FOOD FRYING

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Summary

Frying is a popular method used in food preparation and manufacturing. During frying, several physical and chemical changes occur in foods that impart desirable characteristics. For example, a popular fried food, French Fries, is noted for its crunchy exterior and soft, moist interior. While oil is an excellent heating medium, a number of physical and chemical changes occurring in oil during heating are detrimental to the properties of oil. These changes, due to oxidation, hydrolysis, and polymerization, require that used oil be discarded at frequent intervals. The design of batch and continuous fryers is influenced by such changes in cooking oil. Oil migration into foods is another critical issue in frying. Recent developments in mathematical models provide quantitative descriptions of heat and mass transfer to help minimize oil uptake by foods during frying.

1. Introduction

Frying is an old and widely used method of cooking and processing food. Typically, a food is immersed in heated oil for a short duration in a process known as immersion-oil frying. Numerous types of edible oils of plant and animal origin are used in frying, depending on regional availability. Palm oil is often used in Southeast Asia, coconut and groundnut oil in the Indian subcontinent, and olive oil in the Mediterranean region. During the last five decades, the Western food industry has become increasingly dependent on the frying process to manufacture a variety of snack foods. Fried foods such as potato chips, French fries, and fried fish and chicken have gained worldwide popularity. In this article, the term frying is used to describe a process in which a food is cooked by immersion in heated oil. Alternatively, this process is also referred to as immersion-oil frying and deep fat frying.

A wide variety of products are fried on an industrial scale. Among the most popular are potato chips (also called potato crisps), expanded snacks, roasted nuts, French fries (also called potato chips), extruded noodles, doughnuts, and frozen foods covered with batter, such as fish and chicken.

2. Physicochemical Changes in Foods during Frying

The immense popularity of fried foods is due to the unique flavor and texture imparted to food as it is fried. Many fried foods typically have a porous, crispy outer crust layer with unique flavor but are also soft and moist internally. With starchy foods, it is generally agreed that the crust layer develops as starches in the food gelatinize and the outer layer rapidly dries. However, the kinetics and mechanisms involved in crust formation and related structural changes have yet to be well understood. These mechanisms are dependent on the physical and chemical properties of the food material and the oil used in frying. The complexity of the frying process can be seen in many aspects. For instance, the structure and thickness of the porous crust layer is dependent on the product composition, the processing time, temperature, and composition of the frying oil and material being fried. Heat transfer between the oil and food surface is largely due to the convection mode, whereas heat flux across the crust layer is characterized by the conduction mode of heat transfer. Inter- and intra-sample irregularities pose a significant problem when trying to understand the basic driving forces involved in the movement of oil in a food during frying. This heterogeneity has led to the development of product-specific, empirical models that yield little in the way of fundamental knowledge. As a result, only limited progress has been made in developing a mechanistic understanding of the frying process.

Frying is often the preferred method of cooking for several reasons. The relatively high temperature of the oil used as a heating medium in the process sharply reduces the cooking time, resulting in desirable sensory characteristics like crispy texture and pleasant aroma (see *Sensory Evaluation, Texture in Solid and Semi-solid Foods*). In fried foods, such as potato chips and noodles, a product is fried until most of the moisture is removed and a porous structure is created throughout the product. With French fried potatoes, among other foods, the potato strips are fried for a sufficient duration until the outer region becomes porous and stiff, giving it a crispy texture, while the inner region is cooked and moisture is retained. Chemical changes create desirable aromas. The amount of oil absorbed during frying increases the total fat content and caloric value of a food, of concern when a low fat diet is desired.

3. Edible Oils Used in Frying Foods

The oil content of selected fried foods is shown in Table 1. In most cases, these foods have little or no native fat prior to frying. Most of the oil absorbed by a food takes place either during immersion in oil or immediately upon the removal from oil. With nuts and other foods having high oil content, the exchange of oil between the food and that used during frying alters the sensory and nutritional characteristics of the fried product.

Product	Oil Content (%)
Potato chips (also known as crisps)	33-38
Precooked potato French fries	10-15
Doughnuts	20-25

Table 1. Typical oil content of fried foods

Some of the commonly used oils in industrial applications involving food frying are listed in Table 2. In addition to the oils mentioned, many modified, fractionated, or hydrogenated oils are used in frying that provide required performance in terms of process, cost, and quality characteristics.

