Food Oils and Fats: Chemistry & Technology

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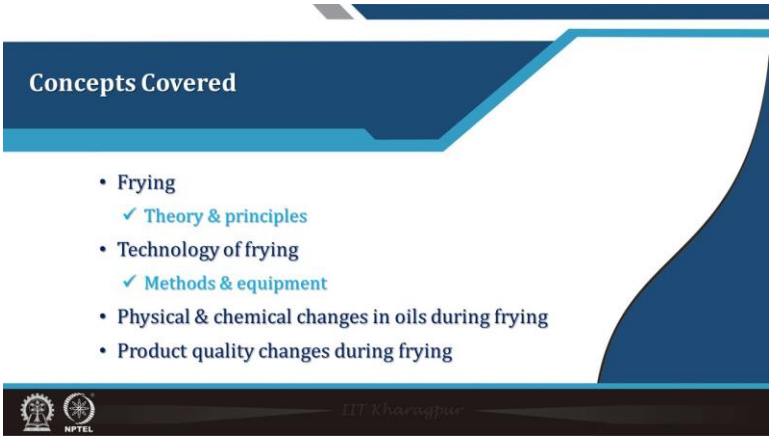
Module 9: Cooking & Frying Oils

Lecture 42: Frying Technology

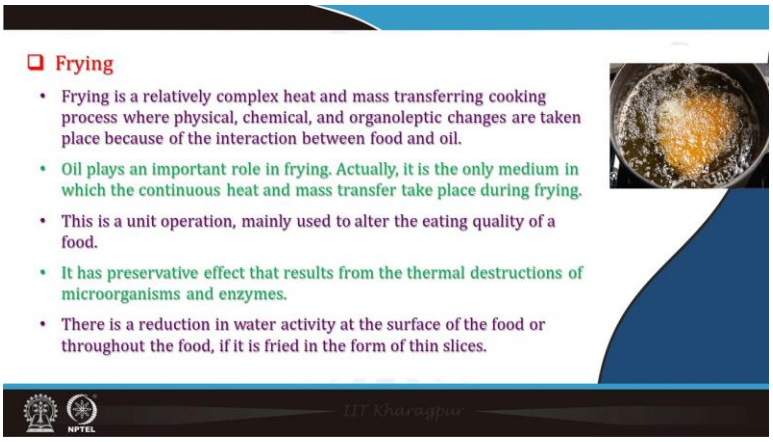
Hello everybody, Namaste. In today's lecture, we will discuss about Frying Technology.



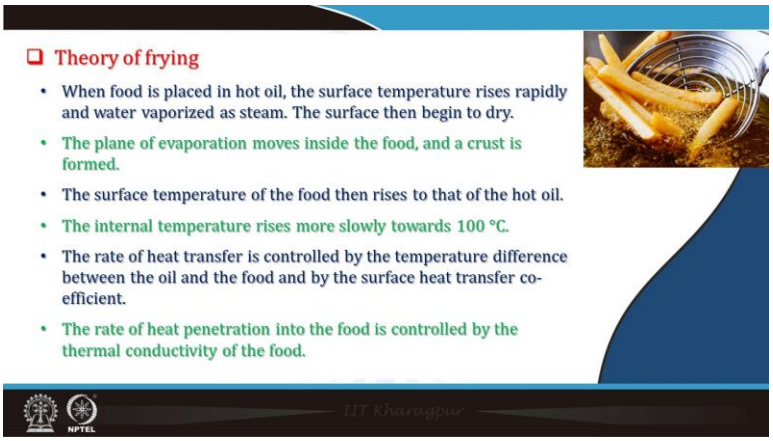
The concept that we will talk about today is what is frying, its basic theory, and principles of frying, we will try to understand. Then, we will also discuss the technology of frying, what are the various methods that are used for frying foods and equipment, physical and chemical changes which take place in oil as well as in the food during frying, and then the product quality changes that is, what are the various quality changes that take place in the food during frying operation.

So, let us see the frying. What is frying? Frying is a relatively complex heat and mass-transferring cooking process where physical, chemical, and organoleptic changes are

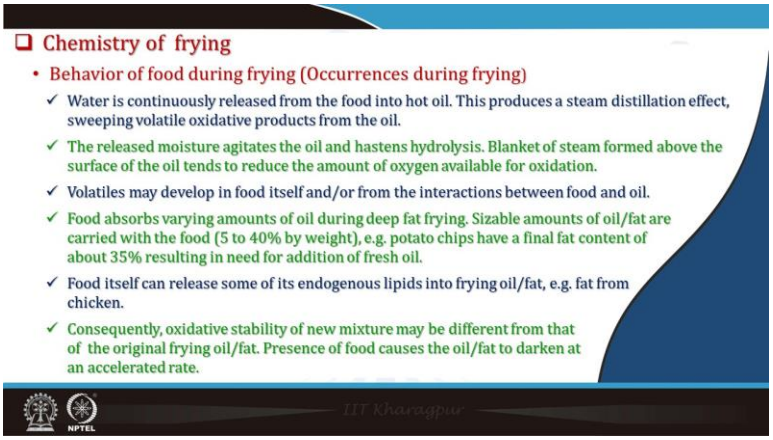
taken place because of the interactions between food and the oil in which the food is being fried.



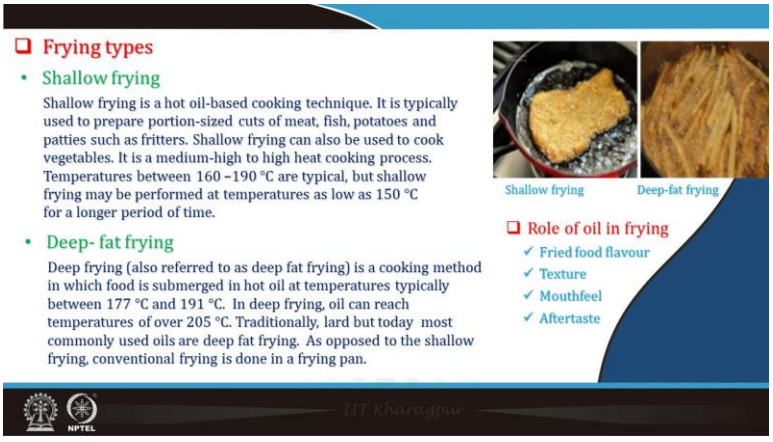
Oil plays an important role in frying. Actually, it is the only medium in which the continuous heat and mass transfer take place during the processing operation during the frying operation. This is a unit operation mainly used to alter the eating qualities of a food. It has a preservative effect that results from the thermal destruction of microorganisms and spoilage-causing enzymes etc. during the frying process. There is a reduction in water activity at the surface of the food or throughout the food if it is fried in the form of thin slices.



