1	--	--	15.3	0.1	2.3	--
VEGETABLE OILS															
Cocoa butter	33-40	--	--	--	0.1	26.3	0.3	33.8	1.3	0.2	0.4	34.4	0.1	3.1	--
Corn	118-128	--	--	--	0.1	10.9	0.1	2.0	0.4	0.1	0.2	25.4	--	59.6	1.2
Cottonseed	98-118	--	--	0.1	0.7	21.6	0.1	2.6	0.3	0.2	0.6	18.6	--	54.4	0.7
Olive	76-88	--	--	--	--	9.0	--	2.7	0.4	--	0.6	80.3	--	6.3	0.7
Palm	50-55	--	--	0.3	1.1	42.9	0.1	4.6	0.3	0.1	0.2	39.3	--	10.7	0.4
Peanut	84-100	--	--	--	0.1	11.1	0.1	2.4	1.3	2.9	0.2	46.7	1.6	32.0	--
Rapeseed	100-115	--	--	--	0.1	3.8	0.1	1.2	0.7	0.5	0.3	18.5	6.6	14.5	11.0
Canola (LEAR)	100-115	--	--	--	0.1	4.1	0.1	1.8	0.7	0.3	0.3	60.9	1.0	21.0	8.8
Safflower	140-150	--	--	--	0.1	6.8	--	2.3	0.3	0.2	0.1	12.0	0.1	77.7	0.4
(High oleic)	82-92	--	--	--	0.1	3.6	--	5.2	0.4	1.2	0.1	81.5	0.2	7.3	0.1
Soybean	123-139	--	--	--	0.1	10.6	0.1	4.0	0.3	0.3	0.1	23.2	--	53.7	7.6
Sunflower	125-140	--	--	--	0.1	7.0	0.1	4.5	0.4	0.7	0.1	18.7	0.1	67.5	0.8
(High oleic)	81-91	--	--	--	--	3.7	--	5.4	0.4	0.1	0.1	81.3	--	9.0	--
ANIMAL FATS															
Butter oil	25-42	1.2	2.5	2.9	10.8	26.9	0.7	12.1	--	--	2.0	28.5	0.1	3.2	0.4
Chicken fat	74-80	--	--	0.1	0.8	25.3	0.1	6.5	0.2	--	7.2	37.7	0.3	20.6	0.8
Lard	48-65	--	0.1	0.1	1.5	26.0	0.4	13.5	0.2	--	3.3	43.9	0.7	9.5	0.4
Tallow (beef)	40-55	--	--	0.1	3.2	24.3	1.5	18.6	0.2	--	3.7	42.6	0.3	2.6	0.7
FISH OIL															
Menhaden	159-165	--	--	0.1	10.8	23.2	--	4.2	0.4	0.1	11.4	10.6	1.3	1.8	1.7
(PHO)	78-85	--	--	0.1	10.5	24.1	--	5.2	0.7	0.3	15.0	12.5	4.9	2.4	0.2

Certain fats and oils have significant amounts of fatty acids other than those listed above.

Butter oil: C4:0 3.6%; C6:0 2.2%; C15:0 2.1%; C14:1 0.8%.
Tallow (beef): C17:1 0.8%.
Peanut oil: C24:0 1.5%.
Rapeseed oil: C24:0 1.0%; C22:1 41.1%; C20:2 0.7%.
Canola (Low Erucic Acid Rape): C24:0 0.2%; C22:1 0.7%; C20:2 0.0%.
Menhaden oil: C16:2-4 4.7%; C18:4 2.1%; C20:2-4 3.2%; C20:5 11.9%; C22:1 0.2%; C22:4-6 9.0%.
Menhaden (Partly Hydrogenated Oil): C16:2 0.9%; C20:2-4 10.5%; C22:1 1.7%; C22:2-4 7.9%.

