Course: Adsorption Science and Technology: Fundamentals and Applications

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Week 01

Lecture 2 | Adsorbents

Hello everyone. So, in this class we are going to talk about different types of adsorbents that are generally used and what kind of properties that one would really look forward to in a adsorbent is something that we will talk about. Adsorbents as I was saying, there are various types of adsorbents which are available and widely used throughout many years for the last 50 to 60 years or even a century back there were reports of adsorption or adsorbents being used. Now adsorbents are typically as I said solid materials. Of course there are some examples of liquid adsorbents but something that we will not discuss much about in this course. So we will talk about solid adsorbents mostly and its key features.

Now one of the interesting important feature of this adsorbent, important feature of an adsorbent is its surface area. More specifically the ratio of active or the exposed surface area to the volume or to the weight or mass of the material is what it is important. So, surface area is essentially you know exposed area per unit volume or mass of the adsorbent is what it matters. So, typically this can range from 10 meter squared per gram to almost 1000 meter squared per gram of the adsorbent.

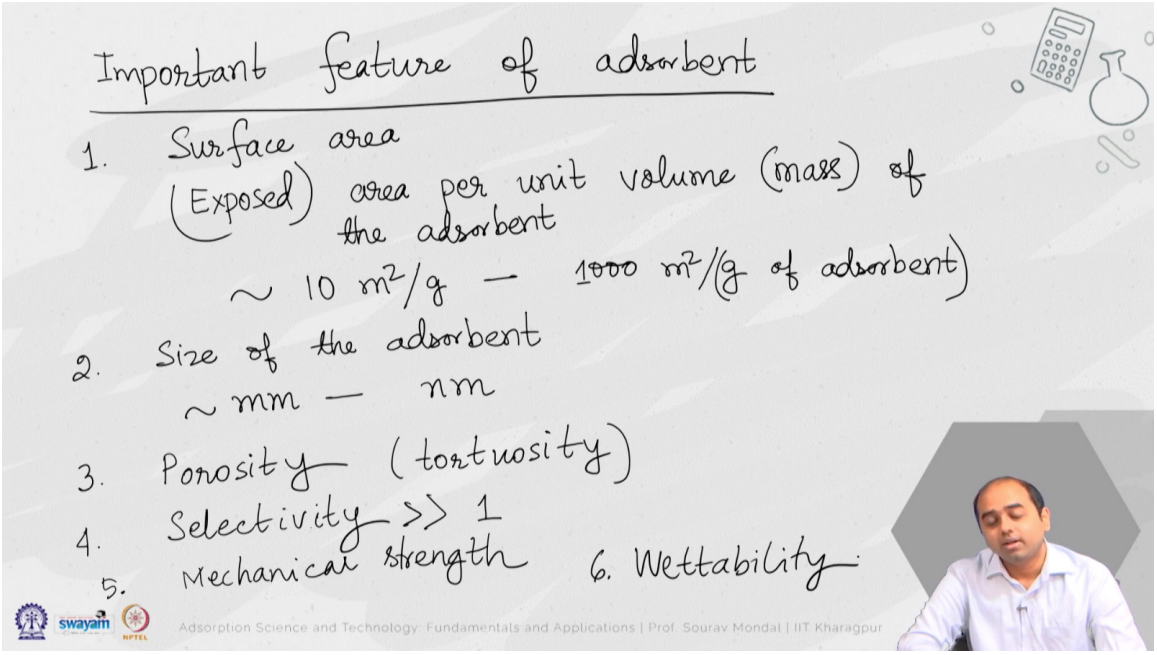
I mean there are reports of even slightly higher than this value, but typically this is generally the range of the adsorbents or the exposed area that is available per gram of the adsorbent. The next very important property of this adsorbent is its size. So, size of the adsorbent is also very important by size I mean the particle size of the adsorbent. So, it can be from few millimeters to few nanometers. So, again this can range from few millimeters to few nanometers scale.