Let’s discuss briefly the theory of frying. When the food is placed in hot oil, the surface temperature rises rapidly, and water is vaporized or evaporated as steam. The surface then begins to dry. The plane of evaporation moves inside the food and a crust is formed, which is normally observed in the fried food at the surface. The surface temperature of the food then rises to that of the hot oil; that is, the surface temperature will equalize with the hot oil temperature. The internal temperature rises more slowly towards 100 degree Celsius, and the rate of heat transfer is controlled by the temperature difference between the oil and the food and by the surface heat transfer coefficient. The rate of heat penetration into the food is controlled by the thermal conductivity of the food.



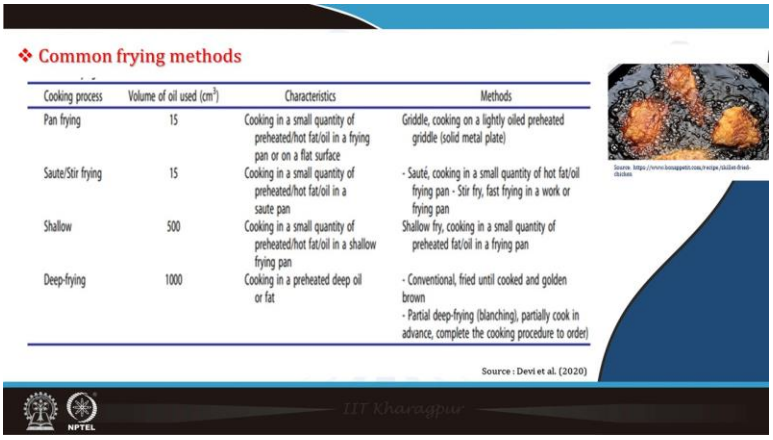
Now, what is the behavior of food during frying that is; what are the various occurrences during frying. Let's see the chemistry, basically the chemistry of frying we will try to understand now. As I told you, when the food material is put into the oil i.e. hot oil then water is continuously released from the food into hot oil, and this produces a steam distillation effect, sweeping volatile oxidative products from the oil. The released moisture agitates the oil and hastens hydrolysis. Blanket of steam formed above the surface of the oil tends to reduce the amount of oxygen available for oxidation. Volatiles may develop in the food itself and are from the interactions between the food and oil. Food absorbs varying amounts of oil during deep fat frying. Full amount of oils or fats are carried with the food, even from 5 to 40 percent by weight of the food. For example, potato chips have a final fat content of around 35 percent resulting in need for addition of fresh oil in different batch operations. Food itself can release some of its endogenous lipids into frying oil or fat. For example, fat from the chicken; when you fry the chicken then the fat contained in chicken is the released into the oil. And consequently, oxidative stability of new mixture may be different from that of the original frying oil or fat. The presence of food causes the oil or fat to darken at an accelerated rate.



So, let's see what are the different types of methods of frying that is two common methods which are used may be shallow frying or deep fat frying. Shallow frying is a hot oil-based cooking technique. It is typically used to prepare portion-sized cuts of meat,

fish, potatoes, patties such as fritters, and similar products. Shallow frying can also be used to cook vegetables. It is a medium-high to high heat cooking process. Temperatures between 160 to 190 degree Celsius are typical of the shallow frying process, but it can also be performed at a temperature as low as 150 degree Celsius. Of course, at the lower temperature the time required for the frying will be little more longer fry period of time.

Then, deep fat frying which is also referred to as that deep frying sometimes is a cooking method in which food is submerged in hot oil at a temperature typically between 178 or 180 to 190 degree Celsius. In deep frying, oil can reach temperatures of even more than 205 degree Celsius in some cases. Traditionally, lard but today most commonly used oils which are used for deep frying that are the vegetable oil like sunflower oil, palm oil, and this even sometime in some places coconut oil, mustard oil, or soybean oil. So, all that is plant oils, they are used. As opposed to the shallow frying, here the conventional frying is done in a frying pan. This deep frying is done in a frying pan. So, here you see that shallow-frying and deep-frying figures are shown. So, role of oil in the frying, that is, it has to perform certain role that is number one it influences the fried food behavior, flavor, texture, mouthfeel and aftertaste. Even there are several examples of the food which are processed using shallow frying, deep frying, and using different oils and there is a difference in the texture, taste, appearance of the food frying with the both the methods.

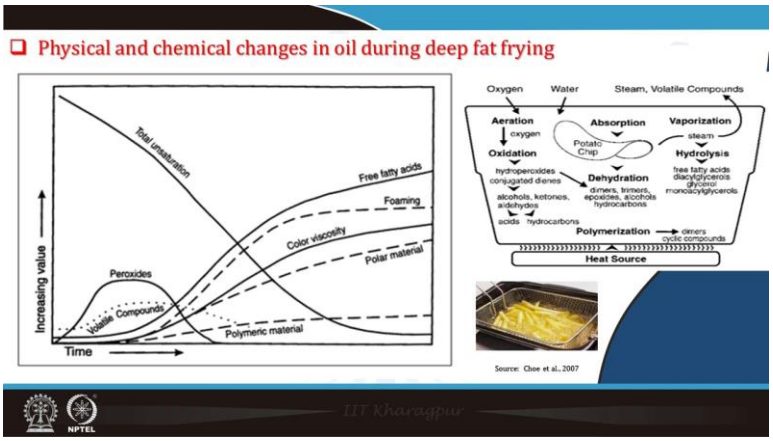


So, again the common frying methods, if you see little elaboration that the pan frying, saute or stir frying, shallow frying, or deep frying. These depend upon what is the volume of oil used, other characteristics, time, and temperature of the frying, and even the method per equipment used can be categorized. Like for example, in pan frying, the volume of oil used is 15 cubic centimeters; in the saute or stir frying also the similar volume is 15 cubic centimeters in general. Whereas, in the shallow frying, it may be 500 cubic centimeters, or in deep frying, even it is 1000 cubic centimeters.

