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# Lecture - 12 Adsorption

Today we are going to start a new topic that is called an adsorption. Adsorption is used in the early stage of downstream processing, adsorption can be used for recovery of a desired product or sometimes it can also be used to remove some unwanted products.

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Adsorption is a surface phenomenon; suppose there are impurities present in your broth which may hinder your remaining downstream then we may resort to adsorption to remove that particular unwanted product. Sometimes if you are interested in a protein in a very large fermentation broth; so, we may resort to adsorption to slightly concentrate the protein on to the surface of an adsorbent. So, basically adsorption consists of a surface phenomenon where the molecules of interest or the species of interest gets accumulated; when, you compare it with the concentration in the bulk the concentration at the surface will be much higher.

This happens because of several forces; generally, we may have a non-bonded interaction like van der Waal forces, electrostatic forces, ionic forces and so on. Because you generally do not go for a irreversible adsorption; then, the adsorbent gets totally

spoilt and you will not be able to regenerate it. So, the generally the adsorption is a reversible adsorption process. So it is a surface phenomenon and it arises because of the unbalanced or residual forces that are present at the interphase. For example, interphase between a solid and a liquid or a gas and the liquid and so on actually. So that is the place where the adsorption takes place.

So, the molecules or the species get attracted to the surface of say for example, a carbon particle or a zeolite particle and so on. So, the species get attracted to these adsorbent and they remain on the surface. You also must have heard about absorption that is a b; whereas, adsorption is a using a d so both are different the absorption and the adsorption. In absorption what happens is a solute or the species of interest gets uniformly distributed inside the solvent or the liquid medium.

So, that is called absorption. For example, carbon dioxide gets absorbed in ethanolamine solution or sodium hydroxide solution; whereas, in adsorption the solute gets attracted to the surface and it remains on the surface. So, it is a surface phenomenon. So, rest of the bulk of the solid does not have the solute present so that is the main difference between the absorption and adsorption.

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But in some situations you may have combination of both the absorption and adsorption and that is called sorption; as you can see here sorption.

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So, there are 2 components present in the adsorption process; one is the solute of interest or the species and that is called the adsorbate. For example, if you look at this particular picture this is the adsorbate which is getting adsorbed on an adsorbent. So, the adsorbent is the activated carbon or zeolite or alumina or any solid material. And, the adsorbate is gas or a liquid small molecule or even large molecules like protein they get and get adsorbed on surface. So, the remaining bulk will never have this particular adsorbent present. And, generally they form a monomolecular or bimolecular or multilayer of this particular adsorbent on top of the adsorbate.

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So, if you look at liquids; for example, if you look at the water molecules present in the liquid, water molecules are uniformly distributed inside the liquid. But if you take a water molecule right inside the bulk it will be surrounded by many water molecules; so, the forces are acting in all directions so the net force will be 0. The attraction because of the hydrogen bondings; so, the net hydrogen bonding forces, the electrostatic forces will be 0; whereas, if you take a water molecule which is almost near the interphase between the liquid and the gas.

It is getting attracted from all the sides where there are water molecules present whereas, in this particular area you have only gas molecules; so, there are no attractions. So, what we find here is unbalanced forces. So, the water molecules that are present near the surface of the liquid gas interphase experience an unbalanced force; that is why you get something called surface tension whereas, the water molecules that are present right inside the bulk have many water molecule surrounded and the attraction forces cancel each out.

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So, adsorption in solids you also have residual forces that is coming because of unbalanced valence; unbalanced valence in various atoms present on the surface of the solid material. This can happen due to cleavage of big crystals; when the big crystals gets cleaved they form smaller crystals and that lead to many vacancies and that lead to many

residual forces actually. And, these residual forces get sort of balanced by the particular adsorbate which is going and settling down on this adsorbent.

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It is a spontaneous process because if you look at thermodynamics of the adsorption process you will see very interesting information; the delta G of this entire adsorption process is generally negative. And, you all know this second law of thermodynamics delta G is equal to delta H minus T, T delta S. And, delta G is generally negative because it is a very spontaneous process. And, during the adsorption process; the molecules which are randomly present either in the liquid or in the gas once they get adsorbed the randomness decreases, the number of degrees of freedom also decreases.

