Particle Characterization

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Particle Relevance of Particle Characterization: Environment and Human Health

Welcome to the thirty-eighth lecture in our particle characterization course. In the last few lectures, we have been looking at some real world as well as industrial applications, where particle characteristics and characterization are very important. In the last lecture, we discussed various aspects of ignition and explosion involving solid particles as well as liquid droplets, and we discussed various parameters that are of importance in determining the rates and the viability of these processes.

Today, we are going to look at some more consequences of particles that we encounter in everyday life, and again examine specifically, which characteristics of particles affect this phenomena. In particular, we are going to look at human health and environmental aspects.

Now, as we know the atmosphere around us is loaded with all kinds of chemicals and also with particles. Dust is probably the most common particulate constituent of the environment that we live in, but there are also more specific sources of particles that are generated from industries or from automobiles or just from various things that we do as part of a everyday life.

So, these particles are constantly floating around us. So, obviously, there is an interaction and interface between us and the particles that are suspended in air around us. Now, if you look at how the human body receives particles from the outside, there are really three major mechanisms by which it happens.

One is simple swallowing or ingestion; the second is inhalation - the particles enter through our noses and the third way, which is applicable for very fine particles, is through penetrating our skin. Particles that are nano dimensional in size can easily penetrate our skin and enter our body that way. Now, if you look at these different mechanisms by which particles can enter us, there is clearly a relationship to particle size, shape and density. For example, particles that we inhale come from a general population of particles that are around us and the range of particle sizes can vary from 0.00 something microns all the way up to large microns and millimeter sizes.

Now, in terms of particles that are inhaled and then exhaled, these particles tend to be in a much narrower size range particles that are in the 0.1 micron to 1 micron size range are easily exhaled by the body. So, they do not stay inside the body and the reason for that is because as we have seen in earlier lectures, particles in that size range are the most difficult to capture.

Their transport properties are such that they cannot be easily retained by any filtration mechanism or by adhesion to surfaces. So, even though we will be ingesting many of these particles into our system, they are also easily expelled from our body. So, they do not really cause harmful consequences, but if you look at the very heavy particles or large particles, they are mostly retained by of course, our, you know the mucus membrane in our nostrils and so they do not really enter our body through our breathing system.

However, these larger particles can easily be swallowed. So, they can enter the human body through the digestive system and they can be retained by the human body, which means that they can cause acute as well as chronic effects. An acute effect is one which is intense, but occurs over a short period of time. Chronic is essentially, a long term condition which can actually lead to fatalities in some cases, and so, these large particles that are swallowed have the potential to cause such harmful effects and then you have the very fine particles that are smaller than 0.1 microns.

Now, again if you look at our lungs and even our digestive systems, the path ways are very tortuous. You know huge lengths of the passage is compressed within a short area. So, you can imagine that there is a lot of essentially tortuosity in our systems, which means that it is actually very unlikely that a particle can make it all the way through and for example, end up at the bottom of our lungs, but the particle that can do that, is the very fine particle.

A nano meter sized particle has sufficient diffusivity that it can actually penetrate all the way through this tortuosity and end up in our lungs. So, very fine particles can also cause acute and chronic effects because of the diffusive tendencies. Of course, once they get into our lung and deposit in the lung, you know that has very severe harmful consequences. Basically, what happens to smokers; smokers are constantly ingesting particles, very fine particles in cigarette smoke and depositing them in their lungs, and that eventually leads to lung cancer and so on. So, the particle size clearly plays a huge role in whether the human body accepts the particle or rejects the particle. Now, shape also plays a significant role because a spherical particle is more likely to be exhaled compared to a non-spherical particle.

Fibrous particle has a maximum probability of retention by the human body and so, that is why fibers are considered especially dangerous, if they can be either breathed in or even swallowed. Density also plays a role because you know particle is very dense, very heavy, the probability that can actually settle in one of the chambers in our body is rather large and of course, other properties like solubility plays a role because a particle that is insoluble in saliva, in the human blood and so on, has a better chance of being again expelled from the body without causing harmful consequences.

Whereas, a particle or any Foreign body that can dissolve in our bodily fluids obviously, has much greater potential for causing harm. Just as you know, if it is a medicinal particle it can cause good because of dissolution properties, a harmful particle because of its dissolution properties will cause more damage to the human body than a particle that is not soluble.

