Food Oils and Fats: Chemistry and Technology

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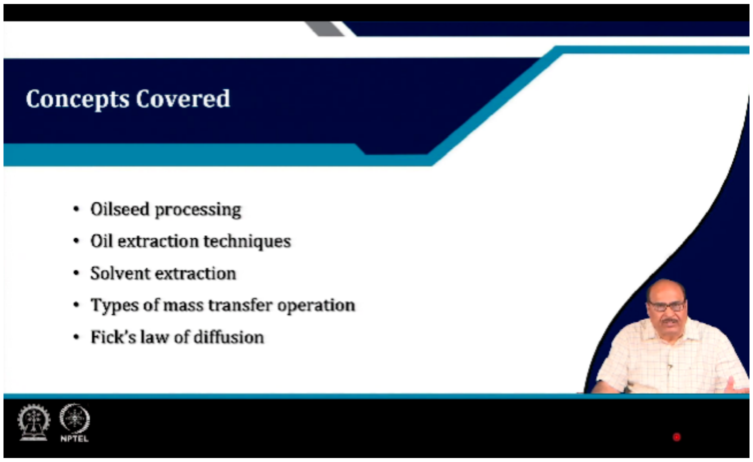
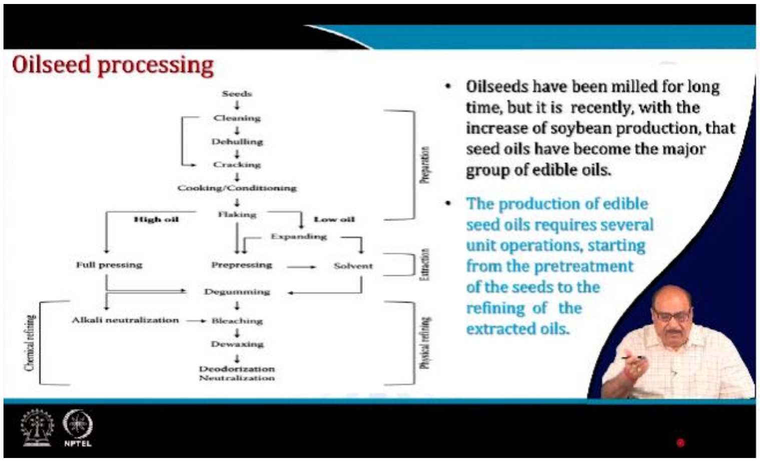
Module 05: Solvent Extraction of Edible Oils

Lecture 21: Oil Extraction Principle and Mechanism

Hello everybody. Namaskar. We are now in the fifth module of this course, and this fifth module in the next five lectures, we will talk about solvent extraction of edible oil. Today's lecture will discuss oil extraction principles and mechanisms in general.

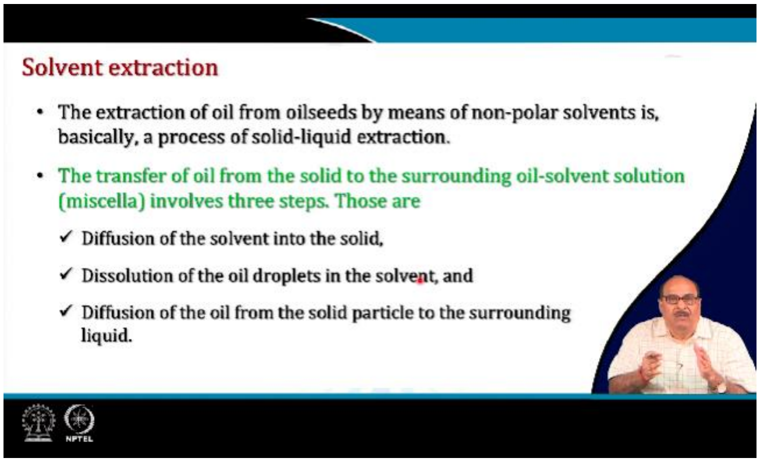


In general, oil seed processing, oil extraction techniques, solvent extraction, type of mass transfer operations, and Fick's law of diffusion.