So, what happens the delta S becomes negative here. So, what happens to the equation delta G is equal to delta H plus T delta S. And, because it is a spontaneous reaction and delta G being negative; you also need to have delta H much more negative than this particular positive term that is what we have put here. The value, numerical value for delta H must be much larger than the T delta S. And, delta H has to be negative so that delta H, G also becomes negative.

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So, adsorption always is an exothermic process. So, heat is generated when this adsorption takes place; that means when the adsorbate gets adsorbed on the adsorbent. So, there are 2 types adsorption; one is the physical adsorption, the other is the chemical adsorption. So, as I originally mentioned the forces that are acting are things like van der Waal forces or there could be weak chemical bonds which are strong forces of attraction. And, so this leads to 2 types of adsorption; the physical as well as the chemical adsorption. And, both of them differ from one another; the way they respond when you change temperature or when you change pressure or when you change neither operating conditions actually.

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So, physical adsorption it is also called physisorption; generally, happens under weak forces like when you have weak van der waal forces of attraction then it is generally called the physisorption or physical adsorption. And, a the enthalpy of this process the delta H is of the order of 20 to 40 kilo joule per mole; physisorption energies are much lower than chemisorptions energies. So, the energy enthalpy is around 20 to40 kilo joule per mole; you will form a multilayer of adsorbate on the adsorbent that means you will have one layer of the adsorbent.

And, you can also have another layer of adsorbent on top of it and so on actually. And, generally happens at low temperature below the boiling point of the adsorbate. And, as the temperature increases the process of physisorption also goes down. So, as you keep on rising the temperature and you as you keep nearing it is boiling point the physisorption keeps going down. And, that is the time when the chemisorptions happen actually.

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So, chemisorptions is nothing but chemical adsorption. So, here the forces of attraction are chemical forces or chemical bond type of forces; whereas, in physisorption you have weak forces like a van der Waal forces. So, you generally form a unilayer of the adsorbate on the adsorbent. And, if you look at the delta H that is the enthalpy of adsorption is very high 200 to 400 kilo joule per mole; whereas, in the previous case we talked about almost 20 to 40. And, it can happen at all temperature that means much above it is a vaporization or the boiling point; with the increase in temperature chemisorptions first increases and then it starts decreasing; whereas, in physisorption with increasing temperature the process keeps going down all the time.

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For example, this is a typical adsorption isotherm it is called the adsorption isotherm that means at constant temperature; if I keep varying the pressure that is the pressure in the X axis. And, what you have is the amount of adsorbate that is adsorbed on say m amount of adsorbent. The graph will go up like this that means as you keep increasing pressure the amount that is getting adsorbed on the adsorbent will keep increasing and after some time it will not increase further. So, you will not see much change here actually this is basic adsorption isotherm.

But there are situations where you might not reach Plato; you may reach Plato. But then again you may see some more increase and so on when there is a multi-layer adsorption taking place after the formation of a monomolecular or a uniform single layer actually. So, but basically as you increase pressure; the amount that gets adsorbed keeps increasing and it will Plato after sometime at a constant temperature. So, I can have this type of curves at different temperatures as well actually. So, I can have a series of adsorption isotherm at varying temperature that describes the entire adsorption process.

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There are different types of adsorption isotherms; we have terms like linear adsorption isotherm Freundlich, Langmuir and the BET theory and so on; we will talk about each one of them slightly more in detail. And, these types of adsorption isotherms are used in calculating the amount of adsorbent required in the entire process of adsorption and so on actually. So, we for designing a adsorption process; the type of equilibrium relation between the adsorbent and the adsorbate is necessary that means you need to determine the relationship between the adsorption process that is the adsorbent and the adsorbate in your lab. So that you can use that data for large scale design.