So, the physical properties as well as the chemical properties, the composition of the particle also plays a major role in terms of how these atmospheric particles interact with a human body. Now, if you look at the effects of these particles on the human system, there are really a few classifications that you can offer. There is a phenomenon called fibrosis. Fibrosis is associated with primarily ingestion of fibrous particles. A classic example is silicosis which happens because of ingestion of silicon oxide particles.

Another example is asbestos. You know the reason that you are discouraged from having asbestos roofing is because the asbestos fibers that can be shed by asbestos surfaces, if injected into the human system can become toxic to the system. Another example is beryllium. Beryllium fibers are generated wherever beryllium materials are being machined or processed and beryllium fibers also have very high toxicity effects. So, these are examples of particles which are particularly dangerous because of their shape. Now, an asbestos particle, if you just swallow it, probably, would not cause you much damage. It is the asbestos that you breathe in, that causes damage to the human system and the main reason is the shape. Because of the fibrous shaped particles, these asbestos fibers tend to get retained in our lungs and eventually they will lead to carcinogenic effects of the human body.

The other type of interaction that these foreign particles can have with the human system is toxic effects. Now, that is why the chemical nature of the particle becomes important, when you are constantly swallowing particles. I mean as I am speaking, I am probably swallowing hundreds of particles into my system. Luckily, not too many of them are cancerous or toxic. So, I survive, but if you happen to be in an environment where there are many toxic particles floating around, you know you would not be so lucky. For example, lead poisoning is a case, where the particle that you swallowed - lead does have toxic effects and it can cause you harm.

Another example is cadmium, particularly cadmium oxide, extremely toxic. So, if you happen to be in a location, where cadmium is being processed, you better make sure that you are wearing masks and other things to prevent these particles from entering your system.

Another example would be radioactive material. You know, if you are In fact, there is a story that in the old days, you know watches used have radium for being able to read the time at night. The problem is the radium itself was applied with brushers. So, the operators were not coming in contact. However, they used to lick the brushers before they applied the radium and many of these workers in watch factories over time started showing symptoms of cancer. That is because of the radioactive particles that were entering their body through this act of licking the brush, actually to get more uniform application of radium on the dial.

So, these are some examples of toxic particles. They may have the same size, shape, density characteristics as a dust particle, but they are clearly much more harmful because of the nature of the particle. So, we have talked about fibrosis, we talked about toxicity and the third kind of effect that environmental particles can have on humans is just irritants. You know, we all sneeze. Sneezing is caused by an allergic reaction. So, things like pollen can cause allergic reactions or just dust - house hold dust. If you go into an environment, where it has not cleaned for a long time, the dust accumulation can cause you to sneeze.

Certainly, many people suffer from pollen allergies and interestingly, in Chennai because the weather is so humid, we do not really have to deal with allergic problems because the particles that are emitted, for example, by plants, actually because of the humidity, they quickly agglomerate and just settle and that is the reason that people do not suffer too much allergies when they come to Chennai. The same person who goes to say Bangalore or goes to a foreign country will immediately suffer severe allergic reactions because the humidity there is much lower. So, there is no tendency for particles to get wet and settle down.

So, these irritants again can cause both chronic effects as well as acute effects. An acute effect is just discomfort – sneezing. A chronic effect, you know is things like you can develop asthma, if you have a severe allergy type of conditions. So, the effects are there, I mean there are many harmful effects due to particles that are present in our system. The intensity of the effect depends a lot again on the nature of the particle and also, on the person. Some people are more prone to allergic reactions than others; so, that also comes into play. Another example is you know in cotton mills people that work for a long time in cotton mills develop severe allergic reactions and this is due to essentially, cotton lint that is present. Many people develop an adverse reaction to that.

So, the science of dealing with particles in the atmosphere, from the view point of their interaction with a human body is clearly very different from other applications that we have talked about. Now, other thing to keep in mind is I said that the third way in which particles can enter the human body is through the skin and that is the reason, why actually, if you compare the effects of an atom bomb versus nerve gas, which do you think is more harmful to humans?

It is actually, the nerve gas because the human body can actually screen out radioactive emissions because these tend to be larger particles, but nerve gas can easily penetrate through your skin and it can affect your nerves; it can affect your tissues and that is why, you know the use of nerve gas in battles is prohibited around the world because it can have a very immediate and highly debilitating effect on anybody that comes in contact with the with gas. Again, the reason is that your skin porosities are of the order of nanometers.

