Lec 34: Adsorption: Principle and Applications

Hello everybody welcome to this massive open online course on solid fluid operations. So, as we have already discussed different modules on this specially for particle characteristics, size reduction, size enlargement, fluid flow through the solid beds, even particulate materials, their flow through the bed and also how to separate those particles and also we hire discussing about the solid particles by membrane process. There are different types of membranes that we have discussed and also we have discussed that what are the nanoparticles and their characteristics and how that nanoparticles can be synthesized. So, in the last module of this course is basically adsorption. Here in this adsorption module, we will try to discuss about what is the principle of adsorption, what is the application of adsorption and what are the analysis method of that adsorption process, what are the adsorption equilibrium, how that equilibrium can be utilized to assess that adsorption isotherms and also we will be discussing about the kinetics of that adsorption and what are the different kinetic equation even models to assess that adsorption we will be discussing in this module. Today we will try to discuss about that what is the basic principle and also what is the application of that adsorption.

Before coming to that point, the general term for separation of particles or separation of gaseous molecules or separation of some other compounds or ions that actually being done on a certain solid surface. So, that general process of that separation of that molecules from the other streams on to a surface of solid that will be called as adsorption process. So, the adsorption is basically an operation or you can say process in which a certain components in a mixer are selectively transferred to insoluble materials that is suspended or packed in a column or in a suppose in a bed. Now in this case, the terms of the adsorption is basically the common terms.

Now you will see that some will be adsorption means here absorption or maybe adsorption both terms may be coming. So, here one is that called adsorption another is called absorption. Adsorption means AD, adsorption means that gas or liquid molecules to be you know transported from the gaseous medium or liquid medium to the solid surfaces. So, this is called adsorption AD whereas absorption AB in that case it is generally considered that when gaseous molecules to be transported from gaseous stream to the liquid streams that is called absorption AB. So, that is why this absorption basically consists of these two terms that is called absorption and adsorption.

Now in term in case of adsorption that is AD where that gaseous molecule or liquid molecules to be transported to that solid surface that is called adsorption AD. That adsorption may be of different types maybe sometimes you say that it is called ion exchange sometimes it is called chromatography and simply adsorption also. So, they are all the terms basically in the same that principle of that transporting that gaseous molecule or liquid molecule to the solid surface. So, that is called adsorption. Sometimes ion exchange also to be called as an adsorption because here in this case ion will be transported from the one stream to the solid stream.

So, that is called ion exchange. Chromatography itself also it is one method or process you can say by which you analyze what are the molecules how much molecules quantitative or qualitative analysis of that molecules in a particular streams that can be assessed by this chromatography. This is basically by transporting that molecules to a surface of the solid. So, this is called chromatography. So, these are all actually under that adsorption common term absorption process.

So, in this case if we consider that adsorption process you will see in the slide it is shown that there will be two terms one will be called solute or sorbates and another term is called sorbent. Solute or sorbates is basically the components that are selectively transferred are known as solutes and in this case the sorbed solutes would be called as a sorbates. Whereas, sorbent is basically a solid surface on which that sorbates or you can say that solute to be transported. That means the materials that is used for sorbing the solutes are known as sorbents. So, which materials to be used to adsorb or taking or attaching those materials on the surface of that material.

So, it is called sorbent. So, there are two terms basically one is called solute another is called sorbent or can say other terms sorbates which is called a solute also. Now, what are the application of that adsorption? There will be some industrial application of this adsorption. Some application will be as gas purification some will be as liquid purification. Gas purification basically coming as that sometimes you need to remove some organics from the vent streams of gaseous that is effluent and also sometimes you need to remove all of sulphur dioxide from vent streams.

You need to remove all of sulphur compounds from gas streams. You need to water vapour removal from air or other gaseous streams. Also, you need to remove of solvents and odours from air or sometimes you need to remove that NOx from that air stream or carbon dioxide can be removed from the natural gas or some other bulk gas separation into its different components can be done by this adsorption process. You see sometimes acetone and vent streams there acetone to be separated where a mixture of ethylene and vent streams they are so that ethylene to be adsorb or separated by this adsorption process. Normal paraffin or isoparaffin mixture where you have to separate that normal paraffin from that mixture of normal and isoparaffin also other aromatics.

So, these are some important applications which are industrially done by this adsorption process and then coming to that liquid purification there you will see sometimes moisture or water that is to be separated from the organic solutions. So, there adsorption process can be used. Even some organic compounds that is also to be removed from the water stream there also this adsorption process can be used. Even some other application like removal of sulphur compounds from organic solutions, decalorization of solutions, liquid bulk separation, normal paraffins, isoperapines mixture where you can separate the normal paraffins as a liquid from that mixture. Even paraxylene or mixture of this paraxylene with

other aromatics that you can separate those paraxylene or other aromatics just by adsorption process.

Even you can separate some fructose dextrose mixture from which you can separate fructose or dextrose separately by this adsorption process. So, these are some also important application for that liquid purification by this adsorption process. Other applications for that ion exchange and chromatography those are also adsorption process. So, in this case sometimes for water softening, water demineralization, even decalorization of the sugar solutions, recovery of uranium from acidless solutions, even recovery of antibiotics and vitamins from the fermentation broth that you can do it by this ion exchange method. We will discuss about that ion exchange later on.