There are examples of you know big large size particles for example these activated charcoal granules or these clay silica granules. These are all you know millimeter levels then you have examples of powderized or powder form adsorbents for example alumina then you have you know laterite dust then you have granulated charcoal, activated carbon, you know slug, dust, fly ash to some extent. These are all in the micro level and nano scale sized adsorbents are all nano particles in nature, which are you know typically

synthesized for high selectivity. So, along with the size, also the important parameter which comes is the porosity. Higher the porosity of the adsorbent, it is likely to have more exposed surface area, but of course, this may not be always true because it can have large voids which can increase the porosity of the particle, but it may not essentially increase the surface area or the active exposed surface area of the particle.

So, the porosity as well as there is a factor known as the path tortuosity, both of which are very important parameters. So, higher is the path tortuosity which is of course, possible in a highly porous you know particle, but not vice versa you can have higher surface area of the particle, so, or the adsorbent. So, these are the different you know porosity, then size of the adsorbent, then surface area, which is of course the primary and the key factor of this adsorbent. Besides the selectivity is what defines the particular adsorbent towards a particular species and the ratio of binding probability or adsorption probability for up towards the targeted molecule should be higher compared to the other molecules. So, for example, activated carbon is a very popular adsorbent, but it also adsorbs multiple you know compounds.

So, unless this is more selective towards a specific target molecule over the other molecules that is present in your bulk phase this is not so important right. So, the selectivity generally has to be higher. So, for any process ah the selectivity factor should be much larger than 1 which means that it should selectively, you know adsorb a particular species more compared to other species right. So, generally a good adsorbent should have selectivities higher than 6 or 10 or even larger. So, selectivity is a very key parameter.



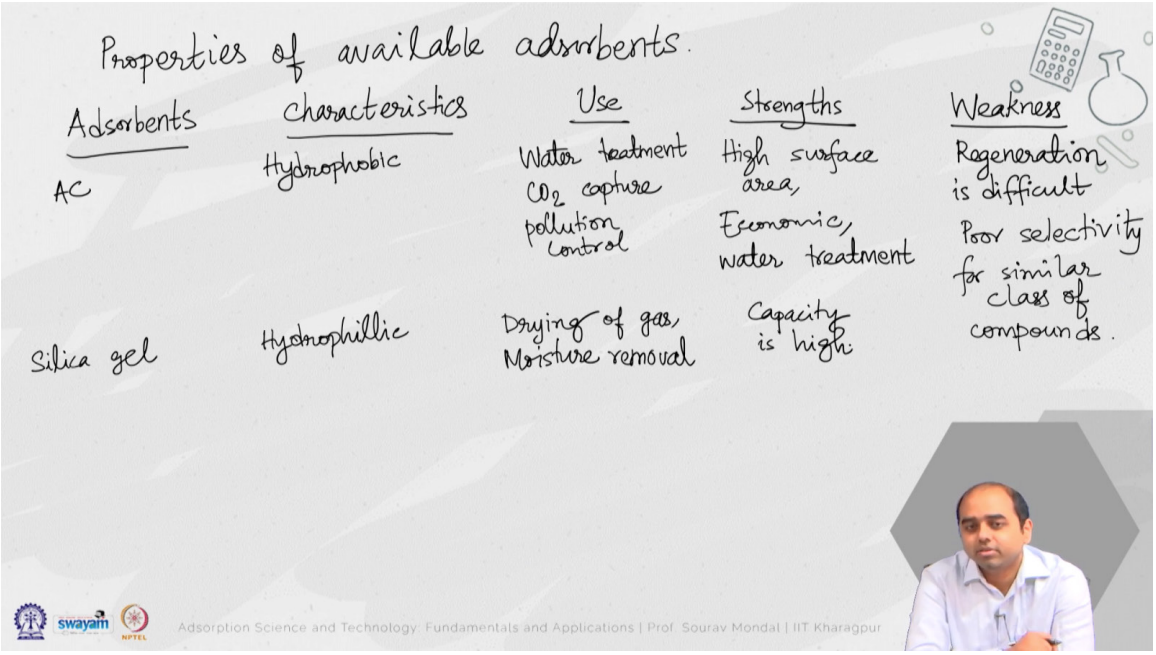
The other parameter of course, is very important particularly is its, you know, mechanical strength. So, the particles should not deform or do not get disintegrated during the operation that is also very important. So, the mechanical strength of the adsorbent molecule is also very important that it should have enough strength and stability during the process related to, you know pressure or temperature changes. So, these are generally the important features that you know, is is very important in any adsorbent. There is one more property.