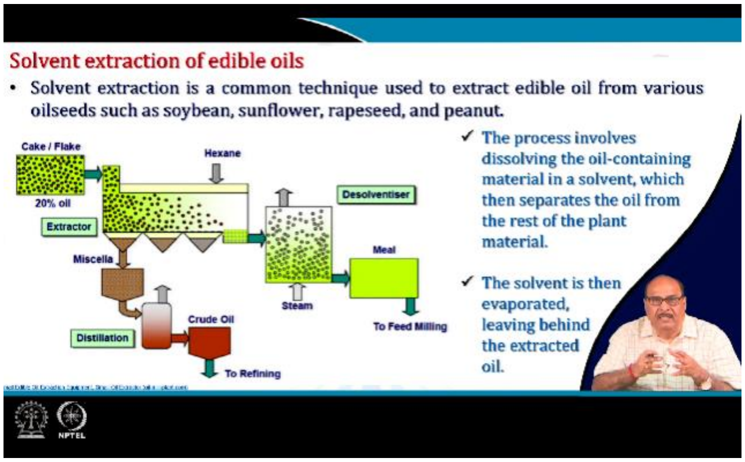


You know the oil seeds have been milled for a long time, but recently, with the increase in soybean production, seed oils have become the major group of edible oils. The production of edible seed oils required several unit operations, from the pretreatment to refining the extracted oil. In the earlier classes, we also discussed that the seed must first be subjected to various pretreatments for better extraction yield and oil quality. Then, after the pretreatment, these oil seeds are subjected to extraction technique either by pressing or solvent extraction or by both prepress solvent extraction processes. And finally, the oil which is obtained by these processes, like crude oil, is sent to the next step of refining.

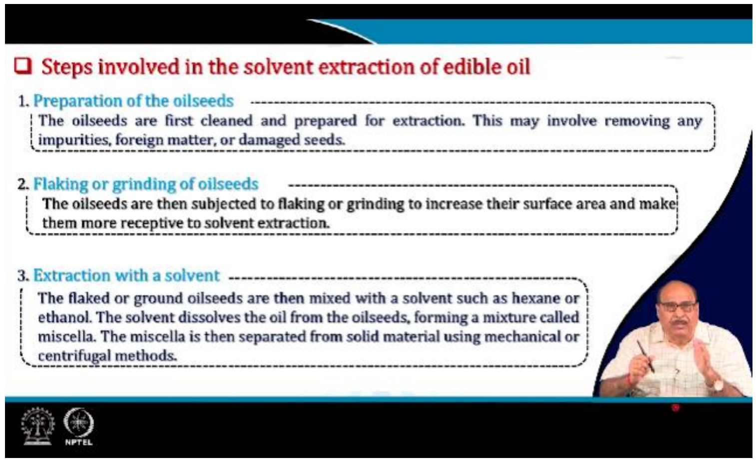
So, our country's main oil seeds are raw materials used for edible oil extraction, including sunflower seeds, soybeans, sesame, palm seeds, rapeseed, olive seeds, and cotton seeds.



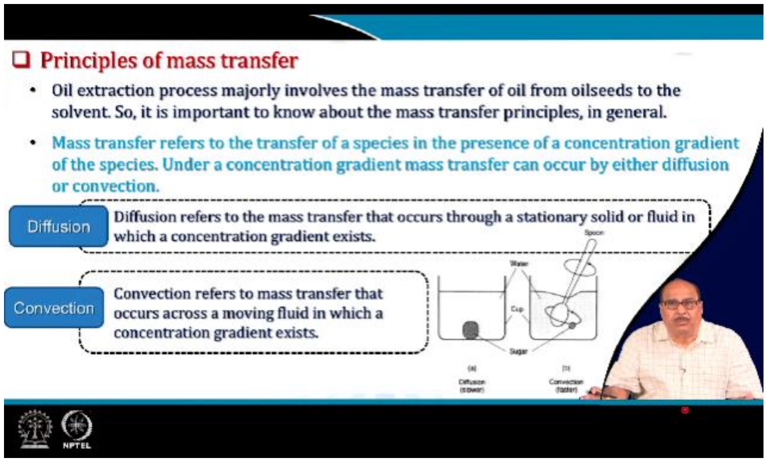
If you want to understand solvent extraction technology, this oil extraction from oil seeds using a non-polar solvent is a solid-liquid extraction process. The transfer of oil from the solid to the surrounding oil solvent solution, commonly known as miscella, involves three steps. And what are those steps? They are diffusion of the solvent into the solid, dissolution of oil droplets in the solvent, and distribution of the oil from the solid particles to the surrounding liquids.