The characteristics of the products which are fried in pan frying, saute frying, etcetera that is cooking in a small quantity of preheated hot oil or fat in a frying pan or on a flat surface, it is in the pan frying. But in the saute frying, saute pan is used. In shallow

frying, it is a shallow frying pan is used. So, there is a different change in the characteristics of the material after the construction or design of the frying pan which is used. Then, in the deep frying that is cooking in a preheated deep oil or fat, the deep pan is used.

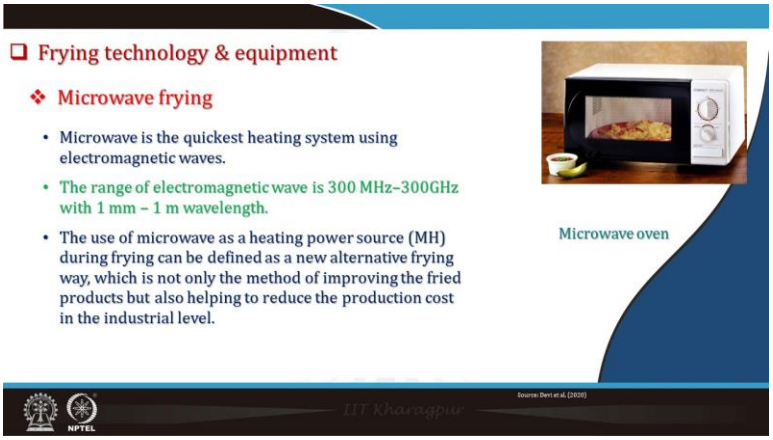
The method, also accordingly, I have given pan frying is the griddle, cooking on a lightly oiled preheated griddle, then saute is cooking in a small quantity of hot fat and oil is preheated, fast frying at a work frying pan. Then, deep frying is a conventional fried until cooked and golden brown until material is fully cooked and it becomes in golden brown color.



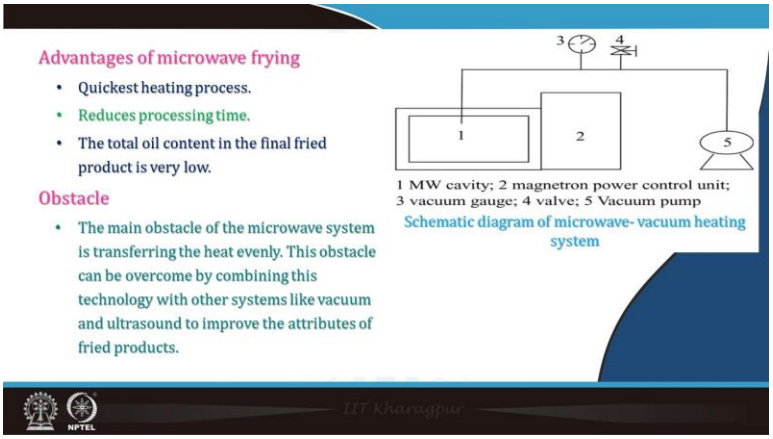
So, here you see that just this graph I have taken from the literature reference is given here, to show what are the various changes, that is with time as well as with increasing the value that is the changes like the value of the total unsaturation. You can see that as the time of the frying increases, the total unsaturation of the oil increases. Whereas, the value of volatile compounds first, it will increase, and then after sometime, it may decrease. The polymeric material, polar material, viscosity, foaming, and free fatty acids, there you see that is the increase or decrease and then after sometime it becomes constant.

Even the peroxides you see, it is first increases, remains constant for some time, then decreases. So, these are the various changes depending upon the characteristics, temperature, and all those things. Different changes in the oil will take, and obviously, these changes in the oil will have an effect on the food characteristics as well.

So, here you see what is happening in the frying when you are giving a heat source. So, various reactions, that is aeration, absorption, vaporization, hydrolysis, dehydration, polymerization, all these various reactions because when you are giving the heat, the oil is getting heated, from the oil the heat is being transferred into the food and from the food, moisture is being transferred into the oil. So, these different operations, heat and mass transfer operations influence the product characteristics as well as the characteristics of oil also change.

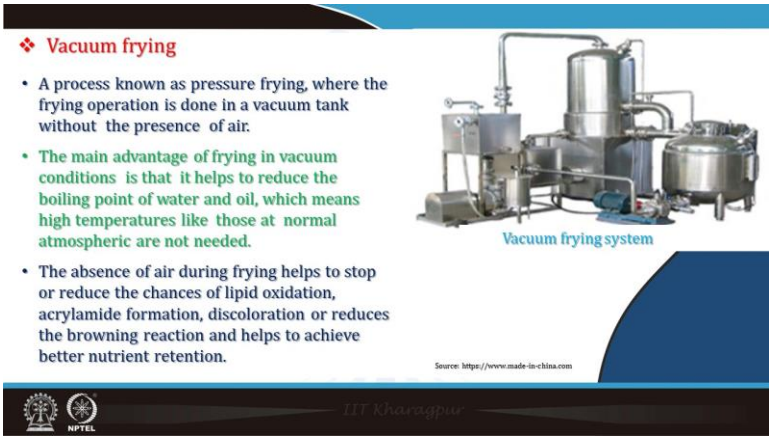


Now, let's talk briefly about the frying technology and equipment, that is, number 1, microwave oven or microwave frying. It is the quickest heating system using electromagnetic waves. Now, you know that microwave ovens are very common. So, this can also be used for frying. The range of electromagnetic waves is around 300 megahertz to 300 gigahertz with 1 mm to 1 meter wavelength. The use of microwave as a heating power source during frying can be defined as a new alternative frying way which is not only the method of improving the fried product, but also helping to reduce the production cost in the industrial level.