So, it is very difficult for particles that are larger than the nanometer dimension to penetrate through the skin whereas, gases obviously because the molecules are much smaller can easily diffuse through the skin. So, here is a case, where the transport characteristics of a particle actually prevents it from becoming harmful to the human body because it is not able to diffuse through the pores that are present in our skin.

So, these are some immediate health and hygiene effects that humans can suffer from due to particles, but if you look at the environment itself, we have all read about global warming and before that ozone depletion was a big issue and the cause behind all these is obviously, pollutants that are present in the atmosphere. The ozone problem - ozone depletion problem was basically happening because of emission of chlorofluorocarbon molecules CFCs to the atmosphere.

Global warming, on the other hand, is a much more complicated problem and it is not clear whether the presence of particles helps or hurts in the context of global warming. You know essentially, global warming happens because the heat that is incident on the ground is not able to reflect back into the stratosphere. So, it is trapped close to the earth’s surface and results in a gradually increase of surface temperatures. Now, what role can a particle play in this.

So, if you look at pollution in general there are two kinds. One is what we call industrial pollution; many of the industries that are operating emit contaminants to the environment, but actually industrial pollutants are in a way easier to deal with because you can actually find the source. You know if you capture the pollutant, analyze its composition, you can pretty much tell which industry it came from and so, you can trace it back to the source and you can put in containment measures.

So, you can control it fairly effectively, but the other kind of environmental pollution is just smog; smog is smoke plus fog and this is contributed by virtually everything that happens on planet earth. You know automobiles, people doing things, cooking whatever you do you are contributing to the atmosphere. So, it is very difficult in this case to pin point the sources. You have to essentially ascribe many different sources essentially contributing cumulatively to the population of particles that you find in the environment. Now, in this case, the role that particles play is actually quite subtle; particles themselves are a pollutant obviously and as we have seen depending on what the nature of the particle is you can cause direct harm to humans or not it may be a benign particle or it may be a harmful particle, but particles also play a secondary role in terms of serving as condensation nuclei.

So when very fine particles are present in the environment, if there is a vapour that is also present in the environment, the vapour may have stayed as vapour in the absence of the particle, but in the presence of the particle, heterogeneous nucleation happens and you as to form a condensed phase.

Now, in some cases that is good and in some cases that is not. In one of the previous lectures we talked about how rain happens. Rain happens because water vapour that is present in the environment finds these fine particles on which it forms a condensate and this heterogeneous nucleation process gives rise to what are known as condensation nuclei and it promotes the formation of water droplets.

So, in that sense, it is a good thing to happen, but on the other hand for example, there are many sulphur emissions again from automobiles, from factories. Now, if the sulphur stayed in the atmosphere as sulphur trioxide or sulphur dioxide gas, it probably would not harm us too much, but what we see happening is what is known as acid rain. The sulphur in SO_2 and SO_3 gets converted to sulphuric acid liquid, which then essentially rains back down upon the earth and causes many harmful consequences.

So, how does acid rain happen? How does SO_2 gas get converted to H_2SO_4 liquid? Here, particles actually play a major role; they play the role of a catalyst; they provide the surface on which the SO_2 particles can interact with H_2O molecules, I mean the SO_2 vapours interact with H_2O vapours to form H_2SO_4 as a liquid condensate on the surface. Now, there are two ways in which it can happen; the SO_2 molecules can react with H 2 O in the vapour phase, form H 2 SO 4 vapour; that H 2 SO 4 vapour can then condense on the surface of the particle to form H 2 SO 4 liquid; that is one mechanism.

The other mechanism is where the H 2 O vapour and the SO 2, SO 3 vapour come together on the surface of the particle and form the H 2 SO 4 liquid. So, in one case, you would call it a physical vapour deposition process and in the other case, you will call it a chemical vapour deposition process, but the net result in both cases is a formation of a thin layer of the liquid on the surface of the particle.

Now, if you look at how this happens, again there are two possible mechanisms. One is simple physical adsorption and the other is chemical adsorption or chemical reaction that causes the formation of this liquid film.