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Basic Adsorption Isotherm Adsorbate gets adsorbed on adsorbent.		
adsorption Adsorbate + adsorbent desorption	Adsorbed species	
Le-Chatelier principle = the direction of equilibrium would shift in that direction where the stress can be relieved.		
In case of application of excess of equilibrium system, the equilibrium will where the number of molecules decreas	of pressure to the shift in the direction es.	

So, let us look at the basic adsorption process. So, what happens the adsorbate interacts with the adsorbent and you form a adsorbed species it is called a adsorption. The same thing can get desorbed and you can have the vacant sides as well as the species in the gas and the or the liquid phase that means it can come back to it is original form. So, this is called a adsorption equilibrium process. So, you can have adsorption, you can also have desorption taking place in the entire process actually.

So, if you look at Le-chatelier principles what the principle say states is the direction of the equilibrium either forward or backward is governed based on the stresses. And, the direction will match so that the stress gets relieved; that means if the stress is very high in one direction, the stress is very low in the other place. So, it will move from one place to another place so the stress gets relieved or released. So, if putting access pressure to the equilibrium system; the equilibrium system will shift so that the number of molecules decreases.

For example, if I take a adsorbate and adsorbent; if you assume this as one molecule and another molecule and you end up with one particular species the adsorbed species. So, if I you are starting from 2 molecules ending up with one and complex species; so, there is a decrease in the number of molecules. So, when you apply pressure it should move in the forward direction that means from the left to right.



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So, with the increase in pressure what happens? We will move from this left direction to the right direction so the forward direction is favored in the equilibrium reaction. So, when you decrease the pressure so what happens; the adsorbed species get desorbed. So, if I want to capture a gas one particular gas from a mixture; so, adsorption is a very good downstream approach. So, I have a adsorbent and the particular gas or species gets adsorbed at high pressure. And, once my gas mixture is passed you have the adsorbate getting adsorbed on the adsorbent. And, then I just reduce the pressure what happens the gas that got adsorbed gets released; so there by I can collect the gas.

For example, if I want to remove a very useful gas from a mixture of several gases; I can use this type of principal in fact the pressure swing a adsorption where you are generating nitrogen from air is based on this principal. So, air is passed at a high pressure and the nitrogen gets preferentially adsorbed on some adsorbent. And, then afterwards the pressure is released; nitrogen gets dissolved. So, you collect the nitrogen then again you pass the air at high pressure nitrogen specifically or preferentially get is adsorbed. And, again you release the pressure nitrogen gets desorbed; so that way you are able to separate nitrogen from air.

In fact it is a very very cheap and very simple system and that is how nitrogen is produced in very large scale using air and this is called a pressure swing adsorbed. Otherwise, in olden days they use to have cryogenic systems where air use to be cooled and nitrogen gas used to be cooled and collected as liquid. And, that is a very expensive system because you need very extensive cooling and cooling cost are very very high; whereas, as the pressure swing adsorbed all you need is a compressor where the air is compressed and sent into the system. And, then the afterwards you desorbs by releasing the pressure.

So, the zeolite which is used for performing this operation can be regenerated many many times and so the operating cost is just running the compressor that is all nothing else. That is a extremely cheap way of a getting nitrogen from a mixture of a nitrogen oxygen that is air. So, these types of adsorption systems are found in industrial applications as well especially for separation of gases, purification of gases, separation of a toxic gas and so on actually.

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So, what happens after saturation when I keep on increasing the pressure the amount that is getting adsorbed does not change? Because why? Because the number of sites, active sites available for the adsorption are limited. And, hence once the active sites are saturated you do not get any more solute attached to the solid; of course the main assumption here is it is a monomolecular adsorption that means you are not going to have another molecule of the species on top of already existing monomolecular layer actually.

So, at high pressure all the sites are occupied that is why at very high pressure; the adsorption process is independent of the pressure. So, at very high pressure it is a 0 order reaction whereas, at low pressure it is almost like a first order. But then it varies; let us have a look at many types of adsorption. And, the main assumption here is the number of vacancies or sites available for adsorption is limited that means you are not creating new sites during the process. So, all the sites get a filled up; so, no new species or molecule can get attached or get adsorbed.