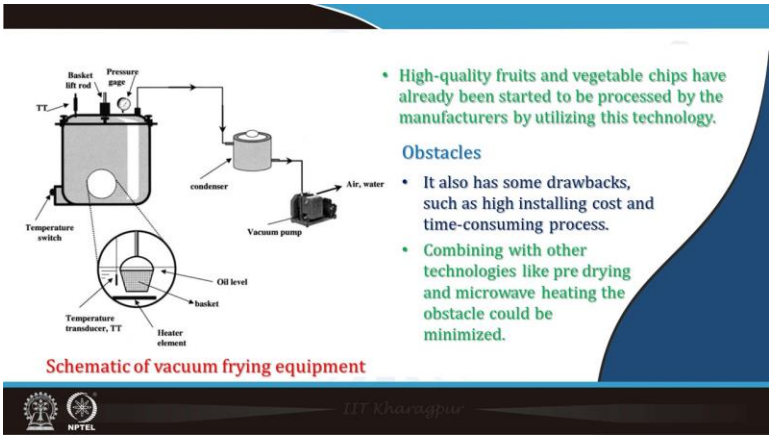


Advantages of the microwave frying include, that it is the quickest heating process, it reduces the process time accordingly, and the total oil content in the fried food or fried product is reduced to very low in this case. The schematic you see here, there is a microwave cavity, and there is a magnetron, which is a system to transport the microwaves into the cavity. It is a power control unit then a vacuum gauze, etcetera, or provider valve, and vacuum pump. So, these are the accessories and instruments required in the microwave system.

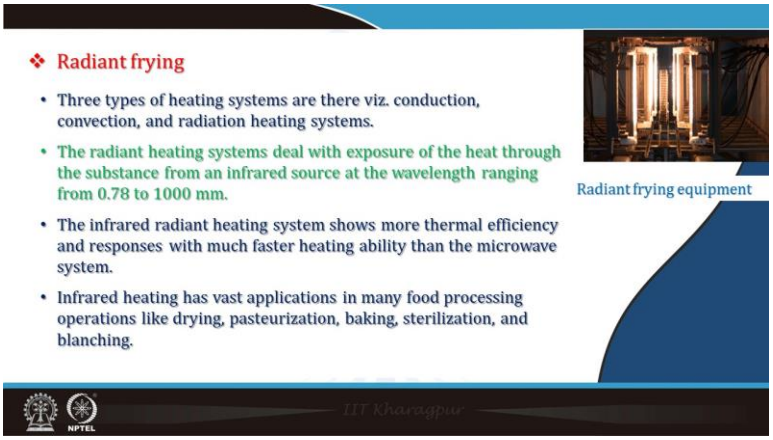
So, the main obstacle in the microwave system is transferring the heat evenly. This obstacle can be overcome by combining this technology with other systems like vacuum frying or ultrasound-assisted system to improve the attributes of the fried products.



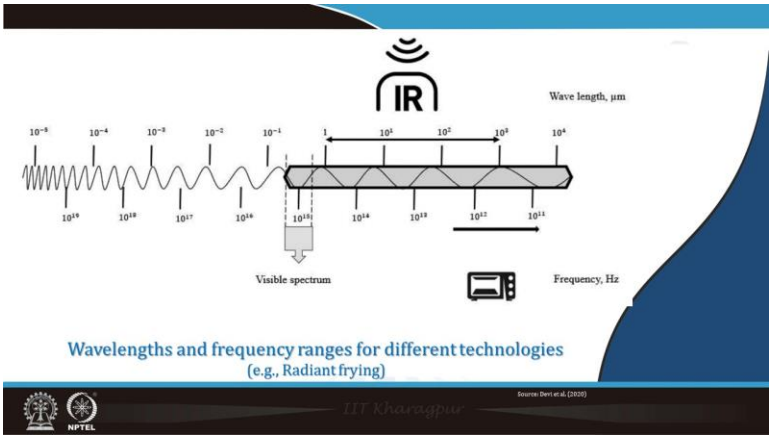
Vacuum frying, a vacuum frying setup is shown here. It is a process known as pressure frying where the frying operation is done in a vacuum tank without the presence of air. The main advantage of frying in vacuum conditions is that it helps to reduce the boiling point of water and air, which means high temperatures like those at normal atmospheric nations are not needed here. The absence of air during frying helps to stop or reduce the changes of lipid oxidation, acrylamide formation, discoloration, or it reduces the browning reactions and helps to achieve better nutritional characteristics or other properties in the fried product.



So, this is a schematic arrangement of vacuum frying equipment. You see here, that the pressure is provided at the basket lift for lifting the food, pressure gauge etc. and air, vacuum pump, condenser is provided, this is the system. So, here, high quality fruits and vegetables chips have already been started to be processed by the manufacturers utilizing this technology, this vacuum technology. Because of the superiority of this product characteristic quality of the product which is obtained by this method. It has become the choice of technology for the manufacturers or for the industries. It reduces energy, it improves retain quality in the food fried product better. It also has some drawbacks such as high installing cost, and it is a time-consuming process. Combining with other technologies like pre-drying and microwave heating, the obstacles could be minimized.



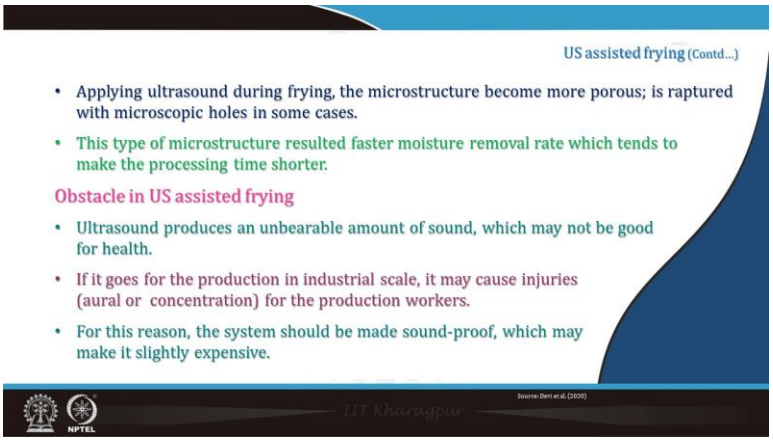
Then, radiant frying. There are three types of heating systems which are used like conduction, convection and radiation heating systems. The radiant heating system deals with exposure of the heat through the substance from an infrared source at the wavelength ranging from 0.78 to 1000 millimeters. The infrared radiant heating system shows more thermal efficiency and responses with much faster heating ability than the microwave system. Infrared heating has vast applications in many food processing operations like drying, pasteurization, baking, sterilization, and blanching and so, it also can be used accordingly for the frying operations.