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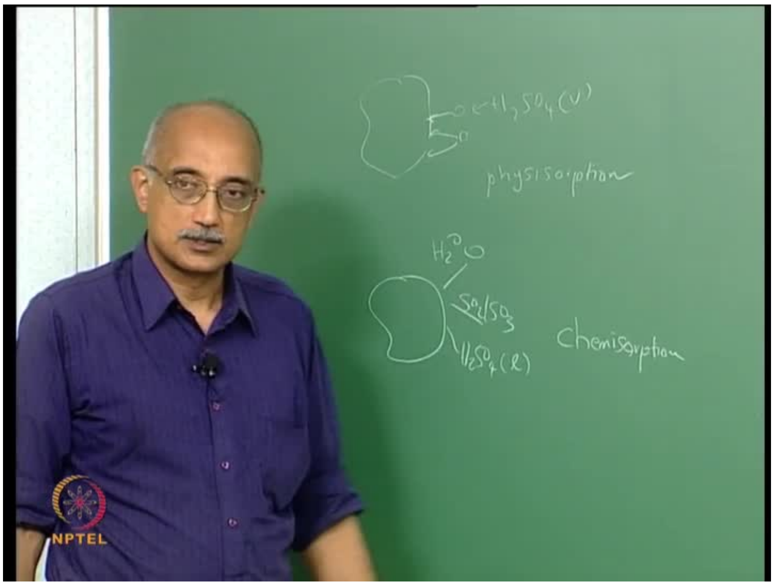

So, physisorption is basically what happens when you have a particle and you start forming these H 2 SO 4 vapour molecules in the atmosphere and eventually, these molecules attach themselves to the surface of the particle. This is a physisorption process.

The other process is as I was mentioning, you have H 2 O molecules and SO 2, SO 3 molecules coming together on the surface to form H 2 SO 4 liquid on the surface and this is a chemisorption process because the reaction to convert the vapour species to the condensed phase happens on the surface. You can also look at this as a homogeneous nucleation process and we can look at this as a heterogeneous nucleation process.

If you look at the kinetics of these two processes and try to figure out which one is more likely to happen, physisorption is essentially a physical adsorption process.

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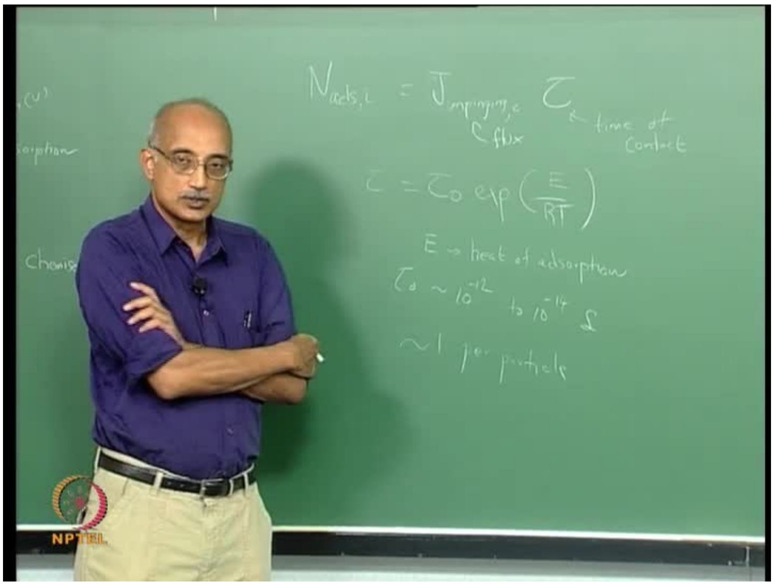

So, it depends on how many molecules are approaching the surface and what time they spend in contact with the surface. So, you can look at the number of molecules that are adsorbed of any species i by physical sorption as being equal to N impinging of the same species i times a time and let us call that tau. So, this is actually, this is a flux of species that is approaching the surface. Let us use a different notation just to clarify.

Let us call this some J. So, this is the flux of material that is impinging on the surface of the particle. Tau is the time of contact between the vapour and the particle surface. So, J times tau gives you the number of molecules that are adsorbing per unit area of the particle surface. Now, this tau can be written as some tau 0 times exponential E by RT, where E is your heat of adsorption.