And also chromatography is basically used in food industries to separate and analyze additives. Is there any additives in the food contents or not that can be analyzed by this chromatography method. Even vitamins, what is the amount of vitamins in a particular that plant or plant or other organic sources there. So, that can be analyzed by this chromatography method and also some preservatives that you have to analyze that is actually used in food as ingredients there. And also you will see that some amino acids also that is mixed in the food materials for increase or enhance that protein contents there in the food.

So, what will be that amino acids that can be also assessed by this chromatography. In paper chromatography you will see that it is used as a purification and separation of different organic compounds from the mixture. So, these are some industrial applications of ion exchange and chromatography. Then coming to the point that here some suitability criteria of the absorbent for industrial applications. In which cases or what will be the basic criteria based on which you can select this adsorption process or ion exchange or chromatography process that you have to know.

This is basically depends on that some material characteristics of that adsorbents even what molecules to be adsorbed that molecule characteristics also will be you know effect on that selectivity of that adsorption process. Also you will see that to you know minimize that absorbent utilization sometimes that the capacity of that materials to be considered for that selection process and also sometimes you will see that some hardness or mechanical strength of materials which are being used for adsorbing those gaseous or liquid molecules that you have to assess. And also sometimes some materials that you have to select for adsorption that should be easily regenerable means once it is used for adsorption and after adsorption process complete then you have to reactivate that material so that you can use reuse that material again that means for further operation. So, that materials should not be wastage in the operation. So, in that case capacity of that solid materials to be known whether it will be that easily regenerable or not.

Also sometimes that you have to consider that basic understanding of transport processes

of compounds from the gaseous streams or from the liquid streams to the solid surface or through that pores of that solid surface there. So, you have to understand transport process, mass transfer processes even sometimes heat transfer processes of materials that assess what extent of that adsorption can be done based on that capacity of adsorption or that mass transfer capacity of that material or heat transfer capacity of material. Sometimes after adsorbing those materials by adsorbent or solid materials you will see that there will be some resistance to be generating after continuous adsorption of that solid surface. So, those materials whenever it will be adsorbed on the solid surface they will make some fouling or deposition as a layer that sometimes will resist that further adsorption of the molecules. So, that is why fouling or that resistivity of that materials by depositing those adsorbed material on the surface that also to be assessed.

Also, you will see that you have to choose that low cost adsorbent or that you can you get high proficiency of that materials adsorption by this low cost materials that will be more economic. Also, you will see that whether these materials to be thermally stable or not or chemically stable or not whether that some corrosion materials will happen just after adsorption of chemical compounds or gaseous compounds on the surface of it or not. So, that also you have to know stability that means here that how long that materials can be adsorbed those materials after adsorption also whether that can be easily reasonable or not just by supplying heat or heating that materials and based on that heating of material whether that materials will be enough hard or enough strength to resist that temperature or not. So, temporarily temperature strength that is to be also assessed. Also, you will see that some materials to be used that that easily can gets at us those that adsorbate molecules on the surface.

So, in that case sometimes that surface area of the adsorbent to be known also you will see that sometimes some adsorbents per unit gram that more surface area will be creating in that case more adsorption will be there. So, based on surface area available surface area of that solid material some materials after synthesis or adsorbent you will see that that may be from the natural source or from other chemicals or composite materials you will see that adsorbent after synthesis that may give some specific surface area that a specific surface area means what will be the surface per unit gram of that material. So, for different materials the specific surface area will be different. So, in that case those materials will be giving more surface area per unit gram that can be used for adsorbent. Of course, that parallelly you have to judge whether those materials have enough capability of adsorbing other organic or gaseous materials on the surface or not that also to be considered and also sometimes you will see that during that adsorption there will be some chemical reactions will happen with the adsorbed molecules with that adsorbent molecules.

In that case that chemical adsorption to be considered in what will be the adsorption capability and based on that reaction whether that desorption capability will be enough or not that also to be assessed after reaction. So, in this case we have discussed that what will be the application what is the basic mechanism and also what is that different application

for ion exchange chromatography even also what are the different points to be considered for that adsorption materials. Now, let us discuss about that adsorption more reliable at here. In this case, adsorption can be simply defined as we can say the process based on which the concentration of a solute which may be molecules in a gaseous stream or a dissolved or suspended substance in a liquid stream that will be attached on the surface of a solid by diffusion. So, basically the adsorption is a process where based on the concentration gradient the solute will be transported from the gaseous or liquid stream to the solid surface of that adsorbent or dissolved on that substance in the liquid stream to the surface of the solid by diffusion.

So, this is the basic definition of the adsorption process. Here in this case molecules or atoms or ions in a gas or liquid that will diffuse to the surface of a solid where they bond with the solid surface or are held there weak intermolecular forces. So, whenever that particles will be transported from the gas stream or solid stream sorry liquid stream you will see that during attachment of surface of solid that is adsorbent during that adsorption that molecules or atoms or ions that will be transporting to that solid surface and to be held there onto the surface of the solid just by intermolecular forces. So, this is that you have to remember here in this picture it is shown that adsorbed solute is coming here as yellow color object here it is coming on the surface of the solid here and it is being attached by the intermolecular force. So, on which material it will be adsorbed or attached it will be called as adsorbent whereas those molecules which will be coming onto the surface of these molecules and attached of the surface that will be called as adsorbed solute and you will see that some materials that is adsorbent sometimes it will have some force that means there will be a gap between that inside solid materials.