This is figure just shows the wavelength and frequency ranges for different technologies like for example, radiant frying, you see the visible spectrum; it is a frequency in hertz 10^{15} and wavelength in this same like 1 to 10 and then IR becomes 10 to 10^2. So, these are the different ranges of the frequency or wavelength for this different technology.

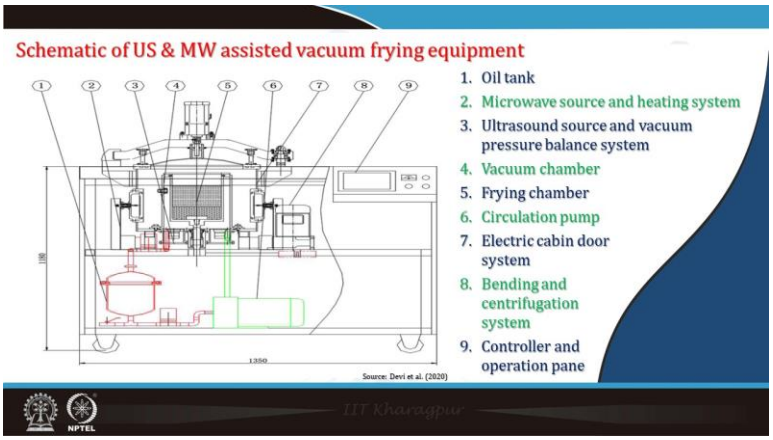
Then, ultrasound-assisted frying. Ultrasound has been applied comprehensively in different food processing system as a non-thermal synergistic system to enhance the production. The acoustic waves used in this treatment range between 220 kilohertz and 10 megahertz. Ultrasound is mostly used in drying, extraction, pasteurization, and sterilization, and now also it is becoming a popular choice in frying operation. Use of

ultrasound is a relatively new and novel technology for the snack food manufacturing industry. Use of ultrasound treatment during vacuum frying helps to produce a better-quality product with low oil content and crispier with a high efficiency of production rate. It has been reported that the use of ultrasound during frying helps to increase the heat transfer rate during frying because of micro-vibrational, sponge, and micro-streaming effects due to the incorporation of ultrasound.



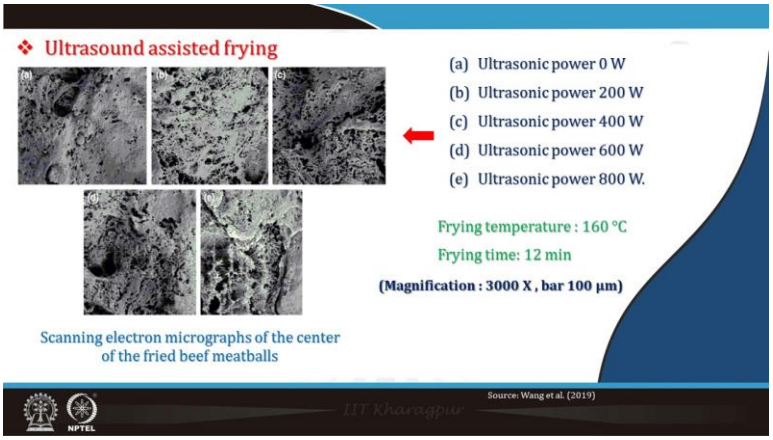
Applying ultrasound during frying, the microstructure becomes more porous and is ruptured with microscopic holes in some cases. This type of microstructure resulted in faster moisture removal which leads to make the processing time shorter.

Obstacles in ultrasound-assisted frying include that this ultrasound produces an unbearable amount of sound which may not be good for the health of the person operating the equipment. If it goes for the production in an industrial scale, it may cause injury may be aural or concentration for the production workers. And for this reason, the systems will be made soundproof, which may make it slightly expensive.

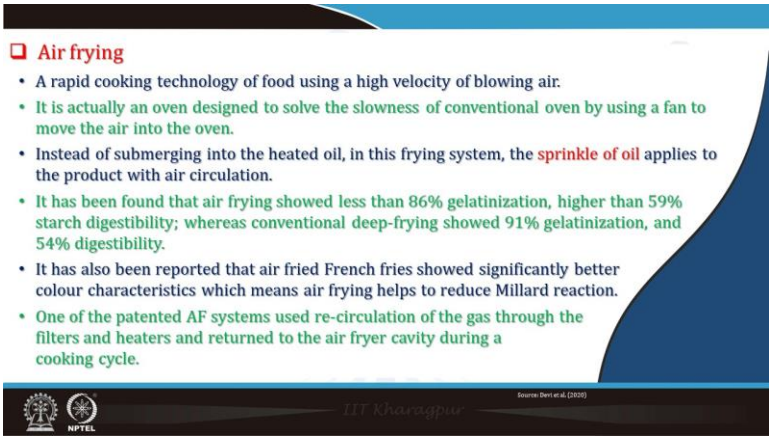


Schematic of the ultrasound- and microwave-assisted vacuum frying equipment is shown here in this figure. It has one oil tank, then microwave source and heating system, ultrasound source and vacuum pressure balance system, then there is a vacuum chamber number 4 here, then frying chamber, circulation pump, electric cabin door system,

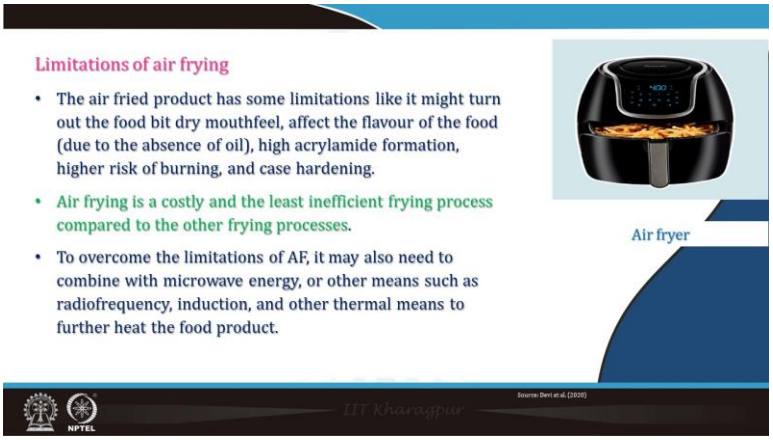
blending and centrifugation system, and controller and operation panel etc. that is controller where all the switches and buttons are provide to control the system. So, this US and microwave-assisted vacuum frying equipment is provided with all these accessories and then this can be used to control the product can be treated with the ultrasound to create pore etc., which will improve or helping the oil, moisture in the top operation and heat transfer and mass transfer during frying and the microwave that is used to heat the things and then the vacuum. So, all these things are combined into one setup and it gives a better efficiency.



