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HYDROGENATION OF DIETARY OILS

Introduction

Over the past few years, hydrogenated and partially hydrogenated oils (trans-fats), have been vilified by the media as one of the leading causes of coronary heart disease and a major risk factor for diabetes. The American Heart Association (AHA), recommends that the daily intake of trans-fats should be less than 1% of a total daily caloric intake.[1] Although the media have called trans-fats the most recognizable villain in the food industry, many people may not know much about trans-fats and ask, "What are hydrogenated, partially hydrogenated oils, and trans-fats, and how are they different from regular cooking oils? Also, why do the cooking-oil industries continue to make and restaurants continue to offer them if they are so harmful?"

Although many industries have reduced the amount of trans-fats, complete absence of trans-fats in the hydrogenation process is not wanted because trans-fats provide desirable characteristics to consumers; removing trans-fats in hydrogenated oils could significantly reduce sales. However, companies such as J.M. Smucker have developed hydrogenated oils containing low amounts of trans-fats, with properties similar to those of trans-fat-containing hydrogenated oils.

Since the early 20th century, the process of creating hydrogenated dietary oils has continuously improved. Use of nickel catalysts and research toward use of other catalysts, and low-temperature processes have helped to reduce trans-fat content. Chemical engineers have significantly contributed to that effort.

Chemical Structure

Food oils typically contain 18 carbons with an acid group and an omega end* as shown in Figure 1.[2] Saturated oils contain no double bonds, monounsaturated oils contain one double bond, and polyunsaturated oil contains two or more double bonds.

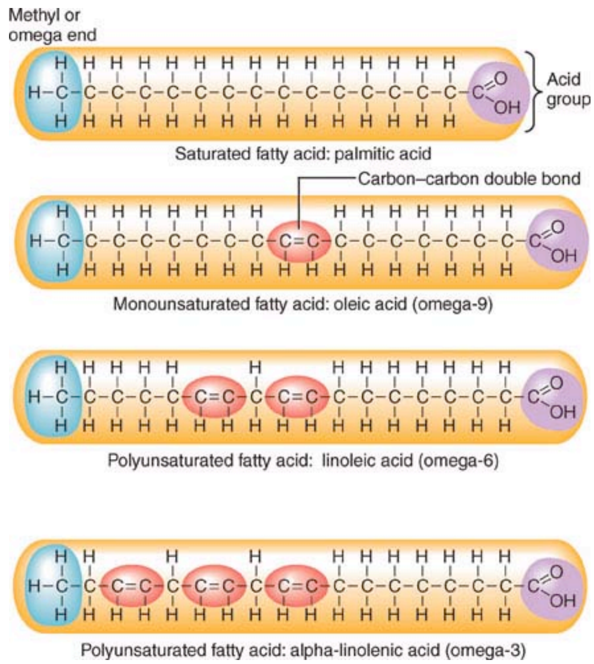

Figure 1: Saturated and unsaturated fatty acid structure [2]

Fully hydrogenated oils have all double bonds converted to single bonds. These oils have the same structure as that of saturated fats and are therefore similar to saturated fats. They have similar health risks for diseases as natural saturated fats found in tropical oils and in meat.[2]

Partially hydrogenated oils have some double bonds hydrogenated and some left un-hydrogenated. Trans-fats are created when the hydrogenation of oil causes at least one of the unsaturated carbon double bonds to refigure from the natural *cis* configuration to a

* Omega end refers to the end of the fatty acid opposite to that of the acid group.

trans configuration as shown in Figure 2.[2] Hence, the terms partially hydrogenated oils and trans-fats are used interchangeably. Conversion of the cis configuration to a trans configuration allows better packing of the fatty acid chains in the solid phase, and increases the melting point. This is a highly desirable characteristic for consumers and food industries because the fat can then be spread, for example, on bread.

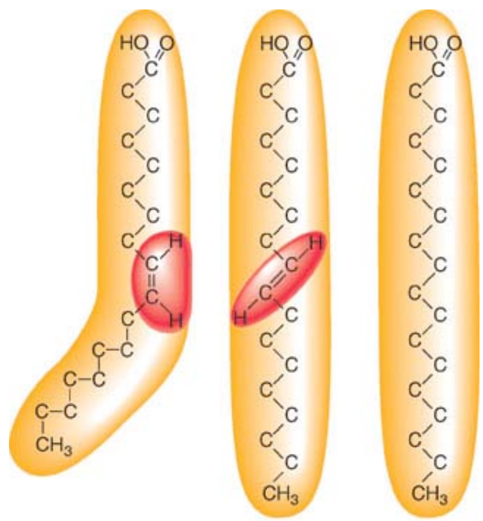

Figure 2: Cis, trans, and saturated fatty acid structure [2]