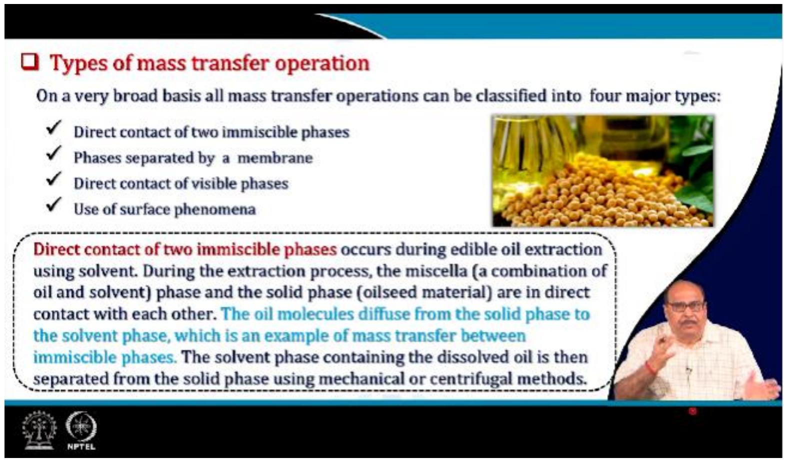
Solvent extraction is a common technique used to extract edible oil from various oil seeds such as soybean, sunflower, rapeseed, peanut, etc. The process involves dissolving the oil-containing materials in a solvent, separating the oil from the rest of the plant material. The solvent is then evaporated, leaving behind the extracted oils. So, you can see in the figure here that the prepared oil seed material is sent to the extractor, where direct and intimate contact is allowed between the prepared seed material and solvent. Then oil gets dissolved into the solvent, and we finally get the miscella, a mixture of solvent and oil. Now, this miscella is passed to the distillation unit where this solvent is evaporated, and for reuse, we get the crude oil which is finally sent to the refining process. On the other end, the meal obtained after the extraction of the oil seed material also has a significant amount of solvent in it. So, this meal is sent to the desolventizer toaster or desolventization process, where the solvent is removed from the meal, and then this meal is treated for feed and food materials.



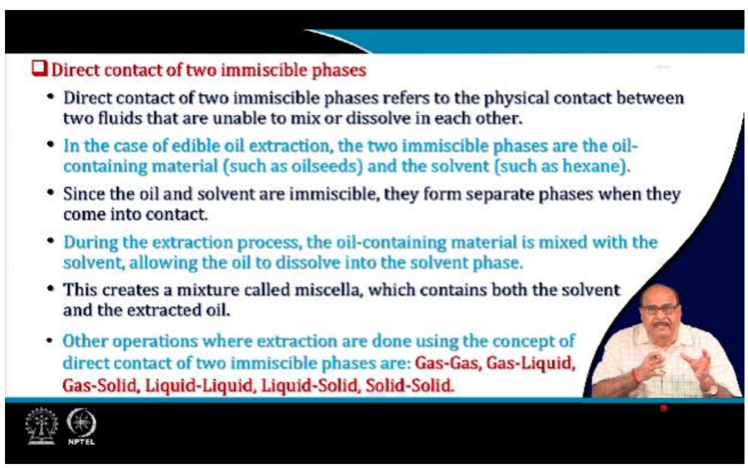
So, overall, the steps involved in the solvent extraction of feedable oil, as I told you, the preparation of oil seeds okay. The oil seeds are cleaned and pretreated for extraction, and this may involve removing impurities, foreign matter, damaged roots, etc. this step is very important as far as the quality of the oil is concerned. Then, flaking of the grind flaking or grinding of the oil seeds is done to increase their surface area and make them more receptive to the solvent extraction process. Finally, the heart of the whole process is extraction with a solvent. The flake or ground oil seeds are then mixed with a solvent such as hexane or ethanol to dissolve the oil from the oil seeds, forming a mixture called miscella. The miscella is then separated from the solid materials using mechanical or centrifugal methods. The distillation of the miscella in all it is subjected to is done to recover the solvent from the solvent oil mixture. And then, the extracted oil obtained by this process is known as cooled crude oil, and then this natural oil is sent to the next steps of the refining process to remove various impurities that might be present in the oil. Finally, the refined oil is sent to the packaging of refined oil, or sometimes, in some cases, crude oil or crude virgin oil is shipped to the packaging for further use and consumption.



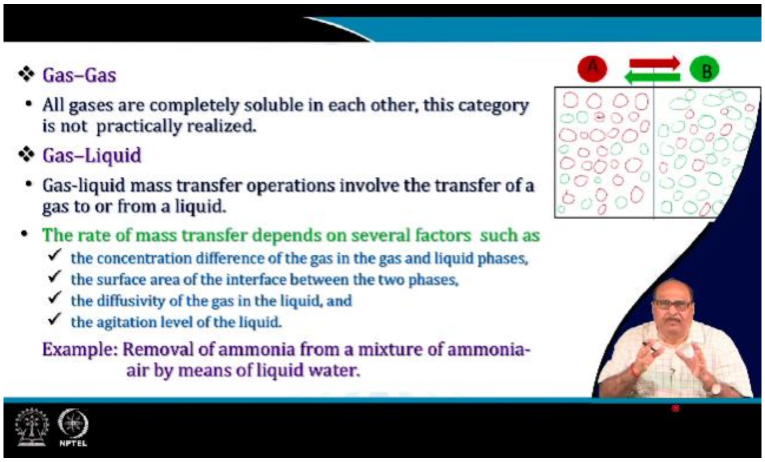
This oil extraction process involves the mass transfer of oil from oil seeds to the solvent. So, it is important to know about the mass transfer principles in general. Mass transfer refers to the transfer of a species in the presence of a concentration gradient of the species. Under a concentration gradient mass transfer can occur by either diffusion or by convection. Diffusion refers to the mass transfer that occurs through a stationary solid or fluid in which the concentration gradient exist. Whereas, the convection refers to the mass transfer that occurs across a moving fluid. The fluid is here in this case moving in which a concentration gradient exist. The primary driving force for the mass transfer is concentration difference. When a system contains two or more components whose concentration varies from point to point there is a natural tendency for mass to transfer from one point to the other. Mass transfer requires the presence of two regions at different chemical composition and mass transfer refers to the movement of chemical species present in the medium. The transfer of mass within a fluid mixture or a cross phase boundary is a process that plays a major role in many industrial processes. Mass transfer may occur in a gas mixture, a solid solution or solid. Mass transfer occurs when there is a gradient in the concentration of a species and the material moves from one place to other place. The basic mechanism are the same whether the phase is a gas, liquid or solid.