Coconut oil
Corn oil
Palm oil
Palm oleine
Rapeseed oil (low euricic acid)
Soybean oil
Sunflower seed oil

Table 2. Different types of oils used in food frying

3.1. Physicochemical Changes in Oil during Frying

Oil is an excellent heating medium, because it allows high rates of heat transfer into foods being cooked (see *Thermal Properties*). However, the frying process also causes a number of chemical and physical changes in the oil. These changes not only influence the heating characteristics, but also bring about changes in the sensory and nutritional characteristics of foods. Physicochemical changes in the oil are due to three factors:

- Oxidative changes due to atmospheric oxygen entering the oil from the exposed surface of the oil to the surrounding atmosphere (see *Kinetics of Chemical Reactions in Foods*).
- Hydrolytic changes due to water vapors from the product undergoing frying.
- Thermal changes due to oil being maintained at high temperatures.

Hydrolytic reactions cause cleavage of the ester bond of a lipid, resulting in the formation of fatty acids, glycerol, and mono- and diglycerides. Because oxidative reactions and thermal changes alter the unsaturated constituents of triglycerides, at least one of the acyl radicals of the triglyceride molecule is altered. Table 3 shows some of these changes in oils during frying. The three causative agents—namely, moisture, oxygen, and temperature—have a synergistic effect on the compounds produced during frying. Volatile compounds produced during frying influence the organoleptic quality of the food. Non-volatile compounds in the oil are important, because they migrate into the food undergoing frying and are subsequently ingested. These non-volatile compounds are also the basis of several analytical procedures used to measure alterations in the oil due to frying.

Changes	**Causing Agent**	**Resulting compounds**
Thermal alteration	Temperature	• Cyclic monomers • Dimers and polymers
Oxidative alteration	Air	• Oxidized monomers, dimers and polymers • Nonpolar dimers and polymers • Volatile compounds (hydrocarbons, aldehydes, ketones, alcohols, acids, etc.)
Hydrolytic alteration	Moisture	• Fatty acids • Monoglycerides • Diglycerides • Glycerol

Table 3. Changes in oil during the frying process

The preceding mechanisms occur simultaneously. They depend on different types of foods and on interaction with food components. The reactions taking place in the oil are highly complex and are responsible for variation in the results of analytical methods.

Several changes are observed in oils when used in repeated frying. These changes include:

- Development of unique sensory characteristics of oil and food being fried (see *Sensory Evaluation*).
- Change in density and viscosity (see *Food Rheology and Texture*).
- Change in color, such as darkening due to formation of polar compounds (see *Optical Properties*).
- Formation of foam due to polymer formation (see *Surface Phenomena*).
- Specific extinction of 232 and 270 nm of conjugated double bonds.
- Change in fatty acid composition, with increase in saturated acids.
- Increase in acid value due mostly to hydrolytic reactions.

- Decrease in iodine value due to elimination of double bonds resulting from polymerization and other reactions.

Numerous factors are used to assess the quality of edible oils used in frying: oil color, odor and taste, percentage of free fatty acids, peroxide value, iodine, and smoke point. These factors also play an important role in determining the final quality of fried foods.

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Biographical Sketch

Dr. R. Paul Singh is a Professor of Food Engineering, Department of Biological and Agricultural Engineering and Department of Food Science and Technology, University of California at Davis. At the University of California, Professor Singh teaches courses to students majoring in Food Science and Engineering on topics related to heat and mass transfer in foods. His research is concerned with developing a quantitative understanding of food processes. He uses mathematical models with computer-aided simulations to seek improvements in process efficiency. He is a fellow of the Institute of Food Technologists, American Society of Agricultural Engineers, and the International Academy of Food Science and Technology. He is author and co-author of 13 books and over 200 refereed papers on food engineering topics. His textbook, Introduction to Food Engineering, 3rd edition (co-authored with Dr. Dennis R. Heldman), is used worldwide in teaching food engineering principles and applications.