Early Discovery

Before mass production of hydrogenated oils, primary dietary fats came from beef tallow, tropical oils, lard and butterfat, all high in saturated fats. It was not until the early 20th century when Paul Sabatier, a French chemist, developed a hydrogenation process using a nickel catalyst, making it possible to produce partially hydrogenated fat.[3] Prior to his findings, researchers had developed a direct hydrogenation process using a platinum sponge or platinum black for producing ammonia and methylamine, although this process was not successful because the platinum catalyst had low reactivity.[4]

Sabatier discovered that powdered nickel provides a catalyst that gives high reactivity and long life.[4] By using the nickel catalyst in a batch tank at high temperature (about 200-250 °C) and pressure (about 3 bars), Sabatier was able to hydrogenate many organic compounds.[4] Sabatier's discovery won him the Nobel Prize in 1912. Along with Wilhelm Normann's research, Sabatier's work initiated mass production of hydrogenated oils and trans-fatty acids; chemical engineers scaled up the laboratory experiments to large-scale processes.

Wilhelm Normann was the first to find that liquid oils could be partially hydrogenated to form trans-fatty acids. He patented the process to create *trans-fats*.[3] Procter & Gamble, a company in the United States, licensed the patent and created Crisco, a hydrogenated oil that contains trans-fats.[3] During World War II, trans-fats gained widespread popularity. Trans-fats have low production costs, high shelf life, high melting points, beneficial baking properties (good oil retention in the dough, less oil departure in the mouth) and other desirable organoleptic properties (taste, texture).[3][5]

Prior to research concerning the health effects of trans fats, many people believed that trans-fats were a healthy replacement to saturated fats: margarine was regarded healthier than butter.[6] Studies in the 1960s compared the effects of partially hydrogenated fats with those of unhydrogenated vegetable oils and those of saturated fats on the concentration of total serum cholesterol in blood.[7] These studies suggested that the cholesterol-raising effect of hydrogenated fat was lower than that of saturated fats.[7] It was not until the 1990s when trans-fat research showed that consumption of trans-fats, similar to consumption of saturated fats, correlated with an increase in low-density lipoprotein (LDL) cholesterol that raises the risk for heart disease and obesity.[3] Medical research showed that trans-fats increase triglyceride levels in the blood, increasing the risk of cardiovascular disease.[6] In 2003, the Food and Drug Adminitration (FDA) issued a regulation requiring manufacturers to list trans-fat content on the nutrition label as partially hydrogenated oils.[8]

Food companies today have difficulty in trying to reduce the amount of trans-fats in food products without reducing quality and sales; therefore, they do not completely eliminate trans-fats. By FDA regulations, food companies are able to label their products as "0 grams trans-fats" only as long as there is less than one gram of trans-fat per serving in the product.[3] This labeling regulation has caused controversy among health advocates.[3]

Health Concern

In the United States, cardiovascular disease remains the leading cause of death. Research on trans-fats has shown that the cardiovascular risk associated with trans-fats is due to their effect on lipoproteins such as low-density lipoprotein and high-density lipoprotein cholesterol, as well as on inflammatory mechanisms and on interference with fat metabolism.[9] The Nurses' Health Study showed, after adjustment for age and total energy intake, that for those in the group consuming the highest amount of trans-fats, the relative risk of coronary heart disease was 1.5 times greater than for those in the group consuming the least amount. [9] The Boston Health Study obtained similar results. It stated that a 2% absolute increase in energy intake from trans-fat (equivalent to 4 grams in a standard 2,000-kcal diet) was associated with a 23% increase in cardiovascular risk.[9] It also estimated that reducing commercial trans-fat intake from 2.1% energy intake to 1.1% or (0.1% of energy) could have a dramatic impact, potentially preventing 72,000 or 228,000 cardiovascular deaths per year in the United States, respectively.[9]

Dietary Oil Hydrogenation Process

In the food industries, the most common oil used in the hydrogenation process is vegetable oil. The primary aim in an industrial process for the hydrogenation of vegetable oil is to remove linoleic acid (three C=C double bonds) as completely as possible, while minimizing conversion of the desired oleic acid (one C=C double bond) to the saturated stearic acid.[10] The desired oleic acid takes on the form of a cis or trans configuration.