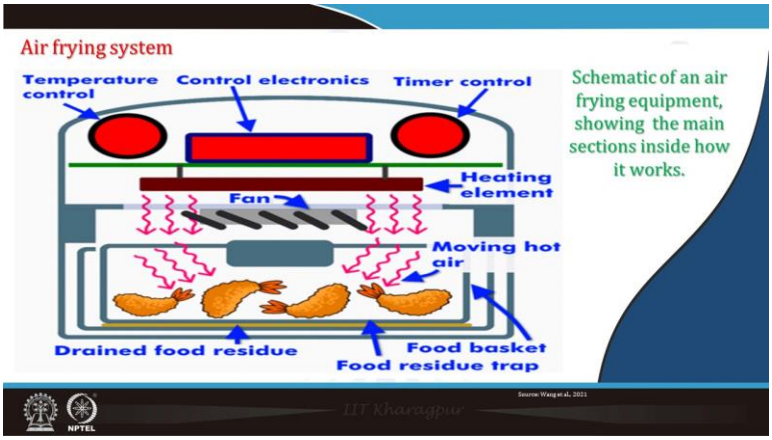
You can see here that is a microstructure electron micrograph for the center of the fried beef meatballs during the ultrasonic power of 0 watts where no ultrasonic power was used, then ultrasonic power of 200 watts this B, and C is the ultrasonic power of 400 watts, D is the 600 watts and E is 800 watts. So, ultrasonic power was increased and the frying temperature was maintained at 160 degree Celsius and frying time was for 10 minutes. So, this figure had a magnification of 3000× and bar 100 µm. So, you can see that microstructure and pore changes, they are clearly visible that when ultrasound power is increased that it creates more structural changes, causes more holes, etcetera, and this helps in the proper heat and mass transfer. You can see when there is no ultrasound applied and when there is more maximum of 800, there is a visible change in the structure.



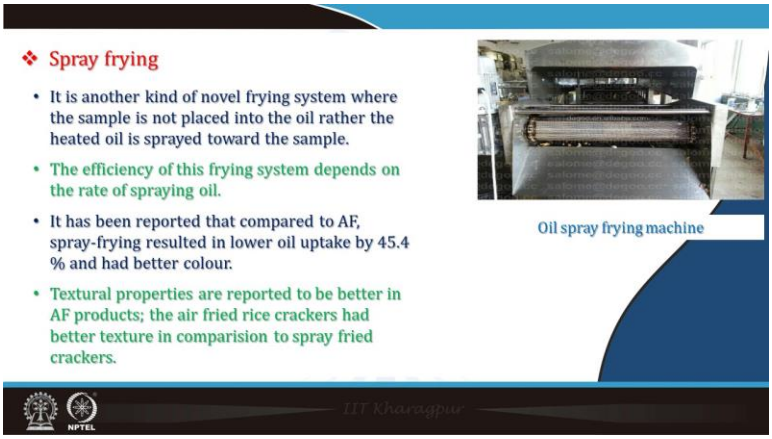
Then, air frying is a rapid cooking technology of food using a high velocity of blowing air. It is an oven designed to solve the slowness of a conventional oven by using a fan to move the air into the oven. Instead of submerging into the heated oil, in this frying system, the sprinkle of oil is applied to the product with air circulation. It has been found that air frying showed less than 68 percent gelatinization, higher than 59 percent starch digestibility whereas, conventional deep-frying showed about 91 percent gelatinization and 54 percent digestibility. It is also reported that air-fried french fries showed significantly better color characteristics which means air frying helps to reduce the Maillard reaction. One of the patented air frying systems uses re-circulation of the gas through the filters and heaters through the filters and heaters and then returns the air to the air fryer cavity during a cooking cycle.



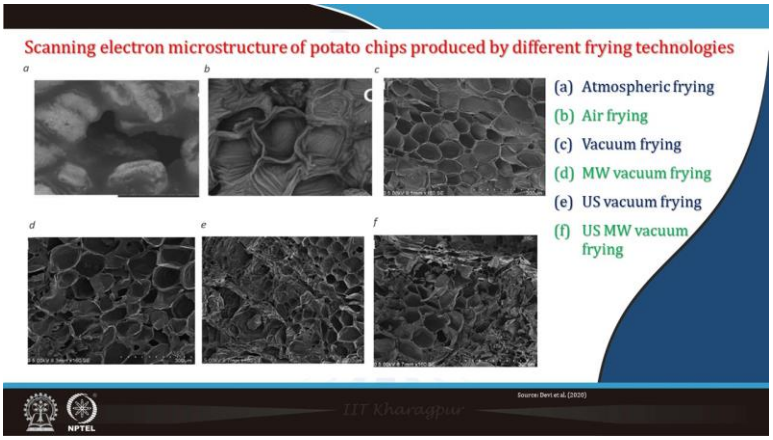
The limitation of the air frying. This system also has some limitations like other methods, that is, the air-fried product has limitations as it might turn out the food bit dry mouthfeel. It affects the flavor of the food due to the absence of oil. It might have high acrylamide formation, higher risk of burning, and case hardening. Air frying is costly and has the least influence and the least inefficient frying process compared to the other frying operations. To overcome the limitations of air frying, it may also need to be combined with microwave energy or other means such as radiofrequency, induction heating, and other thermal means to further heat the product, which may improve the efficiency of the process.