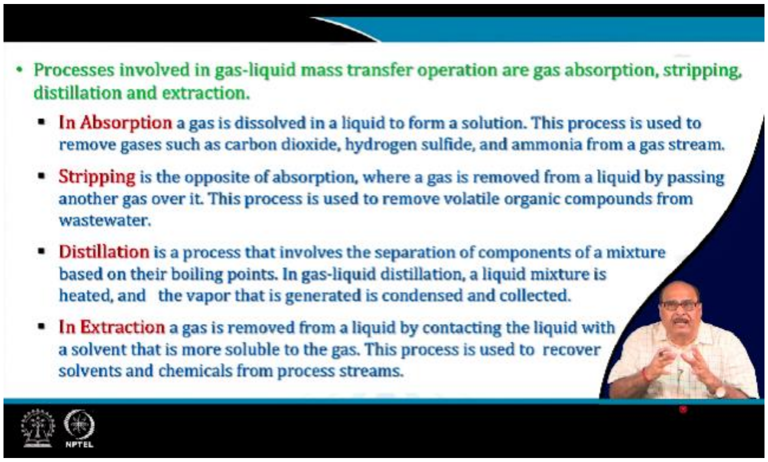
If we discuss types of mass transfer operations that is on a very broad basis all the mass transfers operations can be classified into four major types. These are the direct contact of two immiscible phases, phases separated by a membrane, direct contact of visible phases and use of surface phenomena. In the direct contact of two immiscible phases this occurs during edible oil extraction using solvent. There is a direct contact of two immiscible phases. During the extraction process the miscella which is a combination of oil and solvent that and the solid phase that is oil safe materials are in direct contact with each other. The oil molecules diffuse from the solid phase to the solvent phase which is an example of mass transfer between immiscible phases. The solvent phase containing the dissolved oil is then separated from the solid phase using mechanical or centrifugal methods.



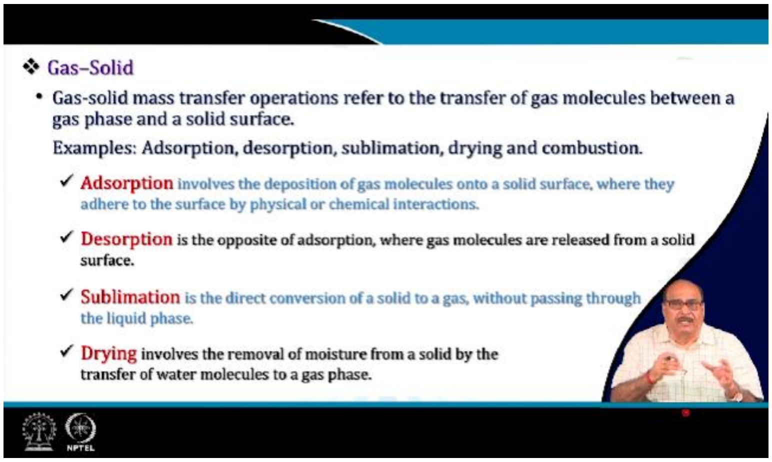
In the case of direct contact of two immiscible phases here there is a it refers to the physical contact between two fluids that are unable to mix or dissolve in each other. In the case of edible oil extraction the two immiscible phases are the oil containing material like oil seeds and the solvent such as hexane. So, here these two are immiscible to each other. Since the oil and solvent are immiscible they form separate phases when they come into contact. During the extraction process the oil containing material is mixed with the solvent allowing the oil to dissolve into the solvent phase. This creates a mixture called micelle which contains both the solvent and the extracted oil. Other operations where extractions are done using the concept of direct contact of two immiscible phases may be gas-gas or gas-liquid, gas-solid, liquid-liquid, liquid-solid, solid-solid and so on. That is these two phases may be in different states of matter either it may be gas-liquid, liquid-liquid, liquid-solid and so on.