So, in that gap also that molecules adsorbed solute will be transporting and they will get the adsorbed on the surface of adsorbent. So, here we can have this mechanism of this adsorption by just how intermolecular force will be acting on solute to get adsorbed on the solid surface. Also, you will see that to achieve a very large surface area for adsorption per unit volume highly porous solid adsorbents with a small diameter interconnected force are used there and the porous structure of that material you will say that can account for up to 50% of the volume of the material and also you will see that at the time of that adsorption the solid adsorbent will become saturated and that adsorption will be continued till its saturation will be there. That means the solid materials will come to an equilibrium condition where there will be no further adsorption of the molecules on the surface of the solid.

So, that is called saturation. So, during that adsorption the solid adsorbent becomes saturated or nearly saturated with the adsorbent. And now to recover the adsorbent and allow the adsorbent to be reused it is to be regenerated by desorbing the adsorbed substances. So, parallely both the things to be considered here that you have to first adsorbed the molecule or solute on the surface of the adsorbent and to reuse that adsorbent to be regenerated just by desorbing those materials for its reuse. So, this is called

that desorption. So, adsorption and desorption both will be parallely will be there in a certain operation.

So, here in this picture it is shown that in a adsorber in a column where some adsorbent bed will be there in that bed maybe you will see that carbon or molecular sieve here it is shown in the picture. And in this molecular sieve you will see that some biogas which contains methane nitrogen oxygen moisture hydrogen sulfide or carbon dioxide all those components there you will see that at a certain pressure and temperature this components can be separated from this biogas whereas at a certain pressure methane gas to be separated from the mixture of other components here like nitrogen oxygen moisture hydrogen sulfide and carbon dioxide. So, here in this picture it is shown that how mixture of that gas is allowed to pass to that adsorber and then it can be separated by this adsorbent like here carbon molecular sieve here which is actually being used to adsorb that nitrogen oxygen or moisture hydrogen sulfide or carbon dioxide molecule on that adsorbent whereas methane molecule will not be adsorbed by this adsorbent that will be separated from that column. And after this adsorption you can regenerate this carbon or molecular sieve just by heating it because if you change the temperature you will see that those adsorbed molecules will be dissolved from that adsorbent material. So, removal of adsorbents can be achieved by changing the pressure or the temperature itself.

So, if you are doing adsorption based on that pressure change that will be called pressure swing adsorption. If you do the adsorption or desorption based on that temperature you know application that will be called as temperature swing adsorption or desorption. So, based on which you will get these two types of adsorption or desorption. Now, what is the mechanism of that adsorption? Here as shown in the picture that we have already discussed here the molecules that is present in the interior of that adsorbent are completely surrounded by other molecules on all sides of the materials and then there will be an intermolecular force that will be act on that molecules by which that molecules will be attached to the surface of the solid. So, a molecule at the surface is surrounded by large number of molecules which will be intact by that intermolecular forces.

And because the unbalanced inward forces of attraction on that surface of adsorbent they have the property to attract and retain the molecules of a gas or solute on their surfaces. So, here you will see that in the solid surface adsorption of gaseous molecules happen and these molecules are attached by intermolecular forces and is being adsorbed after that by temperature or pressure it can be desorbed and it can be separated here. Here also in the animation it is shown that here these some molecules are being adsorbed on the solid surface that is called adsorbent and then that it will be attached on the surface by that intermolecular forces. And before coming to that there will be a transport of that molecules in the bulk phases and after that it will be coming and get in contact with that solid surfaces and intermolecular force will be acting on that molecule and it will be adsorbed on the surface. Now in this case you have to remember some important point here.

Here adsorption always will be an exothermic process and during adsorption process the residual force on the surface of the adsorbent decreases it means surface energy will decrease. This decrease in the form of heat is called that heat of adsorption and heat of adsorption is defined as the amount of heat that is evolved when one mole of any gas is adsorbed on a solid adsorbent surface which is called as heat of adsorption or sometimes it will be called as enthalpy of adsorption. So this is basically that what is the heat is required okay or heat is evolved when one mole of any gas is adsorbed or desorbed on or from a solid surfaces that will be called as heat of adsorption or enthalpy of adsorption or you can say that enthalpy or heat of desorption like this. And this enthalpy that is adsorption enthalpy delta S is always to be negative. So these are some important notes that you have to remember.

And then major types of adsorbents that also you have to know what are the different types of adsorbents are being used for separation of different gaseous or liquid molecules from their streams. So what are those adsorbents you will see that some major type of adsorbents are given here in the slide. Here activated alumina, silica gel, activated carbon molecular, ship carbon, molecular ship zeolites, clay, even polymer and resins. These are widely used adsorbent for the separation of different gaseous and liquid molecules onto the surface of this adsorbent. And this material will have some characteristics such as what is its porosity, what is its pore structure, even what is the nature of its adsorbing services.

