Environmental Quality: Monitoring and Assessment
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Lecture – 6
PM – Particulate Matter

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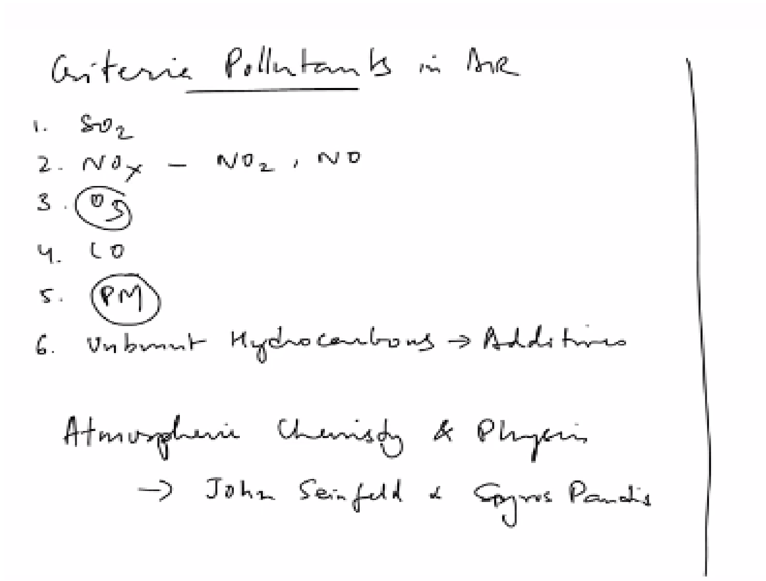

So, just recap. We have SO_2, NOx, so NOx is NO_2 and NO. We have ozone, carbon monoxide, we have PM. Then you could have other things, which are unburnt hydrocarbons okay and along with the additives that are in the fuel. So, a lot of these are related to combustion. The presence of ozone, something like ozone is because of photochemical reactions, the formation of ozone, ozone forms in the atmosphere as a result of reactions that happen sometimes with the unburnt hydrocarbons.

There are various possibilities in which this could happen and also with NOx, there is the ozone chemistry is linked to the NOx content also. So, we will look at it later towards the end of the course if we have time. If we do not have time, we will skip it. That comes under atmospheric chemistry. There are very good references for this kind of atmospheric chemistry and the physics. One good reference book for you is book by Seinfeld and Pandis, the Atmospheric Chemistry and Physics, I think from, I do not remember exactly.

It also deals with little bit about climate change written by John Seinfeld and Spyros Pandis. It is a huge book, it is about 1200 pages long. It covers 3 or 4 courses of this nature okay.

You cannot finish it reading it in one sitting. For an atmospheric physics and chemistry program, it is good. It is like a reference book, nice book, you can have lot of information that any of you who is working in this area can, it is there in the library, if you can check out a copy. I also have it, if you want it, take a look at it. Anyway, so that is it. So, now, one of the things that here we have spent a little more time on this thing called as PM, particulate matter.

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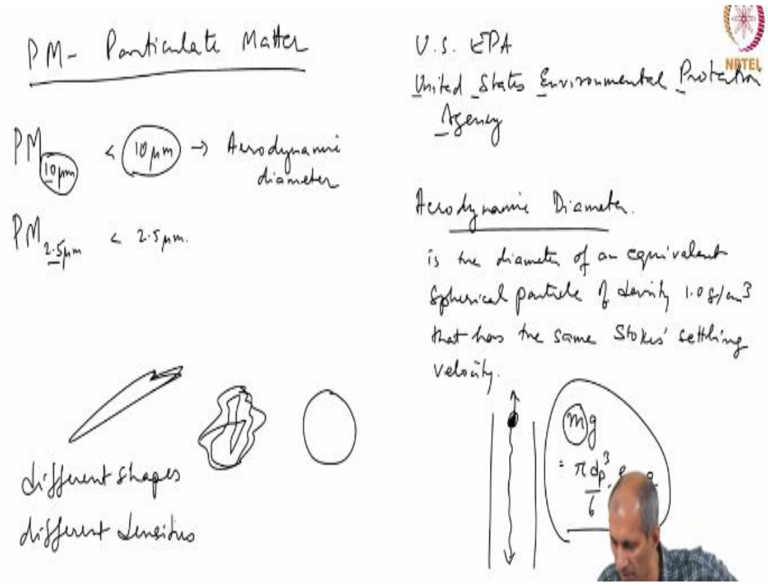