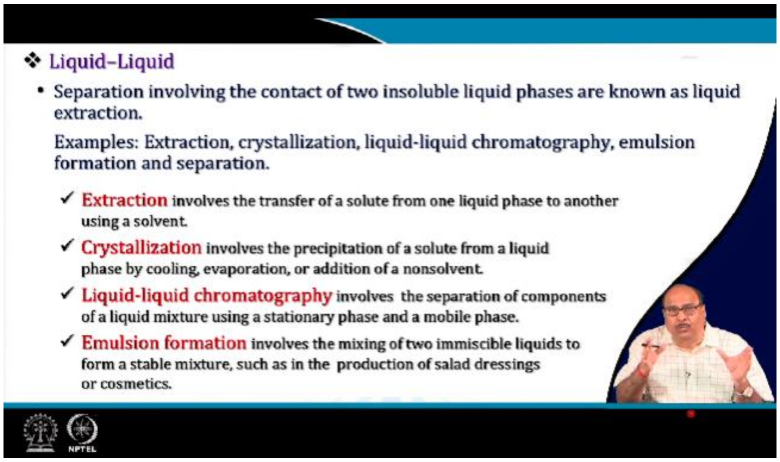
So, let us see little bit more that gas-gas that is all gases are completely soluble in each other and this category is not practically realized is very rare in actual step. But the gas-liquid is an important phase of mass transfer operations that is gas-liquid mass transfer operations involve the transfer of a gas to or from a liquid. The rate of mass transfer depends on several factors such as the concentration difference of the gas in the gas and liquid phases, the surface area of the interface between the two phases, the diffusivity of the gas in the liquid and the agitation level of the medium. And the example of this type of mass transfer operation includes removal of ammonia from a mixture of ammonia air by the means of liquid water.



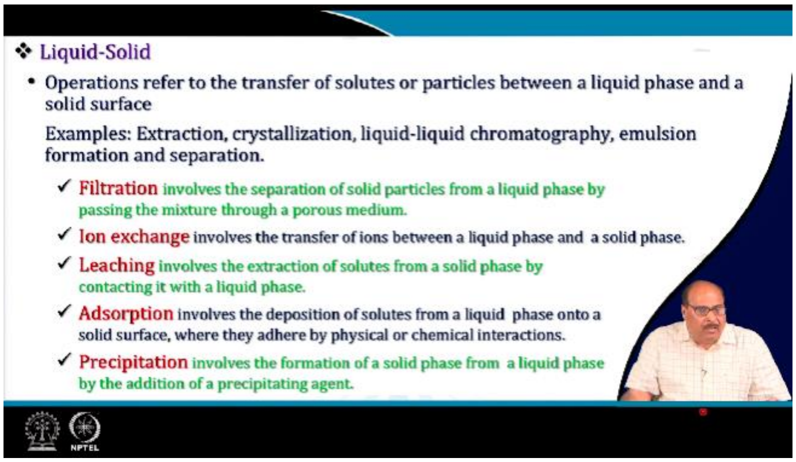
So, this gas-liquid mass transfer operations involves different phenomena like absorption, stripping, distillation and extraction. In absorption, a gas is dissolved in a liquid from a solution. This process is used to remove gases such as carbon dioxide, hydrogen sulphide and ammonia from a gas stream. Stripping is the opposite of absorption where a gas is removed from a liquid by passing another gas over it. This process is used to remove volatile organic compounds from wastewater. Distillation is a process that involves the separation of components of a mixture based on their boiling points. In gas-liquid distillation, a liquid mixture is heated and the vapour that is generated is condensed and collected. In extraction, a gas is removed from a liquid by contacting the liquid with a solvent that is more soluble to the gas. This process is used to recover solvents and chemicals from the process streams.



Now, in gas-solid mass transfer operation, this refers to the transfer of gas molecules between gas phase and a solid phase. Examples include absorption, desorption, sublimation, drying and combustion. Absorption involves the deposition of gas molecules onto a solid surface where they adhere to the surface by physical or chemical interactions. Sublimation is the opposite of adsorption where gas molecules are released from a solid surface. Sublimation is the direct conversion of a solid to a gas without passing through the liquid phase. Drying involves the removal of moisture from a solid by the transfer of water molecules to a gas phase.