You can also look it as a latent heat of condensation of the molecules on the surface and T is temperature. So, as temperature increases, the time that is available for adsorption to happen decreases. So, that is the reason as the environment gets hotter, there is actually less potential for rain to happen. As the temperature gets lower, the probability of rain increases. Similarly, for acid rain also for the formation of H 2 SO 4 liquid on the surface of these particles, the probability of that layer formation increases as temperature drops.

Now, this tau 0 is actually of the order of 10 to the power minus 12 to 10 to the power minus 14 seconds. It is a very short time. So, the time that these molecules spent in contact with any particle in the atmosphere is very small. So, what does that mean? It means that the likelihood of one vapour molecule of H 2 SO 4 attaching itself to a particle surface and turning into a liquid is this value of N adsorption is approximately equal to 1 per particle. So, if you only relied on physical adsorption to form this condensed layer, you will only have about one molecule of it happening over a fairly extended period of time.

Now, if you look at one nanometer sized particle, to cover the entire circumference of the one nanometer sized particle with a monolayer of liquid will take at least about 40 to 50 molecules. So, clearly with this process, the probability is that you will only get 1 molecule to attach it is unlikely that you are going to get 40 or 50 molecules to attach to a particle and form a condensed layer. So, physical adsorption is not a promising mechanism for converting SO 2 and SO 3 vapours to H 2 SO 4. So, the more likely mechanism by which you have acid rain happening is a chemical conversion of the kind that we have outlined here.

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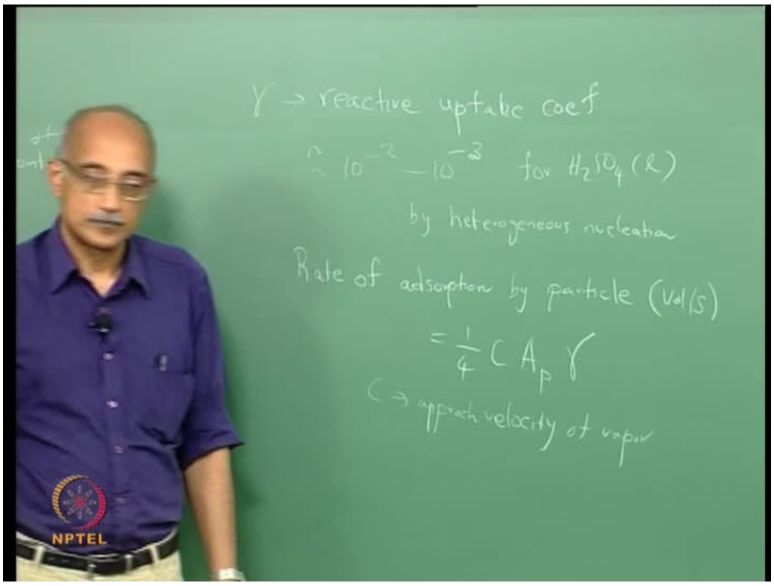

It turns out that the probability of this kind of heterogeneous nucleation of a condensed layer on the outside of a particle is much higher. There is a parameter called reactive uptake coefficient, which dictates essentially, what fraction of incident molecules will get attached to a surface and this is about 10 to the power minus 2 to 10 to the power minus 3 for H 2 SO 4 liquid by heterogeneous nucleation.

So, in terms of probability, this mechanism is much more likely to result in the formation of a liquid layer around a particle compared to the other mechanism and in fact, in this case, the rate of formation of the H 2 SO 4 liquid or rate of adsorption by particle in terms of volumes, volume per second is given by 1 by 4 times C times A particle times this value gamma, where C is the approach velocity of the vapour, A P is the area of the particle, pi d p squared by 4, if you assume a spherical particle and gamma, then the reactive uptake coefficient. So, if you substitute numbers here, it turns out that the rate of formation of a molten layer or condensed layer on the external of the particles is much higher and more in line with what we see in practice.

So, again that the point here is that the presence of particles in the atmosphere plays a direct role in terms of affecting us in many ways, but also plays a very key indirect role in terms of converting vapours into condensed phases. This process is unlikely to happen from an energetics view point in the absence of particles, but in the presence of particles, it is very easy. So, again it has good consequences in promoting rain, but, it has bad consequences in terms of promoting formation of harmful condensed materials like H 2 SO 4 and so on.