So, particulate matter is one of the most commonly used parameter for air quality. So people quote particular matter, PM this and PM that and so what is the definition of this? So, if you look at the specification in the CPCB or any regulatory agency, one of the regulatory agencies that we commonly quote and in the course also I did have lot of information from them is the US EPA, the United States Environmental Protection Agency. There is a lot of literature, so you can go and search for this.

I will put the link in the module in the webpage in course page. US EPA also was formed around the 70s, early 70s and a lot of funding was given for various kinds of monitoring work and they sponsored a large number of analysis methods. Many of the analysis methods that are used are based on some of the work that they have supported and some of the standard methods for analysis and everything as they are coded. It is not they are only one who are doing it.

There are other agencies, several European countries union environmental protection agencies and the Canadian agency as well, but amount of time they have spent is a very large and the resources they have given to this, so it is a very good source to keep as a reference also. So, PM, and this is more or less worldwide and we use the same kind of standards because it is wherever it has originated. So, if you go and look at the standards, anyway so the common thing that we see now what is called PM10 and PM2.5.

So many of you have heard of it, the PM10 and PM2.5. So, what is this PM10 and 2.5 okay? So 10 stands for 10 micron and 2.5 stands for 2.5 micron of particles. So, what it stands this PM10 is anything that is less than 10 microns, all particles less than 10 microns, this is less than 2.5 microns. What do you mean is less than 10 microns? This less than 10 microns is a representation of the size of the particle as you can see there is a dimension there, but what does it mean 10 micron?

So, particles can be in all kinds of shapes and sizes. So, let us say I have a particle that looks like this, and a particle that looks like this, and then the particle that looks a nice sphere, circular spherical particle and a particle that looks like this irregular shaped, particle with a lot of pores and all that, yeah, and as a particle that is hollow, you can have different shapes. You have different densities of particle. The particles which may have a certain size, but then its density may be very small. So, what is this 10 referred to?

So, this 10, this is known as the aerodynamic diameter. So, the definition of the aerodynamic diameter is the diameter often equivalent spherical particle of density 1 gram per centimeter cube that has the same Stocks' settling velocity. So, what this means is that this is looking at a particle that has the same settling velocities. How many of you here are not familiar with settling velocity, what is settling velocities. I think most people from civil engineering or chemical engineering background have seen settling velocity already, so just a recap.

Settling velocity is if I put a particle in a fluid, it will go down due to gravity, it is held back, there is a drag that is acting on the particle and there is also some buoyancy that acts on the particle, especially if it is going in water, but in air that buoyancy is not very significant. So, it is mainly the drag and as a result of which the particle attains some constant velocity and there is no acceleration.

So, if a particle has a very large density, essentially the mass of the particle okay, so the gravity is m into g, m into g is that says if this is a spherical particle is pi dp cube by 6 multiplied by density of the particle into g.

So, a mass of the particle you can have a very high mass if you have low size but very high density or very low density but very high size, either way it is possible. So you just by looking at particle, you cannot make out how it will settle down, but it may be hollow or it may have a weird shape and all that.

So it is not a physical dimension, it is the characteristic of the particle in which how it behaves in a fluid, why Stokes' settling diameter because it is the easiest thing that you can characterize particle, but why is the settling chosen as a reference point to characterize the size of a particle?