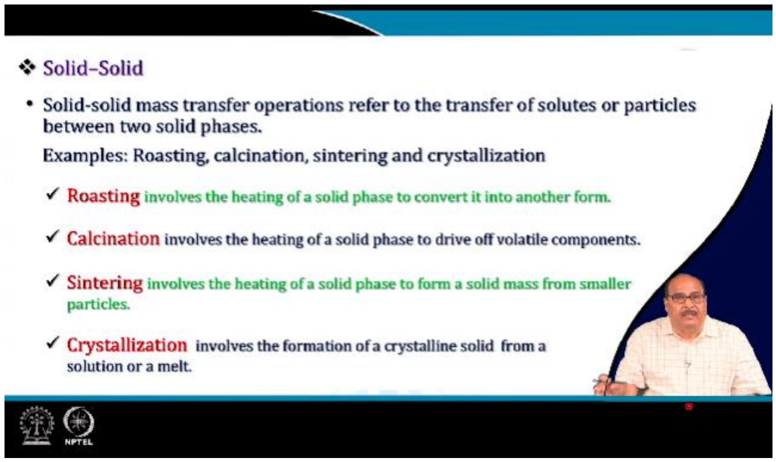


Liquid-Liquid mass transfer operations in this case separation involving the contact of two immiscible or two insoluble liquid phases are known as liquid extraction. An example of this process includes extraction, crystallization, liquid-liquid chromatography, emulsion formation and separation. Extraction involves the transfer of a solute from one liquid phase to another using a solvent. Crystallization involves the precipitation of a solute from a liquid phase by cooling, evaporation or addition of a non-solvent. Liquid-liquid chromatography involves the separation of components of a liquid mixture using a stationary phase and a mobile phase. Emulsion formation involves the mixing of two immiscible liquids to form a stable mixture such as in the production of solid dressing or in case of cosmetics.

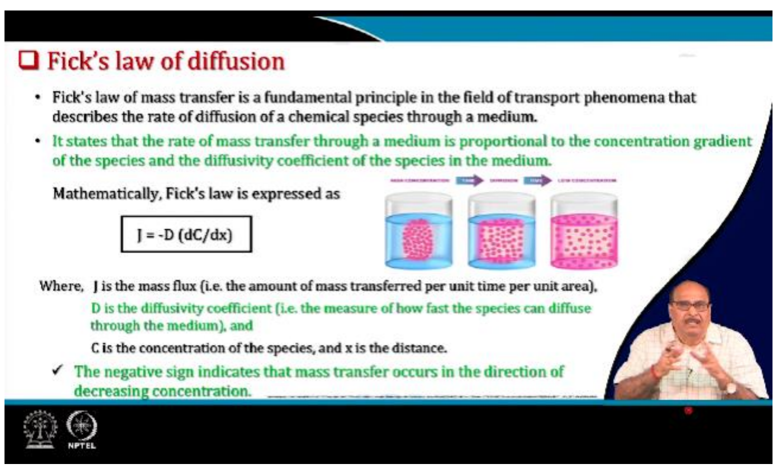


Liquid-solid operation refers to the transfer of solutes or particles between a liquid phase and a solid surface. Examples here include extraction, crystallization, liquid-liquid chromatography, emulsion formation and separation. Filtration involves the separation of solid particles from a liquid phase by passing the mixture through a porous medium. Wine exchange involves the transfer of one ions between the liquid phase and a solid phase.

Leaching involves the extraction of solutes from a solid phase by contacting it with the liquid phase. Adsorption involves the deposition of solutes from a liquid phase into a solid surface where they adhere by physical or chemical interactions. Precipitation involves the formation of a solid phase from a liquid phase by the addition of a precipitating agent.



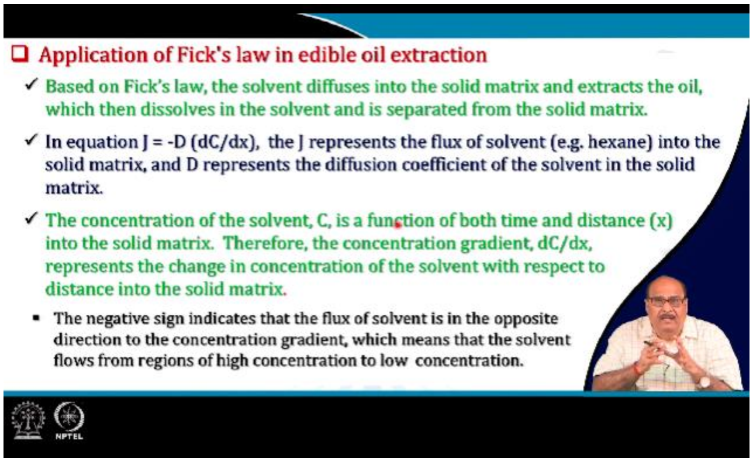
Solid-solid mass transfer operation refers to the transfer of solutes or particles between two solids. Examples of this include roasting, calcination, sintering and crystallization. Roasting involves the heating of a solid phase to convert it into another form. Calcination involves the heating of a solid phase to drive off volatile compounds. Sintering involves the heating of a solid phase to form a solid mass from a smaller particles. Crystallization refers to the formation of a crystalline solid form from a solution or a melt.