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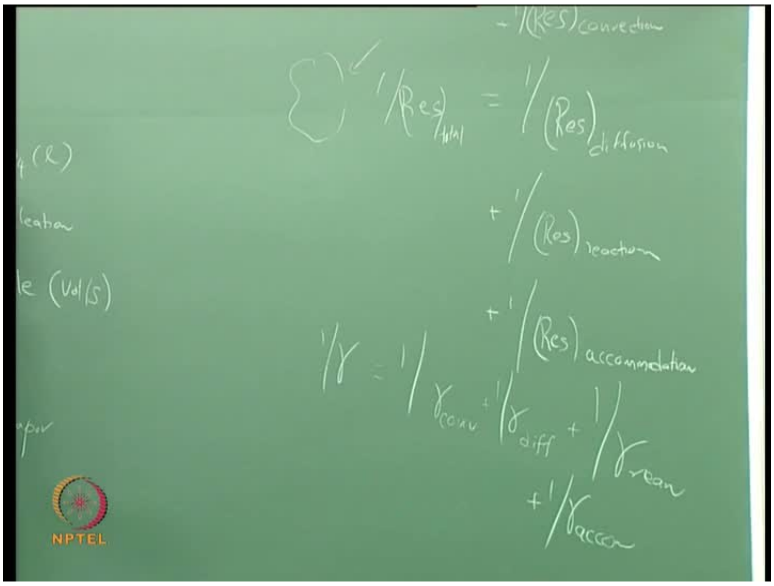

Now, if you look at this process more closely, you know when you have a particle and you have vapours approaching the particle and getting converted to a condensed liquid, there are actually several resistances in series. So, if you look at the total resistance and you write it as one over resistance total, this will be equal to 1 over the resistance to diffusion plus 1 over resistance to reaction plus 1 over resistance to accommodation.

So, first, the species Well, even before that there is even a resistance to convection. The species have to be brought by air flow to the vicinity of the particle. So, there is a resistance associated with that. Secondly, the vapours then have to diffuse through a boundary layer to reach the surface of the particles and there is a resistance associated with that. Once they reach the surface of the particle, the vapours have to find each other and react and there are some kinetic factors involved. So, there is a resistance to this reaction taking place and finally, there is a resistance to accommodation of the product.

The particle has to be able to hold the product that forms and there is a resistance to that because the droplet may want to dissociate from the surface and become re-entrained in the gas phase. So, in terms of the reactive uptake coefficients, you can again write the overall 1 over gamma as 1 over gamma convection plus 1 over gamma diffusion plus one over gamma reaction plus one over gamma accommodation.

So, in order for the ultimately the droplet or the condensate to happen on the surface, all these resistances have to be overcome in series. Now, this is essentially for a dry particle that comes in contact with vapours. Even though this type of heterogeneous nucleation increases the likelihood of formation of a condensed phase, the probability is still relatively low. It is higher than what was predicted just due to physisorption, but it is still fairly low. So, what happens to increase the probability even further? If the particle is moist to begin with, in other words, if the particle itself has a layer of water surrounding it in a condensed phase, then the SO_2 or SO_3 molecules can very easily react with water that is present and get converted to H_2SO_4.

So, the presence of a water layer on the outside of the particles promotes the formation of H_2SO_4. Now, here again, it is a kind of a good news, bad news story. The fact that you can get water to condense on the outside of the particle suggest that you know rain is likely, but on the other hand, as soon as you start forming these essentially condensation nuclei, it also promotes the formation of acids and so on, which are actually harmful. So, environments and conditions that are conducive to rain, it is also conducive to acid rain.

So, that is the problem you have to deal with and so, any efforts that you make to promote rain fall for example, which is considered a good thing to do always keep in mind, there can be adverse consequences as well because the rain drops are effective getters of harmful chemicals from the atmosphere.