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Let us look at one of the adsorption isotherms is called Freundlich adsorption isotherm. So, the equation is x by m is equal to k P raise to the power 1 by n or sometimes people use it as k P raise to the power n as well; we know P is the pressure, k is some, x is the amount of solute adsorbed in m amount of adsorbent; so, this is a solute by adsorbent. But it does not work at high pressure it generally this equation is very good at low pressure. So, the value of this exponent determines the relationship between the pressure and the rate of a amount of a solute that gets adsorbed. So, this equation is good for low pressure. But it is not good for high pressure conditions.

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Let us look at another adsorption isotherm and it is quite popular that is called the Langmuir adsorption isotherm. So, what it says is there is a dynamic equilibrium between the adsorbed gaseous species or molecules and then free. So, if A is your gas in the gaseous phase; and A is the gas that is adsorbed phase and B is your solid or the vacant site. So, A plus B going to adsorbed species and there could be always a desorption taking place actually.

So, the Langmuir adsorption says there is equilibrium between the A in the gaseous phase and the A in the adsorbed phase. And, the B is a vacant site or site available for the adsorption; this could have some unbalanced forces this could have some ionic forces or electrostatic forces which make the gas preferentially getting and absorbed. For example, if you want to have hydrogen adsorbed on nickel; you need to activate the nickel site so that a it can a take up a hydrogen gas on top of it.

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So, when we solve these equation where the assumptions is the amount of gas present in the gaseous phase is in equilibrium with the gas in the adsorbed phase; you end up with a relationship like this you have theta equal to KP divided by 1 plus KP where, theta is the number of sites of the surface which are covered with gaseous molecule, P is your pressure and K is the equilibrium constant. That is the equilibrium constant of distribution of adsorbate between the surface and the gas phase. So, if this K determines

what is the partition or the equilibrium constant of the amount of gas in the adsorbed phase and the gas phase.

So, you see that as P increases; the number of sites which are covered by the gaseous molecules increases. But it is not all the time; because after some condition this number becomes very large. So, it will not a have any effect at all; we will talk about that in the next slide. So, you are not going to have all the time a linear relationship between the P and the theta because you all also have a term one plus KP in the denominator.

And, depending upon the ratio of KP and 1 plus KP the effect of P on theta will vary. Again, the basic limitation in Langmuir model is that it is valid only at low pressure. And, the Langmuir model also assumes a monomolecular layer that means it does not assume that after you form a monomolecular that you can have a another layer of gas sitting on top of the original layer of the gas that got adsorbed.

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So, if you take that equation and if you see at very low pressure KP is going to be very small. So, 1 plus KP will become 1; so your Langmuir equation becomes theta is equal to KP that means what? There is a first order relationship between P and theta. So, the amount of gas that is adsorbed will be directly proportional to the pressure whereas, when you have large KP that means at very large pressure what happens 1 plus KP becomes almost KP. So, the numerator and the denominator gets cancelled theta becomes 1; that means theta is no more a function of pressure, theta has be is now a 0

order with respect to pressure; pressure has no effect on theta. And, the surface gets fully saturated with the adsorbed gas or adsorbed species.

So, at low pressures theta is a first order with pressure that means there is a pressure is directly proportional to theta whereas, a large pressure theta is independent of pressure and a theta will be fully covered with the adsorbed species. Another, interesting thing is if K is very very large that means the equilibrium constant between the gas in the gas phase and in the adsorbed phase is very large. Once again, theta will become 1 that means the adsorption process is spontaneous and the surface gets fully covered with the gas species.

So, the Langmuir model can have 2 different conditions at low pressure; the pressure is directly proportional to theta or theta is directly proportional to pressure or whereas, at very high pressure theta is independent of pressure. So, that is a 0 order reaction; so at low pressure you have a first order reaction with respect to pressure and at high pressure you have a 0 order reaction with respect to pressure.