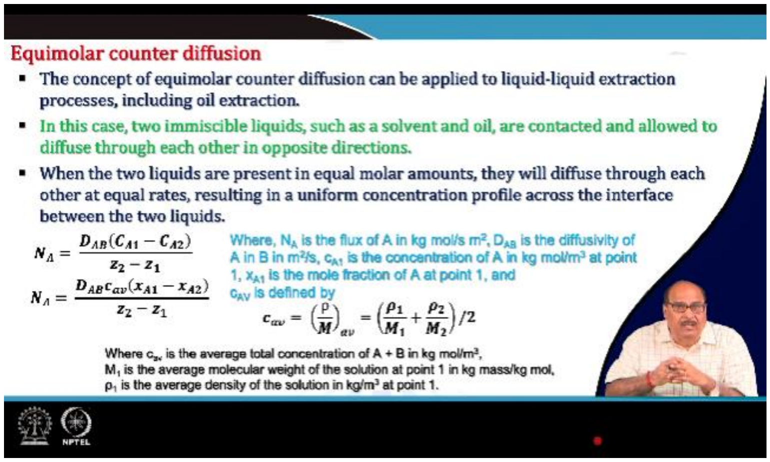
Now, after having understood these different processes, separation process or transfer processes, different phases etc, let us now consider Fick's law of diffusion because Fick's law of mass transfer is a fundamental principle in the field of transport phenomena that describes the rate of diffusion of a chemical species through a medium. It states that the rate of mass transfer through a medium is proportional to the concentration gradient of the species and the diffusivity coefficient of the species in the medium. In this figure it is shown that is a medium of where there are high concentration materials, sometime it diffuses into and finally, it may come to the low concentration material. So, from high concentration the material transferred is become low concentration. So, mathematically Fick's law is expressed as

$$J = -D\left(\frac{dC}{dx}\right)$$

where J is the mass flux that is the amount of mass transferred per unit time per unit area. D is the diffusivity coefficient that is the measure of how fast the species can diffuse through the medium and C is the concentration of the species and x is the distance. The negative sign in this figure indicates that the mass transfer occurs in the direction of decreasing concentration that is the high concentration is coming to a lower concentration.



So, let us see application of the Fick's law in edible oil extraction process. Based on Fick's law the solvent diffuses into the solid matrix and extracts the oil which then dissolves in the solvent and is separated from the solid matrix. In the equation J is equal to minus D multiplied by dC by dx, the J represents the flux of a solvent and in this case that is hexane into the solid matrix and the D represents the diffusion coefficient of the solvent in the solid matrix. The concentration of the solvent C is a function of both the time and distance x into the solid matrix. Therefore the concentration gradient dC by dx represents the change in concentration of the solvent with respect to distance into the solid matrix. The negative sign indicates that the flux of the solvent is in the opposite direction to the concentration gradient which means that the solvent flows from the regions of high concentration to the low concentrations.



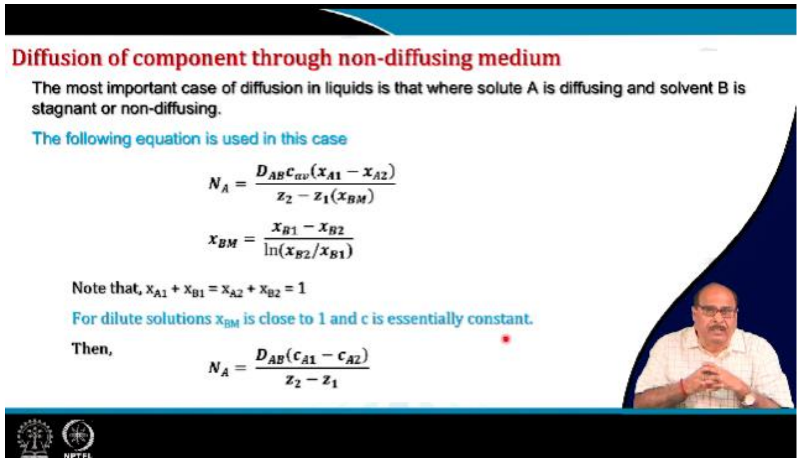
Then let us talk about equimolar counter diffusion. The concept of equimolar counter diffusion can be applied to liquid-liquid extraction processes including oil extraction. In this case two immiscible liquids such as solvent and the oil are contacted and allowed to diffuse through each other in opposite directions. When the two liquids are present in equimolar amounts, they will diffuse through each other at equal rates resulting in a uniform concentration profile across the interface between the two liquids. And this can be expressed mathematically

$$N_A = \frac{D_{AB}(C_{A1} - C_{A2})}{z_2 - z_1}$$

$$N_A = \frac{D_{AB}C_{av}(x_{A1} - x_{A2})}{z_2 - z_1}$$

$$c_{av} = \left(\frac{\rho}{M}\right)_{av} = \left(\frac{\rho_1}{M_1} + \frac{\rho_2}{M_2}\right)/2$$

Can you can see from this figure is the average of or average total concentration of A plus B in kg mole per cubic meter. M1 is the average molecular weight of the solution at point 1 in kg mass per kg mole, rho 1 is the average density of the solution in kg cubic meter at point 1.