And also you will see that what is the pore sizes, how it can be classified, what are the different types of pore sizes will be there. Maybe there are different ranges of pores will be there. some will be macro pores, some will be mesopores, some will be micro pores also. So macro pores adsorbent sometimes you will see that diameters will be in excess of 50 nanometer. Mesopores it will be diameters in the range of 2 to 50 nanometer.

Even diameter in smaller than 2 nanometer it will be called as micro pores like this. So these are different types of adsorbents with their basic characteristics of that solid and their porosity pore structure will be different. So and what are those major types of adsorbents are used for that you separation of those molecules. I think you can understand now in the slides it is given. So try to remember those major types of adsorbents.

And typical applications of that know adsorbents one by one let us have some typical application of adsorbent. If you are considering that activated alumina, this activated alumina actually basically used for drying of gases, refrigerants, organic solvents, even transfer of oils like this. Even this activated alumina is basically used for desiccant in packing sand double glazing like that. Even dew point control of natural gas can be done by this activated alumina. Silica gel is basically used for drying of gases, organic mesh solvents, transformation of oils, also removal of hydrochloric acid from the hydrogen.

Even you will see that hydrochloric hydrogen chloride gas from the hydrogen and hydrogen chloride gas mixture, removal of fluorine in alkylation process. So basically this silica gel are

being used for those purposes. Even will see some typical applications of the commercial adsorbents for activated carbon and molecular ship carbon. These are two types of carbons are generally used for water purification, nitrogen separation from the air, hydrogen separation from the syngas, even ethane from methane and hydrogen gas, even purification of helium, removal of shocks and NOx, even recovery of solvent vapors by this activated carbon and molecular ship carbons, removal of odours from gaseous streams, even separation of vinyl chloride monomer from the air. So all those operations are being done by this activated carbon and molecular ship carbon.

Some other typical applications of adsorbent like this molecular ship zeolites. This is one of the important adsorbent which are widely used for different applications. This is basically used for oxygen separation from air, drying of gases, removing water from the azeotrops, even sweetening sour gases and liquid separation, also purification of hydrogen, separation of ammonia and hydrogen gas, even recovery of carbon dioxide, separation of oxygen and argon from the mixture of air with other streams, even removal of acetylene, propane and butane from the air, separation of xylene and ethyl benzene from the mixture. Even you will see that separation of olefins and aromatics from the paraffins. Other applications like if you want to that control of mercury and NOx and shocks from the air that you can use this molecular ship zeolites.

So these are some applications given for the application of this molecular ship zeolites. Sometimes you will see that some polymers, even resins, some that biomaterials also are to be used for adsorbent or as a adsorbent for separation of different gaseous and liquid molecules. In that case polymers and resins are generally used for you will see that water purification, especially for arsenic removal, even some colour removal from that water, dye removal from the water, even you will see that sometimes the odour removal from that water that can be used by this resins. Even also you will see that removal of organics from the hydrogen peroxide, purification of steroids, amino acids from the mixture, even recovery of proteins, enzymes by this polymers or resins can be done, separation of aromatics from the aliphatic compounds, those also are being used for those separation of that aromatics from the aliphatic compound mixture and also separation of fatty acids from the water and toluene that also used for this purpose. So this polymer and resins are being used in the different purposes as shown in the slide here.

Sometimes clay are also being used for separation or treatment of edible oils, that removal of organic pigments, refining of mineral soils, removal of polychlorinated sometimes biphenyls, those are used for this application. Now there are two types of absorption you will see, one will be physical another will be called chemical absorption. Physical adsorption where you will see that van der Waal adsorption it will be sometimes called, there this van der Waal intermolecular force to be applied for there and in this case the individually of that adsorbent and the adsorbent are preserved there and in this case the adsorption occurs when the intermolecular attractive forces between molecules of that solid adsorbent and the gas are greater than those between molecules of the gas itself. So

this is the main important point here for this physical adsorption process. In this case intermolecular attractive forces of course will be greater than that molecules which are going to be adsorbed on the surface, what is intermolecular forces.

So that should be that intermolecular attractive forces of that molecules of solid adsorbent will be greater than those between molecules of the gas itself and in this case this adsorption basically occurs quickly through mono or multi-molecular layer thickness of that adsorbent surfaces and you will see that chemi-absorption that is activated adsorption it is called. So this physical adsorption and chemi-absorption we can say that classification that will be depending on the type of forces between the adsorbent and adsorbent. In case of chemi-absorption you will see that there is a transfer of or you can say sharing of electron or breakage of the adsorbent into atoms or radicals which are bound separately and chemi-absorption that will be occurs just by formation of chemical bonds between the adsorbate and adsorbent. So this is the basic difference here. Here that bonds will be formed by that adsorbate and adsorbent.

Whereas physical absorption there will be a breakage of that intermolecular force between that solid surface of that adsorbent with the molecule or forces of gaseous or liquid molecule itself there. And chemi-absorption from a gas generally takes place only at temperature greater than 200 degree Celsius and maybe slow and irreversible. Whereas physical absorption is very fast that will be through that mono or multi molecular layer. So these are basic differences of that physical absorption, physical adsorption and chemi-absorption based on that type of forces between the adsorbent and adsorbent action. And also some other points physical and chemi-absorption that you have to remember.