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So, all these models work very well at low pressures, all these models assume just a monomolecular layer or a mono layer. So, in some situations when you have very very high pressures you have multiple layers of adsorption. So, how do you address that? One of the ways of addressing which was performed using the BET adsorption isotherm this was coined; because this isotherm was discovered by 3 scientist Brunauer, Emmett and

Teller that is how it was coined as BET. So, this assumes that there is a multilayer formation unlike the precious theories. And, this assumes that once you form a single layer, you can form the next layer.

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So, when you go to high pressure because if you look at the these theories of a Freundlich or the Langmuir which is very ideal for low pressure; when you go for high pressure you have thermal energy of gaseous molecules decreasing and more and more of gaseous molecules will be available at the surface. So, you will end up with the multilayer adsorption process and the equation becomes slightly more complicated.

So, we have V total that is the adsorbed volume of gas at high pressure condition equal to the volume of gas that is needed for a monolayer adsorption. And, then you have many terms the P by P naught here coming into the picture and so on. So, it is becomes a much complicate equation which takes care of the multilayer adsorption based on the amount of gas that gets adsorbed in a single layer.

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Here, you have a new constant called C; now, C is a function of a 2 terms which is a K 1 divided by K L. And, K 1 is the equilibrium of constant when single molecule adsorbed for vacant site and K L is the equilibrium constant for the saturated vapor liquid equilibrium. So, we have some constants coming here and these are the pressure terms coming into picture actually. So, this particular equation gives an idea about the adsorbed volume of gas at high pressure with as a function of the adsorbed amount of gas; when there is a unilayer or monolayer coverage.

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App	plications of Adsorption
1. C c	Charcoal is used as a decoloriser as it adsorbs the oloring matter from the coloured solution of sugar.
2. S	ilica gel adsorbs moisture from the desiccators.
3. S re	ilica and alumina gels are used as adsorbents for emoving moisture and for controlling humidity of rooms.
4. A a	ctivated charcoal is used in gas masks for toxic gases nd vapours and purifies the air for breathing.
5. A h	dsorption processes are useful in carrying out leterogeneous catalysis.

Adsorption is a very useful technique which can be adopted in several areas both in chemical engineering operations as well as biochemical engineering operations. So, for example, charcoal which used a for de colorizing liquids, it is used in a decolorizing liquids; because it can absorb the colorant present especially sugar solutions, sucrose solutions and so on. Silica gel is used in desiccators you would have all seen silica gel in many places and it adsorbs moisture.

So, if you want to make a environment free of moisture silica gel is the most ideal type of adsorbent. So, you also have silica and alumina gels removing moisture controlling humidity in rooms, in large storage areas and storage bins. Activated charcoal is used as a gas mask; because activated charcoal has a wide range of adsorption capacity and preferences. So, it can absorb many toxic gases vapors, so it can be used as a purifier, air freshener it is also used for some of the breathing apparatus.

Adsorption process are also used in heterogeneous catalysis; suppose, if I am doing a hydrogenous of oil doing using nickel catalyst the hydrogen is the form of a gas, nickel is in the form of a solid and your oil is in the form of the liquid so what happens? Hydrogen gets adsorbed on nickel catalyst and then it reacts with your oil to hydrogenate the oil. So, there adsorption becomes a very important phenomena. And, the rate at which the hydrogen gets adsorbed in nickel plays a very crucial role in the overall rate of reaction. And, if you can improve or enhance the adsorption capacity of nickel; then, the process becomes very economical because we will be using less nickel.

Same thing happens if you look at your burning of a exhaust gases from cars especially Knox and sulfur dioxide and so on you are using a platinum rhenium catalyst. So, oxygen gets adsorbed on to platinum rhenium catalyst then the carbon monoxide or sulfur dioxide or Knox that passes through the exhaust after the petrol gets burned, gets totally oxidized. So, here again the adsorption of oxygen on top of this platinum rhenium catalyst plays a very very important role in the entire process. So, adsorption is a key step in the heterogeneous catalyzed reactions. And, that governs the rate of reaction that governs the capacity of the reaction and so on actually.