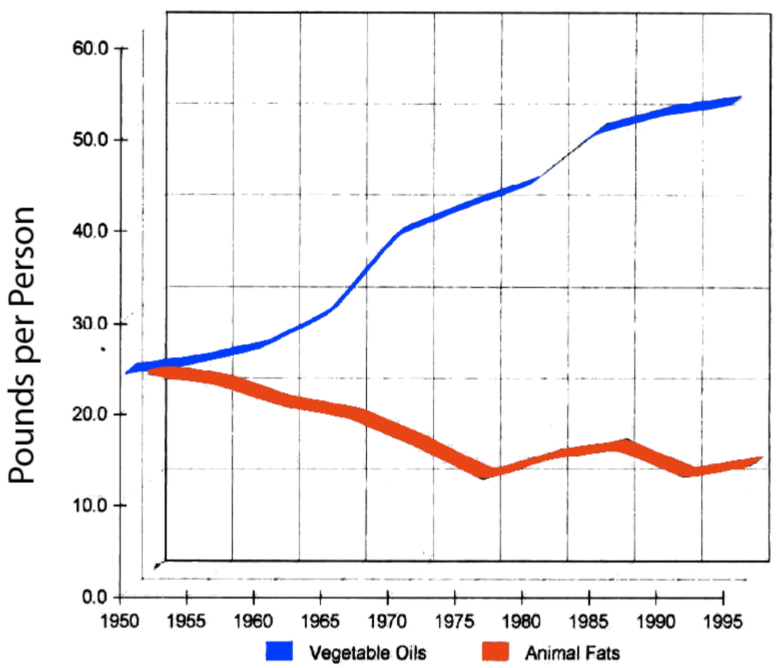

Figure 3: Use of dietary fats and oils per capita in the United States[16-11]

In the 1950's the food-fat market in the United States was split approximately equally between animal fats (lard, tallow and butter) and edible vegetable oils as shown in Figure 3.[11] By 1970, this distribution shifted to three-fourths edible vegetable oils and one-fourth animal fats, as hydrogenated vegetable oils became more popular.[11] In 1995, the food-fat market in the United States reached approximately 82% edible vegetable oils and 18% animal fats, with the total annual production of hydrogenated oils reaching about 25 million tons.

Today, a batch tank is still used in the industry. "Dead-end" batch reactors contain "dead" space for hydrogen accumulation. A typical hydrogenation plant hydrogenates oil in a 15-ton dead-end batch reactor, producing up to 90 tons solidified fat per day.[10] It is performed at 3 bar hydrogen pressure, and 200-210° C with nickel-based, Ni/SiO_2 liquid-phase catalyst.[10] The reaction is terminated by stopping hydrogen flow and reducing the temperature to 100° C.[10]

Current Research

Industries are continuously finding new ways to improve their profits and lower trans-fat content in their hydrogenated oils through research. For example, patent US7585990 B2, licensed by Cargill Incorporated, describes a low-temperature hydrogenation process that can reduce energy costs and yield no more than 6% trans-fat.[12] Many industries are also increasingly using a palladium.[10] Research has shown that a palladium catalyst, although more expensive than a nickel catalyst, yields a lower *trans*-isomer content in the final hydrogenated fat.[10]

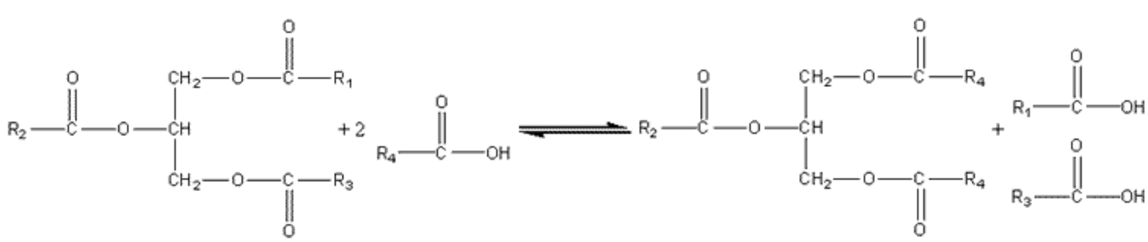

Figure 4: Interesterification of a fatty acid[17]

Additionally, companies such as J.M. Smucker Co., have implemented a process to lower the trans-fats content in their product, Crisco*, to meet the “0 grams trans fat” label requirement.[13] Their process involves replacing trans-fats with interesterified fats. Interesterified fats are formed when the fatty acids on the triglycerides of two fats – unsaturated oil and a stearic acid – are randomized to make the liquid oil solid as shown in Figure 4.[14] Industries now typically interesterify fully hydrogenated oils and unsaturated oils to meet the zero trans-fat label requirement.[15] However, recent studies on interesterified fats have also brought concern to the public. According to a recent study at Brandeis University, interesterified fats have similar, although weaker effects on blood cholesterol levels compared to trans-fats.[16] Interesterified fats can cause an undesired increase in blood glucose level where trans-fats have a weaker effect.[16]

Conclusion

The hydrogenation process, originally discovered by Sabatier in the early 20th century, has revolutionized food industries. Since this discovery, dietary oils have become more accessible to the general public. However, increased accessibility has brought some serious health concerns. Studies have shown an increased risk of cardiovascular disease caused by the consumption of partially hydrogenated oils. The consumption of trans-fats may have caused a significant increase in deaths.

Although the hydrogenation process of dietary oil has become highly developed over the years, it has also become much more difficult for industries to find a healthy and profitable alternative. Current research primarily involves improving the hydrogenation

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* J.M. Smucker Co. acquired the Crisco brand from P&G in 2001.

processes to meet the health concerns of consumer and to increase profits. Recently, increasing use of the interesterified fats has provided a possibly successful alternative to trans-fats for the dietary-oil industries.

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