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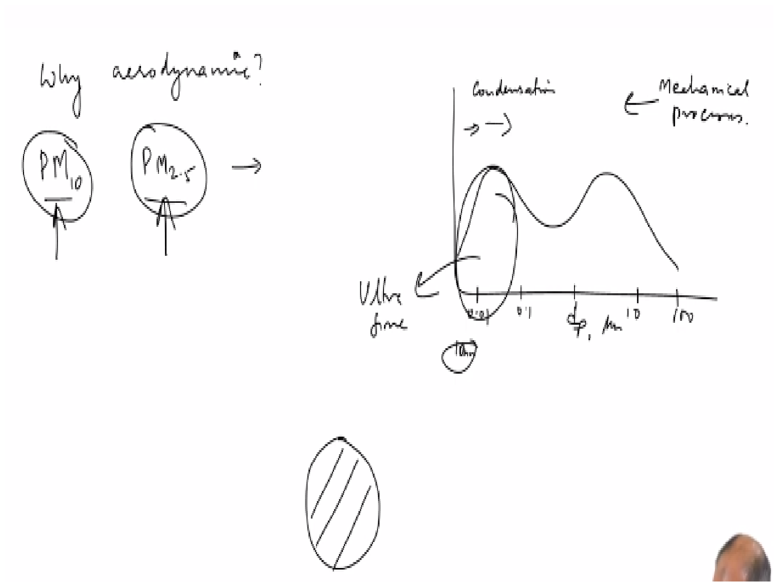

We ask question why aerodynamic behavior of a particle? Why is that? Anybody? Some of you already know the answer. It has to do with, so let me ask you one more question. So you have these 2 numbers. You have PM10 and PM2.5 yeah. So obviously even if you assume that just looking at the size numbers, PM10 was there few decades ago, and then suddenly PM2.5 appeared. Now, there is PM0.1, PM1, and then there are ultrafine particles okay. So the size goes further down.

If you look at the size of particles that exists in the atmosphere, you have a very wide range of particles. These particles if you look at the diameter in microns, you can go all the way you are looking at 100 microns, you are looking at 10 microns, you are looking at 1 micron unit, looking at 0.1, you have 0.01 and so on. You have a very wide distribution. You have distribution that approximately looks like this. This is somewhat bimodal, which means that particles are there all the way from close to 10 nanometers, this is 10 nanometers and up to close to 100 microns in the atmosphere okay.

So, there is a classification for these kinds of particles. These particles in the lower range are considered to be coming from the gas phase from combustion activities and it is their formation due to condensation of gas phase products okay. So, combustion of fuel is coming in gas phase and as soon as it comes out, it cools very rapidly and it forms a particle. If you take a large particle and start breaking it, you will get the other size, from here this is you get the larger size by mechanical processes like breakage or erosion or that those kind of things okay.

So, the smaller side always comes from condensation of a small of gas phase, vapor phase because thermodynamically if stable they will form the smallest particle possible, so that is nanoparticle and then this nanoparticle can grow, they accumulate, this forms a nucleus and it starts growing. So, by the time it comes out of the exhaust, it is already grown some distance, some size, and then other materials can also condense on it and it can become a particle, it can travel.

While it is traveling in the atmosphere, it can grow in size and become micron sized particles and so on. So, from both sides you have particles that are generated. So, then you have to wonder that at some point in time somebody said PM10 and then there is a PM2.5, then we also have this size range which around this size range, which we call as nanoparticles, nanoparticles around the range below 100 nanometers called nanoparticles. We also call it as ultrafine, see do not worry about it nomenclature, nomenclatures are all changing with time.

So you can use absolute numbers okay. So earlier coarse particles are PM10, fine was PM2.5 and ultrafine is the lower range, that may also change. So, why is this change occur, and yesterday I mentioned that the standards are all changing. They are changing because we have more information about behavior and the measurement of some of these issues, particles and what they do in the human body. So, why is PM10, PM2.5, what is the significance of this by aerodynamic? Why are we doing all this complicated business?