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So, what are the factors that affect adsorption; many factors that affect adsorption things like temperature, pressure, surface area, presence of competitive inhibitors and so on actually. Temperature is a very important phenomena; so, at low temperature adsorption increases. So, when generally we keep the temperature low you are going to have a forward reaction. But at high temperature according to the Le chatleir principal at high temperatures it will not favor the forward reaction; so, you will end up having a desorption.

So, low temperature you can have good adsorption; whereas, at high temperature you will end up having a desorption. So, you have to be very careful in maintaining the temperature of reaction. And, because it is an exothermic process and you might have studied in a thermodynamics that any exothermic process; it is ideal to keep operating the process at lower temperature. Pressure we studied in detail just few slides back that pressure plays a very important role in the adsorption process and at a low pressures, increase in pressure increases adsorption until the whole system reaches a saturation level.

And, after that the pressure has no effect on the adsorption process. So, that way pressure also plays a very important role. And, especially in the gas solid type of a process pressure is extremely crucial whereas, in liquid solid type of process pressure is not so crucial; whereas, temperature will play a very crucial part. (Refer Slide Time: 36:27)



Next one is surface area; because adsorption is a surface phenomenon more the surface you have more interaction between the 2 phases so the adsorption process also becomes very affective. So, having a very large surface area is the key to any adsorption process; that is why you have carbon, activated carbon sold in the market having several 100 meter square per gram as it surface area. So, creating high surface area carbon for adsorption is a big challenge that is what industry do actually. So, surface area is a very important parameter and all the adsorption material that is used here are high surface area material.

Next one is activation of the adsorbent; so, how do you activate it you can break the solid crystal into small pieces. So, when you break it you will get more smaller pieces and the forces of attraction or repulsion gets unbalanced; so, the adsorption process also becomes much more effective. For example, charcoal if you take, if you heat it to a high temperature; then, you will have a better activated charcoal and it will be ideal for performing certain adsorption process. Sometime, you can only even do acid wash by doing acid wash you are removing impurities present in charcoal as well as you are activating the charcoal.

So, it becomes more affective in performing certain adsorption processes; because when you put in acids you are generating lot of h plus ions on top of the charcoal. So, you have differently certain cationic material getting adsorbed. So, acid wash is a very useful technique to activate an adsorbent; sometimes, you heat the material for example, if there are any tarry deposits on charcoal or zeolite or even metal particles when you heat it to higher temperature what happens? The tar gets burned so again the catalyst or the surface get regenerated or reactivated. So, using high temperature is one way of activating your adsorbent and that is what is followed in many processes.

So, when you are doing your hydrogenation; the nickel starts getting de activated because of the deposition of the oil and tarry material or waxy material so again it is deactivated at higher temperature. Same thing happens in some of the petro chemical products; when you are passing a fuel you are going to have wax or high molecular weight hydrocarbon deposited on the catalyst surface and the activity or the catalyst surface goes down. So, there temperature is raised and the tar is completely burned off; so that the catalyst again gets degenerated. So, use of temperature is very good for activating your adsorbent assuming that temperature does not affect your adsorbent.

For example, if you use very high temperature there could be centering taking place; so, centering is nothing but agglomeration or conglomeration of a smaller particles of the surface into larger particles. So, when you move from smaller to larger particles the surface area goes down; so, the activity also goes down. So, if you use very high temperature for activating your adsorbent; centering could be a problem which should be addressed as well actually.

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#### <u>Adsorbents</u>

Activated carbon is used as an adsorbent spherical pellets, rods, moldings, or monoliths with hydrodynamic diameters between 0.5 and 10 mm.

> They must have high abrasion resistance, high thermal stability and small pore diameters, higher exposed surface area and hence high surface capacity for adsorption.

Distinct pore structure which enables fast transport of the gaseous vapors.