In this case that the heat of physical adsorption is in the same order of magnitude as the heat of condensation. Whereas you will see that heat of chemi-absorption is of the same order as of the corresponding. And physical adsorption will occur under suitable temperature pressure conditions in any gas solid system. Whereas chemi-absorption takes place only if the gas is capable of forming a chemical bond with the surface. Also you will see that in a physically adsorbed molecules can be removed unchanged at a reduced pressure at the same temperature.

Whereas in case of chemi-absorption the removal of the chemisorbed layer is far more difficult. In case of physical adsorption can involve the formation of multi molecular layers whereas chemisorption is always completed by the formation of a monolayer. And in case of physical adsorption is instantaneous although the diffusion into the porous adsorbent may be time consuming but it will be faster. Whereas that in case of chemisorption it may be instantaneous generally requires activation energy for the separation. And also you will see that some factors that will be affecting on that adsorption that effect may be nature of the adsorbent and adsorbent that depends on that.

That effect may be based on the surface area of the adsorbent that effect may be based on the temperature that effect may be based on the pressure. In case of that adsorption based on that effect of nature of you know adsorbent and adsorbent we can say that the amount of the gas that will be adsorbed that will be depending upon the nature of the adsorbent and the gas which is to be adsorbed. So that means nature what type of materials are there that is also important. And also the surface area means here larger the surface area will give you that extent of adsorption that means more adsorption will be there for that larger surface area under a given condition of temperature and pressure. And according to law Sotelier's principles you will see that the decrease in temperature sometimes would increase the adsorption and vice versa.

And also the magnitude of adsorption increases with the increasing pressure and vice versa. So these are some factors that will affect on adsorption. In this case you have to note that the adsorption usually takes place with the evolution of heat that is exothermic process and also adsorption of a gas is followed by a decrease in volume. And for the adsorption you need to have some idea what are the equipment generally being used for that adsorption. You will see in the market there are different types of equipments available for adsorption process to be executed.

In that case you will see some will be steer tank absorber, fixed bed adsorption, some will be moving bed absorber, some will be desorber and regenerator as an equipment there. So here in this picture some moving bed absorber here, some solid particles would be moving stage wise or in a column or in a that in a stage wise during that movement of the solid materials they will come in contact with the gaseous or liquid molecules and adsorb those molecules and also it will be passing through that desorber system where that adsorbed molecules to be again detaching from their surfaces by a certain temperature or pressure effect. And so also you will see that some adsorber will be fluidized system in that case solid particles would be fluidizing by the flow of gas that is inert gas maybe will be there where that solid particles during that fluidization you will see that will be come in contact with gaseous or liquid molecules in the fluidized bed and then it will be adsorbed those molecules from the stream. And in this case the advantage is that they are getting more mixed inside the fluidized bed and also mass transfer and heat transfer characteristics will be higher compared to the other system there. And also in the star stir tank reactor will see that there are also that some mechanical provisions to be given there to stir that solid liquid or gas especially for slurry systems there you will see that filtration systems or you can say that adsorbent of liquid molecule on the surface of solid surface in the slurry how that can be adsorbed by adsorbent as a solid material there and these solid materials actually mixed with the liquid and it will be made at a slurry and it will be continuously stirred in the stir tank reactor and then after a certain time with respect to time solid particles will be adsorbed on the adsorbent.

And then coming to here it is shown here that stir tank slurry adsorption in this case you will see that a base of liquid will be added to a powdered adsorbent such as activated

carbon in an agitated vessel to form a slurry. The main application is for the removal of very small amounts of dissolved and relatively large molecules such as coloring agents from water and in this case you will see that the required residence time of the operation is mainly determined by how fast equilibrium will be approached. Here residence time required means how long that particles will become in contact with liquid in the tank itself. So that will be required more so that more adsorption efficiency will be there. Generally the spent adsorbent is removed from the slurry by filtration or sedimentation and is discarded there.

So whatever adsorbent will be spent for that adsorption that will be removed from the slurry by filtration process. That filtration we have already discussed earlier so based on that filtration process you can separate those solid materials from the slurry. For large-scale operation multiple base or cross flow or counter current mode can be used here. So here as shown in the picture that multiple base even a counter current mode of this operation is shown here. Then fixed bed absorber here you will see that the adsorption is done in this case a cyclic base operated fixed bed here as shown in the picture.

It is an unsteady state rate controlled process specially it is wise to use for separation of gas and liquid molecules especially for removal of dissolved organic compounds from the water and also adsorption occurs in this case in a particular region of the bed that is called mass transfer zone where you will see that not in that particular zone of this adsorption and this bed generally that up to which region that packing materials will be there and initially that it will take some time to adsorbed on that surface and then it will take and after a certain time it will be increased rate of adsorption and then getting saturation and after saturation there will be no adsorption process there. So there will be certain mass transfer zone in this case and based on which efficiency of the adsorption process can be assessed. So here in the picture it is shown that you will see that two columns are there in one column there will be a mixture of some maybe that components of different types of liquid molecules some molecules will be adsorbed on the solid surface here in a bed some solid surface is there or solid materials it is as it is used as a adsorbent. So this adsorbent will be used and from the feed solution that adsorbent will adsorb that where molecules which is to be adsorbed and then it will be taken out that other unseparated molecules from the bottom where after completion of one base of this adsorbent for this adsorption process those are to be transported to the other column that is called desorption column that is also fixed bed here the solid materials will not be moving that is called fixed bed.