But that is not very common for all species and is particularly relevant for liquid or aqueous phase adsorbents. But maybe I can mention it here also is about the wettability characteristics of the adsorbent, right. So, the adsorbent should be hydrophilic in nature. Because that will preferentially help the targeted species which is present in the aqueous phase to come in contact with the pores or get into the pores of the absorbent and essentially be absorbed. Now let us talk about some of the commercial adsorbents or the available adsorbents and try to see its different properties, its use, its limitations and everything.

So, we will try to discuss this in a tabulated form. So we'll list the different adsorbents in the first column. Then we'll discuss its characteristics, its use or application, its strength and its weakness. So, first one is of course, activated carbon because that is the most popular available adsorbent till date in the market. So, this is of course, have slightly you know hydrophobic surface not to a great extent.

So, there has been efforts to increase the hydrophilicity of this material. So, naturally it favours the organics over you know water and other molecules. But one of the you know important strength that this has is its high surface area. It is very economic, and it is widely stable over you know lot of these different range of the pH particularly making it quite suitable for water treatment process. The major weakness of this adsorbent is that it is selective towards a large number of species.

So, if you are having a multiple species of similar types, then separation is very difficult. So, normally this is this adsorbent can is not at all suitable for something like chromatographic, you know, applications because the selectivity in this kind of adsorbents is very low. But it is very useful for you know water treatments where you want to let us say remove a lot of organics, a lot of different types of you know dyes. So, it is selective towards all the kinds of dye, but not particularly specific type of dye. Similarly, it is not selective towards differentiating between benzene and phenol for example.



So, that kind of selectivity is not possible. So, selectivity is poor, for adsorbent for the same class of the you know compounds, hydrocarbon or organic compounds or whatever and that could be one of its weakness. Again, this has also, not very good for regeneration so the regeneration is difficult for this so what essentially we mean by regeneration is that after the adsorbent is spent or it is no longer have any available binding sites for adsorption this is of no use. So, in that case you would like to regenerate the you know adsorbent by trying to remove all the molecules which is already adsorbed and refresh or reproduce the, you know, this adsorbent for subsequent use. So, generally the regeneration is chemical in nature.

So, you pass or you use a chemical solution where the molecules which are captured or retained or bound to these adsorbents is released and goes into the solution phase. You are trying to do you know the reverse process and take out all the adsorbed materials and the available sites are you know emptied or freed up and in that process you can reuse that adsorbent. But if the chemical potential change or if the free energy change is very large for this binding then this is energetically not very favorable and that is what makes this regeneration to be. So, this is one of the weakness of this particular adsorbent. The other weakness is poor selectivity for same class of, I would say similar class of compounds.

This major application is in water treatment, CO2 capture, pollution control. Next, another popular adsorbent that we have is silica gel. Of course, silica gel as you know is used primarily for removal of moisture. So, this is highly hydrophilic in nature, is mostly

used for drying operation, moisture removal. Capacity, I mean the major strength of this is capacity, is very high.

So, generally the adsorbent capacity is defined in terms of how much the quantity of the adsorbate species can be adsorbed per unit mass of the adsorbent right. So, this is how we define the capacity of the adsorbent. And it can vary significantly by several orders of magnitude across the adsorbents. This also depends on the kind of molecule that you are trying to remove. So, higher is the capacity higher better it is because you can adsorb or the upper this particular adsorbent can be used for a really long time.