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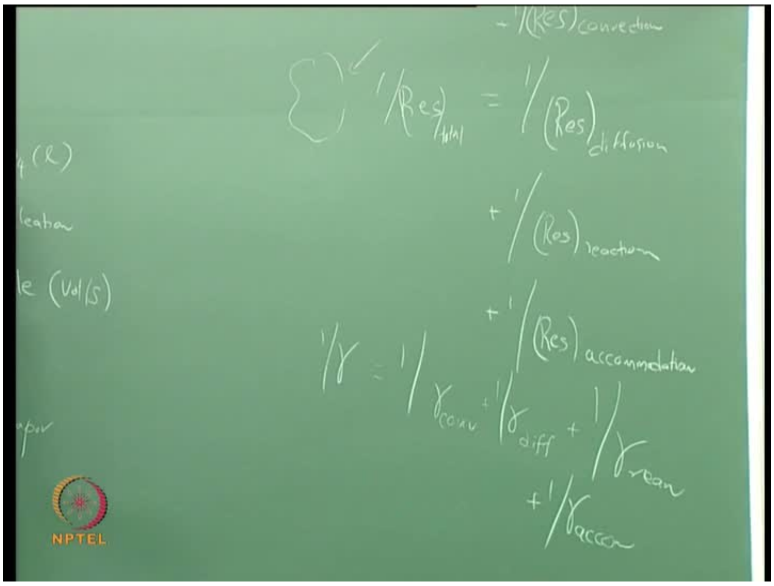

Just like harmful vapours can condense on solid particles, they can also very easily condense on the liquid droplets to be absorbed by the liquid droplets and so, the rain that comes down may not be very pure. In fact, if you sample rain fall anywhere near a major city like Chennai, it is not clean. I mean you cannot take rain water and drink it directly. You have to filter it, you have to purify it whereas, the same rain water that you collect in the Amazons or you know somewhere would be much purer and in that case, the pollutants are not there in the atmosphere.

So, rain is an effective getterer for all kinds of harmful impurities that are present in the environment. So, that that has to be taken into account as well. So, this problem of reactive uptake is one that is something that has been very well modeled and certainly, there is a lot of good understanding about the kinetics of this whole process.

How does rain form? How does acid rain form? So, all these efforts to actually seed clouds in order to bring about rainfall are actually based on a good understanding of how these mechanisms work. How does homogeneous nucleation happen? How does heterogeneous nucleation happen? What is the critical size of a particle that can initiate condensation?

So, when they do this seeding of rain clouds, essentially, what they are doing a shooting at aerosol with very fine particles in it. The sizes of these particles are controlled in a way to promote this type of nucleation, heterogeneous nucleation to happen. So, essentially, by shooting this aerosol through a cloud, you can convert water vapours into water droplets. You know it is basically how artificial rainfall works and so that I mean the science behind is reasonably clear.

Now, it can get complicated, when you start looking at multi component situations, when you have many different species that are competing for accommodation on a surface. The adsorption of one species can lead to desorption of another species and you will have again competition for space, in terms of which species gets preferentially adsorbed on the surface and leads to the formation of a liquid phase and so on.

But these are some interesting examples of particulate applications in environmental chemistry and environmental physics that we should be aware of. Of course, the effect of the particles in the atmosphere, again it can lead to things like people suffering allergies and asthma and so on, but also more practical consequences like lose of visibility.

When there is smog, you cannot see. So, planes cannot take off and the reason for that is of course, the ability of particles to obscure light transmission. So, the net effect of particles present in the atmosphere is something where the different characteristics of the particles have different effects.

So, at the simple interaction of the particles' suspensions with light can have huge consequences in terms of again delaying flights, making it difficult for people to drive on the roads, making difficult for people to see whereas, the chemical aspects of the particles can lead to much more direct as well as indirect effects on human health and you know damage to soil, degradation in quality of water streams and all that stuff. Now, another interesting aspect of particulate behavior in the environment is dust clouds.

As I mentioned earlier, the primary particulate contaminant in the environment is dirt or dust, but how does the dust come to be in the environment because dust actually has good significant mass; it has a tendency to settle.

So, if you just leave dust in an environment like this, eventually it will settle down and all the large particles will sediment and deposit on the floor, but we see that in many places, especially near deserts, the level of dust in the environment remains constant.

So, how does that happen? Well, dust is generated simply because of movement of air flow across a surface containing loose particles of sand. So, obviously in a desert, you have sand storms because there is so much loose sand that can be easily air borne and be transported over long distances whereas, in a place like Chennai, once again, the humidity has a role of getting the dust particles to settle quickly. So, we do not see buildup of dust storms.