So this fixed bed will be used to again desorb those adsorb molecules there. So in this case by this combination of adsorption and desorption process you will see that mixture of light hydrocarbon with that heavy hydrocarbons can be separated by this adsorption process and in this case that you have to remember some factors that may be considered for that design of this fixed bed adsorber or desorber there. In this case some arrangement to be considered whether that total feed flow rate or allowable pressure drop or energy demands length of the MTZ that means mass transfer zone will be economically designed or not that

also to be considered here. So in this case we can say that the factors which determine the number and the arrangement of fixed beds that will include the total feed flow rate allowable pressure drop energy demands even length of that mass transfer zone and also what are the methods of that generation of adsorb material or adsorbent you can say and also what will the capital investment required for this adsorption process and here desorption or regeneration of the adsorbents what is the mechanism for that you will see that adsorbent principles have finite capacity of that fluid phase molecules whereas you will see that an extended contact with the fluid actually from which that components to be separated will ultimately lead to a creation of a thermodynamic equilibrium between the solid adsorbent and the fluid phases and at this equilibrium condition you will see that the rates of adsorption and desorptions will be equal and the net loading on the solid cannot increase further. Therefore, sometimes it will be required to regenerate that adsorbent or to dispose of it for its further use and also that practical methods of desorption and regeneration include like include some important criteria or important points or important you can say that factor that is to be considered like if suppose temperature increase then what will happen if reduce the partial pressure what will happen even concentration if you reduce what will happen and purging with an inlet inert fluid or other change of chemical conditions if you change then what will be the effect on that desorption process.

So, that is to be considered. So, here you will see that desorption and regeneration include one or more usually combination of the following like this increase in temperature, reduction in partial pressure, reduction in concentration, purging with an inert fluid, even change of chemical conditions, displacement with a more strongly absorbing species like this. So, the final choice of regeneration methods depends on technical and economic consideration. Now, different types of fixed bed adsorption process also there you will see that some will be based on that pressure some will be based on the temperature some will be based on that is there any inert gas can be passed for that regeneration process sometimes vacuum to be produced to enhance that adsorption sometimes that displacement parts adsorption process to be followed other adsorption cycle example like electro adsorption also there. So, there are different types of fixed bed adsorption process here it will be called as pressure swing adsorption, temperature swing adsorption, inert purge swing adsorption or regeneration, vacuum swing adsorption, even displacement purge adsorption and other adsorption cycle like electro adsorption. Pressure swing adsorption what is that basically in this case you will see that this adsorption will be taking place at an elevated pressure.

Whereas, desorption occurs at neat ambient pressure also you will see that some specific adsorbent materials like zeolite, activated carbon molecular, sheaves etcetera are used as a trap preferentially that adsorbing the target gas molecules or liquid molecules at a high pressure and in this case the process after adsorption it will be swing to a low pressure operation that is called desorption operation. So, desorption operation will be carried out after that adsorption burst just by lowering the pressure. So, that is why it is called pressure swing adsorption. So, this pressure swing adsorption process can be used to

separate that gases in a mixer because different gases tend to be attracted to different solid surfaces more or less strongly based on that pressure. You will see that under high pressure some gaseous components tend to be attracted to the solid surfaces and hence it is adsorbed.

Whereas, other components will not be attracted to the solid surfaces at that high pressure. So, in that case the high pressure will enhance that adsorption process. So, under this pressure an adsorbent bed of zeolite will attract the suppose nitrogen more strongly than oxygen. This is one example. Suppose there is a mixture of nitrogen and oxygen you will see that at high pressure you will see that zeolites will attract nitrogen compared to oxygen more strongly.

So, this is your pressure swing adsorption and then temperature swing adsorption you will see that for any given partial pressure of the adsorbate in the gas phase you will see that an increase in temperature leads to a decrease in the affinity to or get it detached. That means in the quantity dissolved there. So, in this case you will see that if the partial pressure remains constant at suppose certain pressure P1 and increasing that temperature from T1 to T2 you will see that this will decrease the equilibrium loading from some quantity Q1 to Q2. That means if you increase the temperature there you will see that adsorption capability will be decreasing. So, based on that temperature differences and based on that capability of adsorption based on this temperature the operation will be executed in such a way that after adsorption the temperature to be immediately increased so that at low pressure you can get higher adsorption or for the desorption if decrease the temperature what will happen there you will see that quantity of adsorption will be more there.

So, in this direction the changing of temperature they are that adsorption and desorption to be executed. So, here you will see that an efficient temperature swing adsorption process for separating carbon dioxide from carbon dioxide nitrogen mixer that can be adsorbed by magnesium even you will see that MOF74 system as an adsorbent. So, here you will see that temperature swing adsorption that will be based on that temperature change and you can get that different adsorption and desorption process based on that different type of different capability of that adsorbent molecule based on that temperature. Several commercial applications of the XOR-X process exist as shown in the table here like some process it will be called as molex, olex, parex, evex and cerax.