That is why we say that silica gel if you observe carefully the silica gel when you know almost the life it is over or it is spent you will see almost it becomes like a semi solid you know this, where a lot of water you can physically feel you know the water that is absorbed by this silica gel making into a watery or like almost like a liquid like solution after it has captured that much moisture. But you would not see that kind of effect where and you know this adsorbent activated carbon adsorbing you know some particular organic compounds from the solution. So, the capacity is very high. One of the problems is that we generally see in silica gel or that is generally observed is that the even though the capacity is very high at low concentration this adsorption is not that great. So, the efficiency of the adsorbent at low concentration is poor.

Next popular adsorbent is zeolite. There are different versions of zeolites which are available in the market starting from 4A, 13X, NaX, NaY, many such types are available each one of them has its own characteristics in terms of its molecular structure and its molecular configuration its crystal, sorry, not the molecular structure but the crystal structure of this solid and each one of these different crystal structures have its own use and application. So, for example, 4A, 13X, these are generally referred to as the molecular sieve. So, they are used for, you know, 4A is more useful for separation of, you know, organics in liquids. 13X is more for air separation.

Similarly, NaX and NaY are also used for other applications. One of the characteristic features of this zeolite materials is that besides being a hydrophobic material is the presence of the polar channel groups. So, this is coming from the material chemistry of the compound. But the presence of the polar channel groups makes it highly you know efficient towards separating polar molecules or molecules which has stereochemistry involved not only that it can also remove molecules based on you know charge difference and it is also useful for, you know, attracting or interacting with molecules which has different levels of molecular weights as well as its electronic structures. This is generally used for air separation.

It is also though used for to some extent on dehydration applications. But it is air separation that finds its major used in the hydrocarbon in the processing industries. The adsorption capacity of this material is quite low. So, you do not expect this to operate you know really for a very long time. So, it quickly achieves its exhaustion limits and generally for zeolites the technology is to use about pressure swing or thermal swing adsorption and this is something we will talk about possibly in after few weeks what do you mean by in this pressure swing adsorption but this is this is a very high selectivity (you know) adsorbent.

Another popular adsorbent is activated alumina. Of course, activated alumina is just a different crystalline form of alumina that is processed with some chemical treatment. This is a high capacity adsorbent and it is hydrophilic in nature. It is used for drying of gas streams. It is also used for you know removal of heavy metals from the water streams and it is particularly selective towards quite you know high molecular weight metallic compounds.

It has higher capacity compared to zeolites or you know in the scale of activated carbon. But the problem is that the adsorption capacity is generally not as effective again similar to sorry similar to this silica gel it is not as effective at operation at low concentration of the species. So this is a high capacity adsorbent but its removal efficiency at low concentration is poor. It is widely used for removal of heavy metals and dehydration of gaseous stream. Next is of course, the polymer based adsorbents and that actually brings in a whole can of different types of you know adsorbents that is normally developed or

engineered with specific selectivities or with modified you know molecules attached to those polymeric compounds.

They generally show much high selectivity compared to other types of the adsorbents which are normally available. But one of the major problems with these engineered polymeric adsorbent is its high economic cost because they involves a lot of you know pre-processing steps which is of course necessary to achieve that kind of desired you know say this level of the efficiency. The properties of the adsorbent which we have discussed for example the surface area, the porosity, its size, its selectivity, its capacity all of this is essentially are experimentally measured. The size is measured using particle size analyzer. The surface area is measured or is quantified using an instrument called the BET equipment.

We will talk about the principles of this equipment also in this course. It also talks about the porosity and the adsorption isotherms are also produced using that of course that is for nitrogen is produced by this instrument. The capacity and the selectivity are studied from for the target molecule or towards the target molecule is studied from the isotherm analysis and working out its you know the kind of isotherms that it can follow or it does follow. And this is something we will again talk about in the subsequent lectures. So, this is all about the different properties of the adsorbent which is relevant and which helps you to decide the kind of adsorbents that is suitable for your application.

So, in the next class we will talk about thermodynamics of the process of adsorption. I hope all of you have liked this lecture. Thank you.