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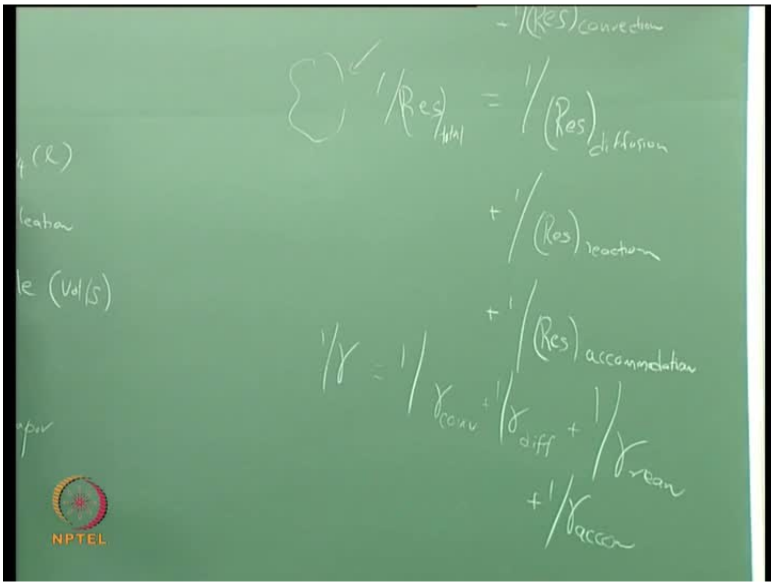

You may have read in the paper that in Delhi they had a major sand storm last night. It happens because Delhi is relatively dry at this time of the year. So, any sand that gets blown in or gets entrained stays in the environment for a long period of time. If you look at the concentration of dust particles in the environment, it turns out that it is very much related to two parameters. One is the mean size of particles that are present in the sand at that location and the second is the velocity of air flow in that location.

The reason that these two parameters are most important is because I mean the particle size plays a role in determining whether it will follow the air flow or not. I mean essentially, the finer the sand particles, the more likely that it will become air borne when you have wind blowing across the sandy layer and it will stay in the environment for a long period of time whereas, if the particles are coarse, then there is a greater probability that it will not follow, the stream lines will not get air borne so easily and therefore, the settling characteristics will be much faster in terms of coarse sand compared to fine sand.

That is the other reason why when you look at places like deserts, where the sand particles have been essentially polished over many years, the distribution of particle size in sand in a desert region tends to be much smaller compared to the distribution of size you will find in dirt in a city like Chennai.

That is the reason why dust storms are so much more intense over dry regions like deserts compared to more humid regions and coastal regions like we have in India for the most part. and the and the reason that By the way, the velocity effect is not a direct effect of velocity; it is actually, the velocity gradient that plays a huge role.

If you have wind for example, blowing on a sandy surface and the velocities are reasonably uniform everywhere, then the effect of entraining particles is much less severe compared to if you have steep velocity gradients. The reason for that is when you have a steep velocity gradient, it is easy for particles that are picked up at one location to essentially become stagnant in that location. You essentially setup these recirculation type of flows and that is really what leads to higher levels of steady state concentration of sand particles in the atmosphere whereas, if you have essentially uniform velocity convective flow, the particles will not stay around in one place for very long.

So, you do not really have to deal with particles in a static mode, I mean they are more dynamic in their nature and again, less likely to cause harm and other effects. So, again the modeling of movement of sand in the environment has been extensively done.

There are very good CFD models that can essentially predict how dust will behave in an environment and clearly, its effect in a built up environment will be very different from the effect in a un-built up environment. In a city, you know particles cannot travel very far without encountering an obstruction to their movement and so, you have a tendency to either settle on a building surface or on a road surface and so on whereas, if you are in a desert, again there is nothing for that particles to attach to and deposit. So, without adhesion being present as a mechanism to remove particles from the gas stream, they tend to stay around in the environment for much longer.

So, the transport characteristics and the long term sustainability of a dust in atmosphere very much depends on the flow environment and what surfaces come in contact with these dust particles. So, the movement of sand and dirt or dust due to air flow is another example of particulate behavior in real life, which if you want to properly understand and characterize it, you do not need to be aware of particularly, the transport properties of particles and how they are affected by the various physical features of the particle.

So, we will stop at this point and then in the next lecture, we will deal with a couple of more examples of particles that we encounter in various applications and how their characteristics affect their behaviour. Any questions? See you at the next lecture.