Appendix B

NOMENCLATURE AND SOURCES OF FATTY ACIDS

SYSTEMATIC NAME	COMMON NAME	CARBON LENGTH	SOURCE
Butanoic	Butyric	C4:0	Btr
Hexanoic	Caproic	C6:0	Btr
Octanoic	Caprylic	C8:0	Bsu, Cnt, Pk, Btr
Decanoic	Capric	C10:0	Bsu, Cnt, Pk, Btr
9-Decenoic	Caproleic	C10:1	Btr
Dodecanoic	Lauric	C12:0	Bsu, Cnt, Pk, Btr, Ld
5-Dodecenoic	---	C12:1	Sperm whale
9-Dodecenoic	Lauroleic	C12:1	Btr
Tetradecanoic	Myristic	C14:0	Bsu, Cnt, C/S, Plm, S/B, Btr, Ld, Tw
5-Tetradecenoic	Physteric	C14:1	Sperm whale
9-Tetradecenoic	Myristoleic	C14:1	Btr, Ld, mTw
Pentadecanoic	---	C15:0	Ld, mTw
Hexadecanoic	Palmitic	C16:0	Bsu, Cnt, Coc, Crn, C/S, Olv, Plm, Pnt, Saf, Sun, S/B, Btr, Ld, Tw
9-Hexadecenoic	Palmitoleic	C16:1	Cnt, C/S, Olv, Btr, Ld, Tw
Heptadecanoic	Margaric	C17:0	Ld, Tw, mTw
Octadecanoic	Stearic	C18:0	Bsu, Cnt, Coc, Crn, C/S, Olv, Plm, Pnt, Saf, Sun, S/B, Ld, Tw, Btr
9-Octadecanoic	Oleic	C18:1	All above
9,12-Octadecadienoic	Linoleic	C18:2	All above
9,12,15-Octadecatrienoic	Linolenic	C18:3	S/B, Crn, HEAR, LEAR, Btr, Ld, mTw
Eicosanoic	Arachidic	C20:0	Olv, Plm, Pnt, Saf, S/B, Ld, Tw
9-Eicosenoic	Gadoleic	C20:1	Marine Oils
5,8,11,14-Eicosatetraenoic	Arachidonic	C20:4	Marine Oils
Eicosapentaenoic	---	C20:5	Herring, Menhaden, Salmon
Docosanoic	Behenic	C22:0	Pnt, HEAR, LEAR
13-Docosenoic	Erucic	C22:1	HEAR
4,8,12,15,19-Docosapentenoic	Clupanodonic	C22:5	Marine Oils
4,7,10,13,16,19-Docosahexenoic	Nisinic	C22:6	HEAR, Menhaden, Salmon

Bsu=Babassu, Cnt=Coconut, Coc=Cocoa butter, Crn=Corn, C/S=Cottonseed, HEAR=Rapeseed, LEAR = Canola, Olv=Olive, Plm=Palm, Pk=Palm kernel, Pnt=Peanut, Saf=Safflower, S/B=Soybean, Sun=Sunflower, Btr=Butter, Ld=Lard, Tw=Tallow (beef), mTw=Mutton tallow

Appendix C

SUGGESTED SPECIFICATIONS FOR INDUSTRIAL SHORTENINGS AND MARGARINES BASED UPON SOYBEAN OIL

The specifications given below are representative of shortenings and margarines presently sold in the United States for industrial uses, particularly in bakery-related production. They reflect average properties of products sold by several different suppliers. These specifications are intended as suggested starting points for experimentation by users, aimed at developing specifications for similar products which will give optimum performance with the equipment and conditions prevailing in their plants.

Certain characteristics are common to the specifications of all these products. In order to save space, these characteristics are listed here. These should be included in each individual ingredient specification written by a baker.

Chemical Characteristics:

Peroxide Value:	1 meq/kg maximum
Free Fatty Acid (as oleic acid):	0.05% maximum
Phosphorous Content:	1 ppm maximum

Physical Characteristics:

Color (Lovibond):	1.5 R, 15 Y maximum
Flavor:	Bland
Odor:	Neutral when warmed

The product applications for each of these shortenings and margarines have been discussed earlier.

Shortening or Oil Type: **RBD (Refined, Bleached, Deodorized) Oil**

Chemical Characteristics:

Iodine Value:	131 ± 4
AOM Stability:	10 hours
Rancimat Stability:	4 hours

Shortening or Oil Type: **Lightly Hydrogenated Soy Oil**

Chemical Characteristics:

Iodine Value:	112 ± 2
AOM Stability:	25 hours
Rancimat Stability:	10 hours
Smoke Point:	225°C

Solid Fat Profiles:

°C	SFC	SFI	°F	SFI
10	< 5	< 5	50	< 5
15	< 2	< 3	70	< 1.5
20	< 1	< 2	80	0
25	0	0		

Shortening or Oil Type: **High Stability Soy Oil**

Chemical Characteristics:

Iodine Value:	70 ± 2
AOM Stability:	200 hours
Rancimat Stability:	80 hours
Smoke Point:	235°C

Solid Fat Profiles:

°C	SFC	SFI	°F	SFI
10	65±4	47±3	50	47±3
15	51±4	41±3	70	32±3
20	37±3	34±3	80	25±2
25	24±3	25±2	92	12±1
30	16±2	19±2	104	< 2
35	7±1	10±1		
40	< 1	< 2		

Shortening or Oil Type: **All-Purpose Shortening**

Chemical Characteristics:

Iodine Value:	78 ± 3
AOM Stability:	75 hours
Rancimat Stability:	30 hours

Solid Fat Profiles:

°C	SFC	SFI	°F	SFI
10	38±3	28±3	50	28±3
15	29±3	24±2	70	20±2
20	22±3	21±2	80	17±1
25	17±2	18±1	92	13±1
30	12±2	15±1	104	7±1
35	8±1	12±1		
40	4±1	7±1		

Shortening or Oil Type: **Icing Shortening**

Chemical Characteristics:

Iodine Value:	78 ± 3
AOM Stability:	75 hours
Rancimat Stability:	30 hours
á Monoglycerides:	2 - 3%

Solid Fat Profiles:

°C	SFC	SFI	°F	SFI
10	44±4	32±3	50	32±3
15	35±3	29±3	70	25±2
20	28±3	26±3	80	22±1
25	22±2	23±2	92	16±1
30	17±2	20±2	104	11±1
35	11±1	15±1		
40	7±1	11±1		

Shortening or Oil Type: **Wafer Filler Fat**

Chemical Characteristics:

Iodine Value:	72 ± 3
AOM Stability:	100 hours
Rancimat Stability:	40 hours

Solid Fat Profiles:

°C	SFC	SFI	°F	SFI
10	76±6	55±4	50	55±4
15	60±5	48±4	70	39±3
20	45±5	41±4	80	29±3
25	32±4	33±3	92	4±1
30	17±2	20±2	104	< 1
35	1±1	2±1		
40	< 1	< 1		

Shortening or Oil Type: **Sandwich Cookie Filling Fat**

Chemical Characteristics:

Iodine Value:	75 ± 3
AOM Stability:	100 hours
Rancimat Stability:	40 hours

Solid Fat Profiles:

°C	SFC	SFI	°F	SFI
10	53±4	38±3	50	38±3
15	39±3	32±3	70	24±2
20	28±3	26±2	80	18±1
25	21±2	22±2	92	9±1
30	11±1	14±1	104	< 2
35	5±1	7±1		
40	< 1	< 2		

COCOA BUTTER REPLACEMENT

Shortening or Oil Type: **Hard Butter, Coating Fat**

Chemical Characteristics:

Iodine Value:	70 ± 2
AOM Stability:	200 hours
Rancimat Stability:	80 hours

Solid Fat Profiles:

°C	SFC	SFI	°F	SFI
10	88±5	64±5	50	64±5
15	75±5	60±5	70	52±4
20	61±5	54±4	80	44±4
25	47±4	46±4	92	20±2
30	32±4	35±3	100	6±1
35	10±1	14±1	104	0
40	0	0		

Margarine type: **Puff Paste margarine**

Chemical Characteristics:

Iodine Value:	70 ± 2
AOM Stability:	200 hours
Rancimat Stability:	80 hours
Moisture content:	18%
Salt content:	2.0%

Solid Fat Profiles:

°C	SFC	SFI	°F	SFI
10	47±4	34±3	50	34±3
15	40±4	32±3	70	30±3
20	33±3	30±3	80	27±2
25	27±2	28±2	92	22±2
30	21±2	25±2	100	-
35	16±1	21±2	104	16±1
40	11±1	16±1		
45	7±1	11±1		

Margarine type: **General Purpose margarine**

Chemical Characteristics:

Iodine Value:	70 ± 2
AOM Stability:	200 hours
Rancimat Stability:	80 hours
Moisture content:	17%
Salt content:	3.0%

Solid Fat Profiles:

°C	SFC	SFI	°F	SFI
10	38±3	28±3	50	28±2
15	30±3	25±2	70	21±2
20	23±2	22±2	80	18±1
25	17±1	19±1	92	15±1
30	13±1	16±1	100	-
35	10±1	13±1	104	10±1
40	7±1	10±1		
45	4±1	7±1		

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