Why not say any particle in the air and that is it they are all dangerous. **“Professor - student conversation starts.”** Particles are carcinogenic, but we are not talking about composition of particle yet. We are only talking about size. There is nowhere, we have not yet mentioned whether this particle is a metal particle or an organic particle or what it is okay, we have not talked about its impact health wise based on its composition. So, what else to see. The settling that will take more time, the 2.5 particles will take more time to settle. Settle where? If it is in air, yeah, then it will take some more time to settle on the lower portion where, so that is the reason. Okay, so why are we worried about 2.5?

If it will not settle what will happen? It will be there within the air, is that, that could be one of the reasons, but it is not the main reason. Your answer is in the right direction, but so why is it not PM100? That is the answer, PM100 will settle down very fast. Where will it settle down? Suppose there is PM100 here, what are you worried about mostly? Inhalation. Your inhalation. So why do not you worry about PM100? It would not even go in, it will settle down before itself, so what about PM10?

So, the next question comes PM10, you are inhaling, assume that you are inhaling it, but then you have introduced one more thing called PM2.5. So, what is the difference between 10 and 2.5? If you are inhaling both, then what is the difference between 10 and 2.5? What can happen? So, settling is the reason, but it is not settling. The settling is a reference, but here what happens in the human body? What happens to the air as you inhale? Maybe PM2.5 reaches lungs. Yeah, why? PM10, why?

You are right, size. Reaches lungs, has a higher probability of reaching the lungs, Why? Its diameter, it will go down from pores because of the smaller size. Smaller size. It cannot be screened in nostrils. Why? How does it screen in the nostril, so that is the important point, you are right. So nostrils are filtering, the human body filters out some of these things okay. So how does it filter? Mucus in the nostril, yeah. **“Professor - student conversation ends.”**

So, we have to back off a little bit, I will give you a little bit of background on this. So there is a let us assume that I think I will take a new slide.

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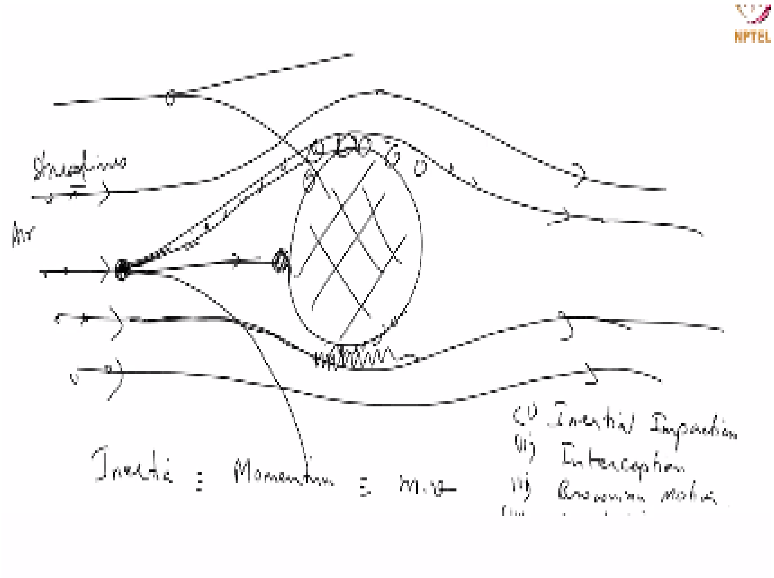

Let us assume that there is solid particle, large solid particle and there is air flowing towards it. As soon as it sees this particle, as it air comes close to it, it tends to move around. These are called as streamlines. This represents the direction in which gases, air is moving okay. Air is moving in some direction. As soon as it sees an obstruction, the air moves around it. So, this is called a streamline separation, this is streamline separated, goes away from the direction of its original path and it goes away.