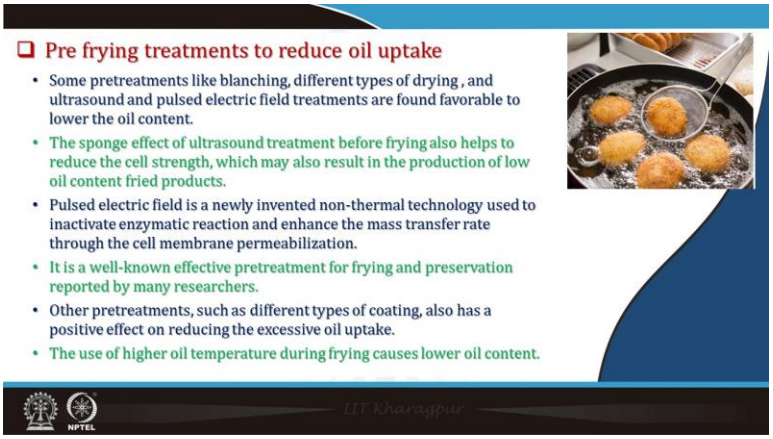
So, here it is an air frying system schematic. The main section inside and how it works is you see that then food products here and the microwave hot air is coming that is the fan is used to blow the air and heat is provided and there are time control electronics, temperature controls, etc. So, inside the oven, that is, along with the fan, the oil is sprinkled over the product.



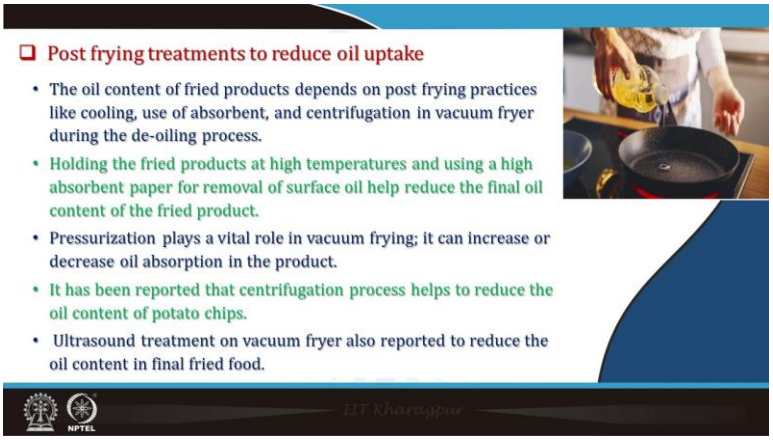
Spray frying. It is another kind of novel frying system where the sample is not placed into the oil rather the heated oil is sprayed toward the sample. The efficiency of this frying system depends on the rate of spraying oil. It has been reported that compared to air frying, spray-frying resulted in a lower oil uptake by around 45 percent and had better colour. Textural properties are reported to be better in the air-fried product. The air-fried rice crackers had better texture compared to the spray-fried crackers.



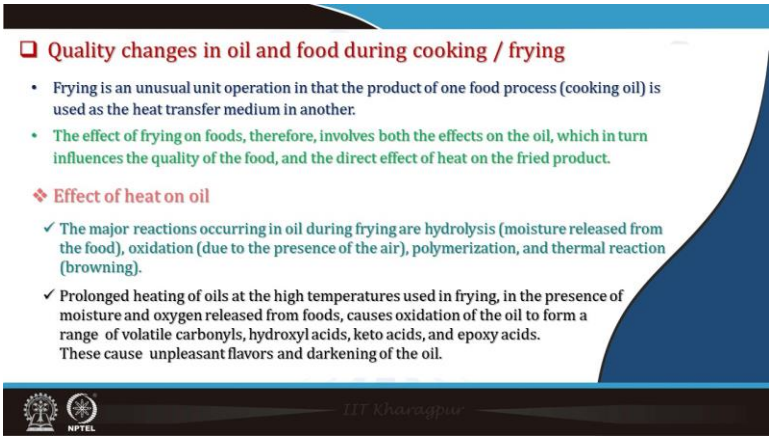
The scanning electron microstructure of potato chip produced by different frying technologies is shown. A is the atmospheric frying sample i.e. normal frying which is done by deep frying, then air-frying B, C is the vacuum frying, D is the microwave vacuum frying, E is the ultrasound-assisted vacuum frying, and then F is the ultrasound-microwave vacuum frying. And you see \how the structures it gives. Obviously, every technology as can be seen in this microstructure of the product, has its own influence. Accordingly, this microstructure changes during the process will have their own effect on the quality of the product.



Now, there are sometimes some pre-frying treatments that are recommended to reduce the oil uptake in the materials. Pretreatment like blanching, different types of drying, and ultrasound and pulse electric field treatments are found favorable to lower the oil content. The sponge effect of ultrasound treatment before frying also helps to reduce the cell strength, which may also result in the production of low oil content in the food product. Pulse electric field is a newly invented non-thermal technology that is used to inactivate enzyme reactions and enhance the mass transfer rate through the cell membrane or permeable permeabilization. It is a well-known effective pretreatment for frying and preservation, which is reported by many researchers. Other pretreatments, such as different types of coating have, also a positive effect on reducing the excessive oil uptake by the product. The use of higher oil temperature during frying causes lower oil uptake.



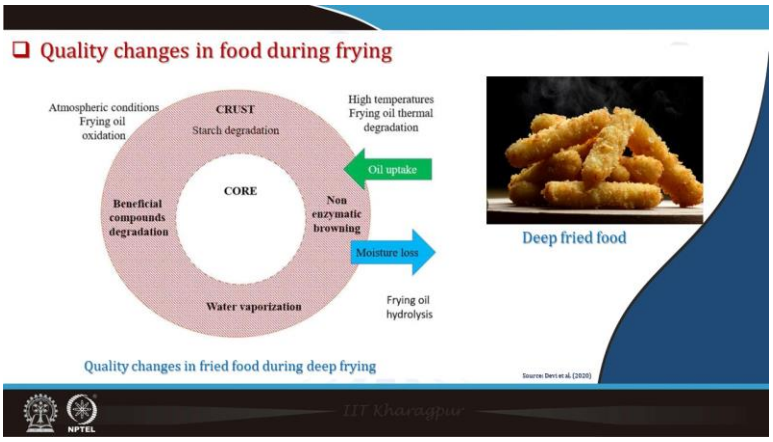
Similarly, post-frying treatments to reduce the oil uptake are, that is, the fried product the oil content can be reduced. There are operations like cooling, use of absorbent, and centrifugation in vacuum fryer during the de-oiling process. Using the fried product at a high temperature and using a high absorbent paper for removal of the surface oil help reduce the final oil content of the fried product. Pressurization plays a vital role in vacuum frying. It can increase or decrease oil absorption in the product. It has been reported that the centrifugation process helps to reduce the oil content of potato chips. The ultrasound treatment and vacuum fryer were also reported to reduce the oil content in final fried food.