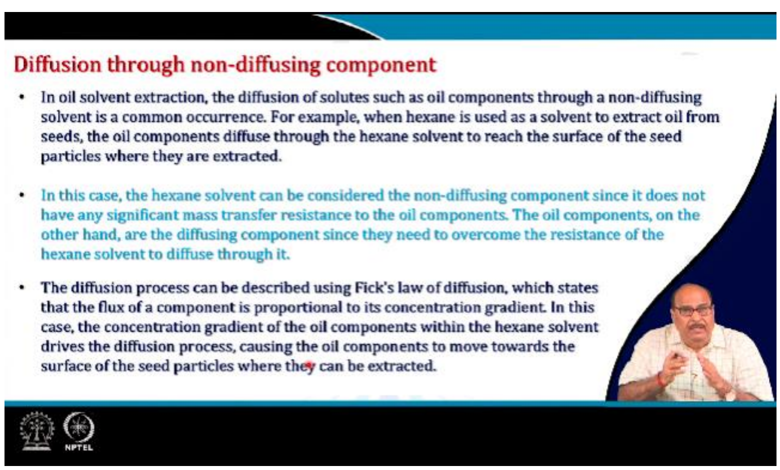
Now, let us discuss the diffusion of component through non diffusing medium, the diffusion of one component into another through a medium that is non diffusing. And the most important case of diffusion in liquid is that where solute A is diffusing and the solvent B is stagnant or non diffusing.

$$N_A = \frac{D_{AB}C_{av}(x_{A1} - x_{A2})}{(z_2 - z_1)x_{BM}}$$

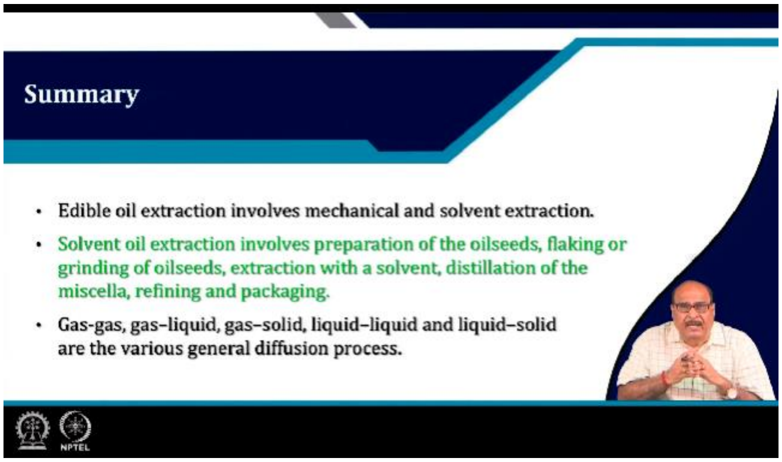
$$x_{BM} = \frac{(x_{B1} - x_{B2})}{ln(x_{B2}/x_{B1})}$$

Note that, $x_{A1} + x_{B1} + x_{B2} = 1$

$$N_A = \frac{D_{AB}(c_{A1} - c_{A2})}{(z_2 - z_1)}$$



In the diffusion through non diffusion component particularly if we see understand it in the case of solvent extraction process, the diffusion of solute such as oil components through a non diffusing solvent is a common occurrence. For example, when hexane is used as a solvent to extract oil from the seeds, the oil component diffuse through the hexane solvent to reach the surface of the seed particles where they are extracted. In this case the hexane solvent can be considered the non diffusing component since it does not have any significant mass transfer resistance to the oil components. The oil components on the other hand are the diffusing component since they need to overcome the resistance of the hexane solvent to diffuse through it. The diffusion process can be described using Fick's law of diffusion which is states that the flux of a component is proportional to its concentration gradient. And in this case the concentration gradient of the oil component within the hexane solvent drives the diffusion process causing the oil components to move towards the surface of the seed particles when they can where they can be extracted.



So, finally, I would like to summarize this lecture that as edible oil extraction involves the mechanical and solvent extraction steps. Solvent oil extraction involve the preparation of the oilseeds material, flaking, grinding of oilseed and extraction with a solvent distillation of the missile or refining and packaging. And this is a typical case of that is the mass transfer operation where the liquid solid extraction takes place. Even liquid-liquid extractions gas that is a even gas-solid, liquid-solid or liquid-solid are the various general diffusion process. But in this case of the solvent extraction process at least this in the case of extraction you can say it is the liquid solid or then finally, distillation of the missile where that is even that solvent is evaporated into the form of gases etc. So, this it is in order to have a proper process efficiency to control the process to have proper equipment design etcetera. It is essential to understand the mechanism of the extraction process and that we discussed in this lecture.

These are the references which is used in this preparing this lecture. This thank you very much for your consideration.