It takes off, goes along the side of the object and then again comes back and forms the streamline again okay. So, as a result of which if this contains particles that are coming along with it yeah, when the streamlined separation occurs depending on, some of the particles will continue in its previous motion and go on and hit the object, the obstacle let us say. Smaller particles will have a better chance of traveling along with the gas and going away. **“Professor - student conversation starts.”**Why is that? Inertia. Larger particles will have inertia so that they may, why, so inertia is correct.

What is inertia? What is the main component of inertia? Mass, momentum. So, we have inertia. Momentum is mass into velocity, yeah. **“Professor - student conversation ends.”** So you imagine you are going in a motorcycle or a cycle very fast. You see an obstacle, you have a reaction time, you have time. If you are going very fast, you do not have enough time to break or to change direction, you go and collide with the object right? If you are going slow enough, you have enough time to turn and go away okay or you have a smaller vehicle also you can do that.

If you have a larger vehicle, you were trying to turn, but you may end up hitting the obstacle, it is roughly like that, it is not exactly like that. So the larger the momentum of the particle, the larger is the chance that it will collide with something in its flow path. If you look at the respiratory pathway, there is a lot of, it not a straight line and it is designed like that possibly for the reason. I do not know what if it is designed like that because nature anticipated PM10, but maybe only PM10 there is.

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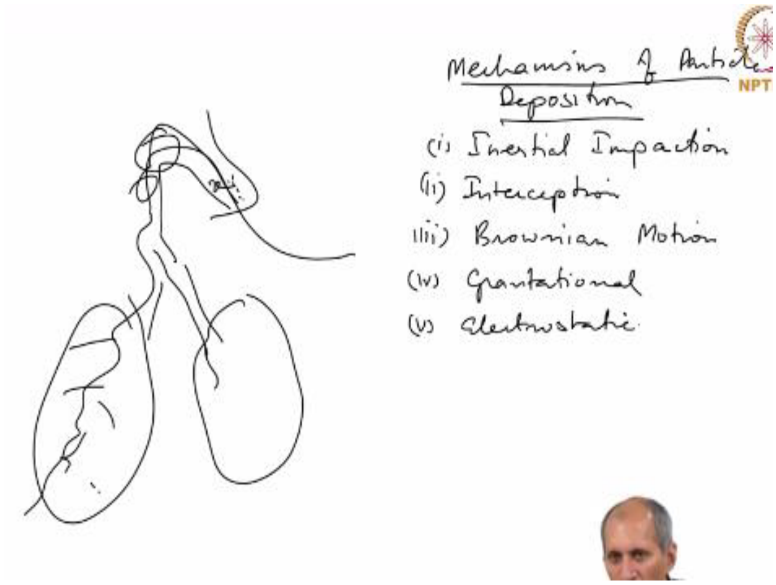

So if you look at the respiratory pathway, this is the nose, there is air here, it has to go here and it goes here, there are a lot of junctions. There are lungs here. There is a big tube here, when it divides into two pathways in the lungs, and again, it distributes further further further and the channels keep on getting smaller and smaller and there are a lot of turns and bends, and each point you are taking air at a certain flow rate. Correspondingly, there is a velocity inside each of these channels, right?

So there is a possibility of deposition throughout the respiratory channel. So, a particle with a higher momentum which means a higher mass having the same velocity, all of them are having the same velocity assuming that they do not deviate from the pathway, but you are breathing at the same this thing. Velocity being the same, if the mass is larger, you are likely to get deposited earlier in the process right here. So it is now being found out that PM10 deposit does not go all the way into the lungs, it deposits near the throat, in the nose.

It causes problems, but it does not seem to be going all the way into the lung, PM2.5 has a better chance of going into the lungs without any other obstruction, and even for smaller particles can go all the way in. If you are breathing deep, it can go all the way into the alveolar sacs and all that. Then, this research is very difficult to do because beyond that point, there are people who have done research in finding out if some nanoparticles go in and come out, they do not get deposited.