Molex means here separation of linear or branched paraffins. In this case some zeolite will be used that will be 5A zeolite it is called aluminosilicate crystal with average force measuring 5 angstrom its size and it can be generated by regenerated by some temperature for this light naphtha separation. And then olex process which is basically that separation of polyphenols from the saturated isomers by CaX adsorbent that is called calcium exchanged zeolite. X is here basically exchanged. Parex generally it is used for that parazylene separation from the C8 aromatics mixer there and it is also being done by strontium barium yttrium conjugates where that potassium barium exchange zeolite also

can be used for this separation as an adsorbent here. And in this case also that para diethyl benzene can be regenerated after this adsorption process.

And evex process generally ethyl benzene from that C8 aromatics adsorbent basically sodium yttrium complex can be used. In this case after separation that regeneration of toluene can be there as a separate molecules and also CEREX they are generally fructose separation from fructose glucose mixer and here also calcium yttrium complex can be used there for separation. Other processes like arosorb, aromax even adsep process like this where arosorb basically the separation of aromatics and saturates from the cracked naphtha. Aromax is basically parazylene from C8 aromatics, adsep basically fructose from fructose glucose mixer and in this case you will see that some silica gel even exchanged zeolite even some resins also can be used respectively. Then coming to that moving bed adsorption and desorption process you will see that some advantage of moving bed processes for the adsorption is that the adsorbent can be regenerated as soon as it its role in the adsorption step has been completed.

And in this case additionally heat transfer in the moving and fluidized bed system will be there and it will give you the better result compared to the fixed bed. And also various types of moving bed systems are available for this adsorption process like simulated moving bed system, fluidized bed system, pulse bed system and rotating bed system. These are the different adsorption, desorption system in this moving condition. Fluidized bed adsorber here one of the important advantage of this fluidized bed adsorber is that that solid particles are being fluidized either by trays wise or continuous way to get that more mixing and also more contact between solute and adsorbent. So, the fluidized bed here in this type of fluidized bed you will see that it is called tray wise fluidized bed and also conjugated or hybrid system with that adsorption system.

So, the fluidized bed here in this case consists of two sections one will be adsorption section and another will be desorption section as shown in the picture here. And the adsorption section shift trays are used with the raw gas that is passing up as given the direction here through the shifts of the tray and thus fluidizing the solid adsorbents particles. And from the adsorption section the solid pass to the desorption section and then solids flow down to the preheating tubes here as shown in the picture and stream is used for indirect heating in both the sets of tubes of that adsorption and desorption systems. At the bottom of that unit you will see that the regenerated solids are to be picked up by a carrier gas and which flows upward through a gas lift line which is placed in the center line of this fluidized bed. At the top that solid particles that means adsorbent you can say that it will be settled out after getting that regeneration mode and it will be settled out onto the top tray again to repeat that adsorption process in this fluidized bed.

So, it will be a cycle wise that will it will be there that in the adsorption section that will be adsorption process or desorption section that solids will be regenerated and that solids will be again used to that gas lifting line and then it will be again falling downward to tray wise.

So, this is the fluidized bed adsorber one typical arrangement or typical procurement of this fluidized bed adsorber. Sometimes without tray also can be used for that gas stream component separation by this adsorption process by some suitable adsorbent. Then rotating bed adsorber here you will see that in this picture it is shown that there will be some provisions of that packing bed where this packing bed will be rotating at a certain flow rate and some gas inlet with that gaseous pollutants to be passed through that rotating packed bed and also the liquid also will be passed through that bed where that liquid in the liquid medium that gaseous molecules can be adsorbed just by passing through that solid bed. So, there will be a void fraction through which that liquid will be passing through at that rotation and the gaseous molecules will be adsorbed onto the surface of the adsorbent or it can be adsorbed on the liquid itself also.

So, polluted air from the manufacturing process large airflow you can say passes through the process zone while the packing rotor turns. Here this is the packing rotor it will be turns and in this case volatile organic compounds that will be carried in this air that will be flowed that will be adsorbed by the rotors. Geolite materials here this is the packing material it will be as a zeolite material and then purified air it will be returned to the purified air to be returned to the atmosphere by this duct. So, in this case gas is coming here in this chamber with volatile component mixture and it will be come in contact with that geolite material and this geolite material with the liquid it will be getting contact immense contact with zeolite materials with gaseous inlets and also liquid and then that volatile components will be come in contact to get more contact that zeolite here and from that zeolite that liquid volatile components will be transferred to that liquid and then it will be taken out from that liquid outlet. So, in this way we can say that rotating bed adsorber can be used and then coming to that ion exchange here in this picture also it is shown that an ion from a solution is to be exchanged for a similarly charged ion attached to an immobile solid particle till it become saturated.

Here the immobile solid materials may be some adsorbent that may be some cationic in nature some will be an ionic in nature. So, ion from the solution which is to be exchanged by this solid materials here in this case one example it is given the ions of you will see that calcium ions which will be exchanged by sodium ion from the solution calcium ion which is conjugated in this adsorbent that is called solid surfaces and this then cationic or calcium ion it will be exchanged by the sodium ion from the solution here. So, the solid ion exchange particles are either necessarily occurring inorganic zeolites or synthetically produced organic resins. So, you can use different types of materials here as a cation or an ionic material as an adsorbent here.