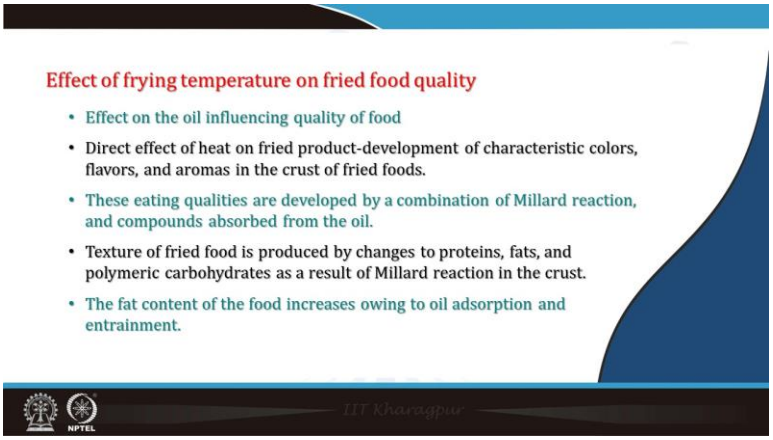
Now, the quality changes in oil during frying and cooking. Obviously, frying is an unusual unit operation in that the product of one food during the food process (cooking oil) is used for the heat transfer medium in another. And the effect of frying on food, therefore, involves both the effects on the oil, which in turn influences the quality of the food, and the direct effect of the heat on the fried food product.

So, first, we see the effect of heat on the oil. The major reactions occurring in oil during frying are hydrolysis that is moisture release from the food, oxidation, polymerization, and thermal degradation. Prolonged heating of the oil at the high temperature used in frying in the presence of moisture and oxygen released from foods, causes oxidation of

the oil to form a range of volatile carbonyls, hydroxyl acids, keto acids, and epoxy acids. These cause unpleasant flavor and darkening of the oil.



Here, you see, the various quality changes in the food that is the earlier we show that there is oil uptake, then the moisture loss. So, it may result in a non-enzymatic browning, water vaporization, beneficial compound degradation, and crust formation resulting in starch degradation. So, these are the various quality changes that may take place.

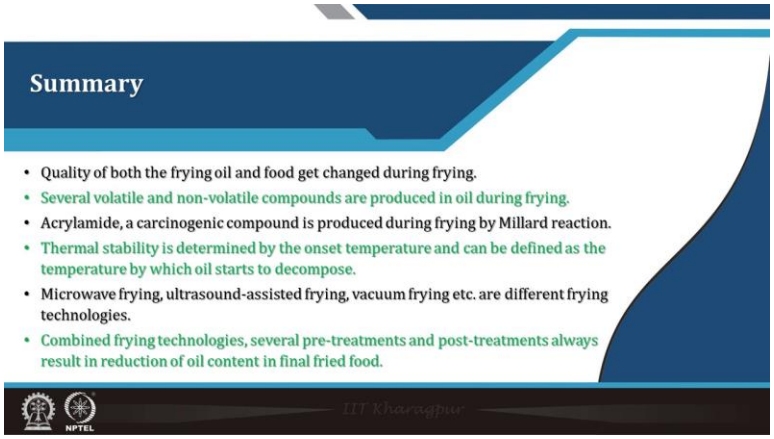


The effect of frying temperature on the fried food quality. The direct effect of heat on fried food product-development of characteristic color, flavor, and aroma in the crust of the fried foods. These eating qualities are developed by a combination of Maillard reaction and compounds absorbed from the oil. The texture of the fried food is produced by changes to proteins, fats, and polymeric carbohydrates as a result of the Maillard reaction in the crust. The fat content of the food increases owing to oil absorption and entrainment. So, these are the various effects which affect the food quality of the food.

There is the food ingredient that influences the frying in developing flavor in the fried food. How is it there? The various ingredients like sugar, amino acids, sulfur compounds, lipids, and phenolics are there. The interaction results like the sugar pyrolysis, caramelization of the sugar, formulation of the Maillard product, and their decomposition

product are responsible for both desirable and as well as undesirable flavors developed during frying.

Then changes in amino acids like direct pyrolysis, deamination interaction with the volatile, aldehydes, and formation of Maillard product because these amino acids also are associated with the sugar and Maillard products and extricate degradation etcetera these are the causes during frying. Then pyrolysis and oxidation and pyrolysis interaction with aldehydes of the sulfur compounds. Similarly, oxidation and cleavage interaction with amines; interaction with sulfur compounds of the lipids; phenolics are oxidation of pyrolysis of phenolics. These are the various ingredients responsible for the changes in the product quality.



So, finally, I would like to summarize this lecture by saying that the quality of both the frying oil and food get changed during frying. Some volatile and non-volatile compounds are produced in oil during frying. Acrylamide, a carcinogenic compound is produced during frying by the Maillard reaction. Thermal stability is determined by the onset temperature and can be defined as the temperature by which the oil starts to decompose. So, oil frying, ultrasound-assisted frying, vacuum frying, etc. are different frying technologies. Combined frying technologies, several types of pre-treatments, and post-treatments always result in the reduction of oil content in the final fried food.

But one thing is important, this fried product, that is, if the frying operation is done in the absence of oxygen like vacuum frying, etc., then it will definitely result because the effect of temperature as well as the effect of air which causes the oxidation of the product and results into the formation of various compounds and many of these compounds might be toxic sometimes. So, there can be chances, if this oil intake/uptake of oil and residue oil content in the fried food etcetera. All those things can be properly controlled if the frying operation is done in a proper manner. So, that is important, and one more care should be taken is the conditions of the frying technology, it should be such that at least minimum if we are able to control or check the transformation that is the formation of trans fatty acid in the fried food as well as acrylamide. These two are the major as the acrylamide content and the conversion of cis to trans fatty acid during frying operations.

So, the frying process technology or equipment, etc. is selected in such a way that these two occurrences are minimized. So, it will be nothing better, otherwise, it gives a very good paste and from a color point of view, the fried product appears much better.

So, these are the references that are used in preparing this lecture.

Thank you very much for your patience here. Thank you.