Because it is so small, the momentum is so small that they are following the air path they go in and the air gets expelled out and it just comes back, but very difficult to do experiments in that because nanoparticles themselves are very difficult to measure and error is very high, but people have tried doing it. People have tried doing these experiments with the animal models to see if there is tagged particles with a fluorescent sensor and they will see where is it depositing throughout the respiratory channel.

So, people have done experiments with mice and other animal models to see where is it depositing. You will send X number of particles and some of them will deposit in different places and they will count and so PM2.5 and further down, the particles with aerodynamic diameter smaller than lower diameters are likely to get deeper into the lungs. We did not know this because I think we did not have the tools to find out probed particles which are lesser size a few decades ago, now you know, now we can measure nanoparticles very easily.

It is difficult even to measure nanoparticles in the atmosphere, even less than what they are doing in the human body. So, these theories are all developed together. So, in this picture, this kind of behavior where the particles go in inertial motion, this is called an inertial impaction. Sometimes, the particle just goes along with the streamline, but it is not able to clear the edge of this thing. So, it will get intercepted here. It will get attached to it. As soon as if it hits it, if it grazes alongside, it will stick to it. So, that is called interception.

If the particle is very small, it can also go along this thing, but it has a Brownian motion. When it has Brownian motion or random motion, there is no inertial interaction, but it is near this, but as it gets close to the surface, it can get attached to this. So there is a Brownian motion component to this. Then of course, we have gravitational settling. This is not important in this example because we are going in this direction, but if you just drop particles.

If your particles are going, gravitation settling means the particle will take a trajectory like, this is particle going in this direction can take a trajectory that goes like this and drop down. It can drop on this surface because of gravity. So it is one of the forces that will make deposition of particles and the fifth one is electrostatic. I will write this again in the next page. Mechanisms of deposition, particle deposition. So the electrostatic sometimes is important because the particle may be charged, there may be slight charge and it can go and attach itself by electrostatic force.

This is the generalized mechanisms for particle deposition for anything. So, the particular deposition is used in various applications, we are using this for inhalation, exposure and all that, but it is also used for removing particles from air by way of filtration or any other device that we are using remove particles. We are also using this to measure particles in the atmosphere. So, we want to measure PM10, PM2.5, we have to manipulate these principles to find out how much of PM10 is there, how much of PM2.5 is there and so on.

So, this mechanism used for that and there are detailed models for this, we will not use any of those models for predicting that, but when you are designing a filter or some such thing then this is very important, this becomes important. There are equations to predict how many particles will get deposited in a given collection of 100 particles or 1000 particles, what is the range of. So, this is the basis for the classification of PM okay and this is likely to change as new information comes, PM2.5 also may become unimportant.

What we mean by important and unimportant is in terms of health risks, what is the health risk if the particle go all the way into the lungs and cause serious, severity of lung respiratory problems are very high or just a nasal allergy kind of thing which is lesser critical than some of the things okay.

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PM - definition

- Aerodynamic diameter
  - Diameter of an equivalent spherical particle of density 1 g/cm^3 that has the same Stokes settling as the particle in question.
  - PM_x – all particles of aerodynamic diameter less than x, where x is aerodynamic diameter (in micron)
  - Examples: PM_{10} or $PM_{2.5}$

So, a lot of these things are still under review. So, it will take a few years, maybe a decade before new information becomes available and established and then people will incorporate it into regulation.

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Aerodynamic behavior

- Behavior of particle in a flow and in response to change in the flow streamline
- Mechanisms of particle deposition on surfaces encountering the flow of aerosol
  - Inertial impaction
  - Interception
  - Gravitational settling
  - Brownian Motion
  - Electrostatic interaction

The other thing is that for it to become regulation, it must be accessible to everybody, the method of measuring it and then preventing it and all that. So until that happens, you cannot enforce it on people because right now it is expensive to measure nanoparticle competitions and all that, we will get to that when we talk about size measurement okay.