So, here you can see that how that sodium ion is being exchanged by this calcium ion here. So, this is basically ion exchange process. So, classification of ion exchange resins here two types of ion exchange will be there one will be called cation exchanger another will be called anion exchanger. You will see that in cation exchanger it has positively charged mobile ions that will be available for exchange whereas anion exchanger it will have some

exchangeable ions which are negatively charged. Both the anion and cations resins in this case suppose as an example are produced from the same basic organic polymers they differ in ionizable group attached to the hydrocarbon network also. Some will be strong acid cation resins similar behavior of that strong acid cation resins to that of strong acid and the resins are highly ionized in both the acids and the salt as shown in the picture and also that equation here and they can convert a metal salt to the corresponding acid by following reaction here the hydrogen and sodium forms of strong acid resins.

Whereas some will be weak acid cation resins here in this case in a weak acid resins the ionizable group is a carboxylic acid as opposed to that sulfonic acid group used in a strong acid resins. Some strong base anion resins also that maybe you will see that strong base resins are highly ionized like strong acid resins and these are used in the hydroxide form for water deionization and also they will react with the anions in solution and can convert an acid solution to pure water. Weak base anion solutions in that case you will see that it is also like weak acid resins in that case the degree of ionization will be strongly influenced by pH level. The weak base resins exhibit minimum exchangeable capacity above a pH of 7.

0 and in this case it will not have actually that hydroxide ion form as does the strong base resin. Also you will see that the less expensive weakly basis reagent such as ammonia or a sodium carbonate can be employed for this. Now application of that ion exchange here water softening to remove its hardness by exchanging calcium ions for sodium ions, deionization of water or to remove all ions in the water, treatment of trade effluents, example process water from metal finishing, even separation and purification of products from bioreactors. Then coming to the point that chromatography, what is that? This chromatography also this is basically that identification of that organic or inorganic components from the solution just by absorbing it onto a surface. Here in this case this chromatography concept is first actually coined by Russian botanist his name is Mikhail Svet. He has given this first term in 1906 and the first analytical use of this chromatography was described by Zemes and Martin in 1952 for the use of gas chromatography for the analysis of fatty acid mixers.

And this is basically a technique of the separation, identification, and purification of the components of the mixer for qualitative and quantitative analysis that is why it is called that chromatography. Basis of chromatography is basically it is based on size and shape, also total charge whether this groups is hydrophobic or hydrophilic in nature and also that binding capacity of surfaces so that solid surface which are being used. Also it is based on that molecular characteristics and interaction type like ion exchange, surface absorption, partition and size exclusion. Also other type of chromatography also there that is based on that stationary bed like column bed, thin layer bed, even paper chromatography bed like this. Now what is the basic principle of chromatography? This is basically one of the phase that works as the immobile porous bed which is called stationary phase as shown in the picture here or in the slide and the other phase that will work as a mobile fluid that flows over the stationary phase under gravity.

And during that movement of the sample under gravity a separated result is formed by the repeated desorption and sorption in the direction of the mobile phase migration. And in this case an interaction between that molecules that will be physical and also involves the weak chemical bonds like dipole-dipole interaction and hydrogen bond formation and adhere to the stationary components. And components that adhere strongly to the stationary phase that will move slowly than those who adhere quickly there. So this is the basic principle of that chromatography. And in this case some factors supposed to be remember based on which that chromatography depends on like partition between liquid-liquid, affinity between molecular weight, even characteristics related to liquid-solid adsorption.

And commonly employed chromatography are like liquid column chromatography, ionic exchange chromatography, gel permeation chromatography, affinity chromatography, dye ligand chromatography, gas chromatography, thin layer chromatography, paper chromatography, pseudo affinity chromatography, high pressure liquid chromatography, even hydrophobic interaction chromatography. These are the different types of chromatography it is being done. And application here you will see that in pharmaceutical sector, even chemical industry, food industry, forensic science, even molecular biology studies, they are actually this chromatography process are being used there. So in that case sometimes you have to detect some unknown compounds and also what would be the purity of that mixture that can be assessed by this chromatography.

Also testing of water samples and also checks air quality. Also what are the quantity of pesticides or some oil compounds in mixture that can be also assessed by this chromatography. Is there any additives in the food or not? Is there any nutritional quality of food or not that can be assessed by this chromatography. Even in forensic pathology and crime seen you will see that sometimes you need to test that blood or their hair samples of that crime. And also like SPLC high pressure liquid chromatography is being used in protein separation like insulin purification, plasma fractionation, even enzyme purification etc. Even some other departments like fuel industry, biotechnology and biochemical process, they are also there using this chromatography process for their analysis of components.

So I think here we have discussed a lot of things about that adsorption. What are the mechanism of adsorption? What are the different types of adsorption? What is the desorption process? How the desorption happen? What is the adsorption process? Also what is the ion exchange process? What is the chromatography? What are the applications of ion exchange? Even chromatography? Even what is the basic difference of physical absorption and chemical absorption? All those things that we have discussed in the lecture. So I think you understood these things and more about this adsorption we will discuss in the next lecture.

There we will discuss about analysis of adsorption by isotherms. So thank you for giving attention. Have a nice day. Thank you.