So, there are many adsorbents present in the market; because adsorption is a very old technology it is well-developed so there are many products in the market like activated carbon, charcoal zeolites, silica aluminates and so on actually. So, these are widely used for large number of gases for liquids, metabolites and so on. So, they are for example, the activated carbon they are found as fierce, pellets, rods, moldings, monoliths and so on actually. So, you have different shapes and sizes and you can produce this material in all those shapes and sizes.

So, if you take activated carbon; generally, the size varies from 0.5 millimeter going right up to 10 millimeter they should have high abrasion resistance. Because as the fluid flows through these adsorbent there is going to be attrition it should not start disintegrating; once, it starts disintegrating it may block the pipe or the tube or it may totally get removed from the reactor it should have high thermal stability, it should have small pore diameters, it should have very high surface area which will lead to a high surface capacity. So, these are the properties of a good adsorbent material; so, when you are buying an adsorbent material or when you are designing an adsorbent material you have to keep these points in mind.

All the adsorbent material have good pore structures some of them have very uniformed diameter pores there is lot of research done in designing these pores of uniformed diameter; you do not want a very large distribution of diameters that means very small diameter pores very large diameter pores. So, if you have a very small diameter pores sometimes the gases might not enter; so, those pores become useless. So, maintaining the diameter to a very uniform number or value is a very important challenge when designing adsorbent. So, designing a uniform diameter pores is very very important; if you want to have a manufacturing product.

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Most of these industrial adsorbents fall into 3 classes; one is called the oxygen containing compounds carbon based compounds polymer based compounds. So, if you will take oxygen containing compounds; so, as the name implies there is an oxygen there that means they are hydrophilic cum polar like silica gels, zeolites; silica gel is nothing but some sort of a sodium silicate so they all hydrophilic. The carbon based is mostly hydrophobic or non- polar like activated carbon, graphite all these are hydrophobic material; so, they are favored for hydrophobic gases whereas, if you have a hydrophilic adsorbent they will prefer hydrophilic or polar gases.

The third type is the polymer based material; so, polymer matrix, so there is a polymer porous matrix you may have polar or non-polar functional groups attached to this polymeric porous matrix. For example, some of the ion exchanges resins you will have this type of adsorption adsorbent crescent. So, 3 types of adsorbent; and depending upon whether you want to separate out a polar or a hydrophilic compound or you want to preferentially taken a hydrophobic compound you can select the type of adsorbent.

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If you look at silica gel it is widely used because it is inert, it is nontoxic, it is polar and it is very very stable you can go right up to 400 degrees centigrade; it is nothing but some sort of a amorphous of silicate SiO 2. So, how do you prepare it; you react sodium silicate and acidic acid. Once after the reaction is done there are lots of post treatments so that you get the proper pore size distribution. As I said in adsorption the pores sizes as well as the distribution of the pores are the most important parameters. So, the preparation is one single step; but later on you do lot of after treatment treatments like aging pickling etcetera.

So that you good pore sizes and pore size distributions are obtained. So, silica gel where do you use; you use for oxygen natural gas you can absorb heavy polar hydro carbons from natural gases you know. So, all these places silica gel is used it is a very good dehydrating agent, So, if you have packaging material, if you have a rooms storage area where you want to bring the humidity down silica gel is mostly preferred.

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Zeolites you have different types of zeolites natural zeolites, synthetic zeolites they are all crystalline aluminosilicates; so, you have alumina and silica present with the repeating pore network. So, you have very defined pore sizes of silica present for example, if you take ((Refer Time: 46:41)) 5((Refer Time: 46:42)) sm 5 it is a 5 an strong zeolite that means the internal pore diameter is 5 an strong. So, similarly you can have different sized zeolites; that means, when you have a pore of that particular dimension it will be able to capture or take in gases of that particular size. So, how do you prepare it, you prepare it with the aluminum silicate in a high temperature the water gets released.

So, it is polar; so, polar compounds nicely travel right inside the cage and you can do very preferential reactions of using molecules of certain dimensions based on the size of the internal pores. So, how do you manufacture this zeolite; it is a hydro thermal synthesis of sodium aluminosilicates or another silica source in an auto clave. And, then you do a ion exchange with certain cat ions like sodium. So, you get sodium ((Refer Time: 47:49)) 5 that means sodium salt of ((Refer Time: 47:53)) 5 or you can have a lithium salt or you can have a calcium salt or potassium or ammonium and so on.

So, the dimensions can be between 2 to 9 or now a days they even have large diameter zeolites; the advantage of a for example, diameter is it will preferentially capture only small diameter molecules whereas, the large diameter molecules go away. So, it is

almost like a filter; you just slow down molecules of that size which get entrapped inside the zeolite cage whereas, molecule larger molecules which cannot enter the zeolite cage gets flushed out or washed. So, you can separate out small molecules as against large molecules.

So, ones you have prepared your zeolite using ion exchange you go into drying; and then it goes into pelletization and binding to form microspores pallets. So, in solid material, solid adsorbent always there is something called pelletization and binding; so that the adsorbent is mechanically stable and it has got a good shelf life as well actually. So, zeolite is another adsorbent which is widely used now a day for gases as well as for moisture removal.

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Uses drawing of process air, CO 2 removal from natural gas, carbon monoxide removal from reforming gases, air separations; I talked about removing nitrogen from air in pressure swing adsorption zeolites is the material that is used in pressure swing adsorption, catalytic cracking, catalytic syntheses that means preparation of a organic molecules from small molecules de forming.

So, it is got a wide application in petrochemical industries; you also have non-polar zeolites so what you have is you use aluminum free silica sources by dealumination of aluminum containing zeolites. Then, by treating the zeolite with steam at elevated temperature that is almost greater than 500 degree centigrade. So, it breaks the aluminum

oxygen bond; which makes the aluminum to be expelled from the zeolite frame work. So, you can make this type of non-pores material also.

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Activated carbon
Highly porous, amorphous solid, microcrystallites with a graphite lattice,
Prepared in small pellets or a powder. non-polar and cheap. drawbacks - combustible.
Manufactured from carbonaceous material, including coal (bituminous, subbituminous, and lignite), peat, wood, or nutshells (e.g., coconut).
NPTEL

Then, you have the activated carbon; so it is highly porous amorphous solids, micro crystals, graphite type of lattice. So, we can prepare in small pellets and it is very cheap; activated carbon is a cheapest of all material. But only drawback is combustible that means in presence of oxygen it can burn; so, you have to be very very careful about it actually. So, we can manufacture from any carbonaceous material coal, bitumen, lignite peat, wood, nut shells, coconut shells. So, practically from any solid carbonaceous material you can make activated carbon that is why it is extremely cheap; to make and most of the adsorption gaseous adsorption this particular adsorbent is used actually.

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So, here what do you do you have a carbonization process and then you have the activation process. So, in the carbonization what do you do; you include drying and heating to separate the bi products, the bi products could be tars other hydrocarbons from raw materials and other gases. So, all these are to be dried and removed completely which activates your material, which activates your carbon; and hence it becomes an activated carbon actually.

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So, here the carbonization process what you do is you perform at 400 to 600 degree centigrade in an oxygen free atmosphere because you do not want oxygen; once, you have oxygen there is going to be oxidation taking place very high temperature, very high temperature can lead to centering and so on actually. Once, you have done that then you expose it to oxidizing agent steam or carbon dioxide at high temperature; by doing that it will remove or burn, the pores that are blocking.

I mean, it burns the agents that are blocking your pores there by you are creating a 3dimensional graphite like lattice. So, the size of this pores depend upon how long they spend a during this particular process actually. So, larger exposure time will lead to large pores, smaller exposure time it will give you smaller pores.

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So, the most popular aqueous phase carbon are bituminous based; because they are very hard, they have very good updation resistance, good pore size distribution low cost. And, then it can be used for a large number of applications like organic substances, non-polar adsobates, waste gas treatments, as an adsorbent and so on actually; that is why it has got very good applications in several manufacturing processes ok.