Environment Air Pollution

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Lecture No. 35

Air Pollution Control Devices – 1

What had we done last time?

[Conversation between student and professor - Not Audible (00:22 min)]

Problems. If you recall, I can go back to the model that we were discussing right from our class one.

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That model or system was…. When I want to do some change in topic, I will go back to my system because all the time I am dealing with the system and I must work for the system. Clear on this, clear on this, clear on this? Sources we understand, the transport mechanism we understand, effect on the receptor we understand and what we have done in the process is we also develop some understanding of source, transport, receptor impact. So much is the quantity and this will result in so much of impact. If the impact is less than the burden that it can receive, if impact is minimal, what would you do? You will not do anything, everything is fine – the impact is minimum and the receptor can accept that impact and you will not do anything.

Then, everything is fine, very good picture, but generally that will not happen – the receptor will suffer, the emission is too much and all the problems are being caused. Then, what will you do? You will do some kind of a linkage as you understand from the air quality modeling. We discussed last time and we developed the linkage between the sources, the receptor was the Taj Mahal and we said there were problems. Then you could say we need to control something – you said refinery must control pollution, the area sources must control the pollution, this problem is very serious on national highways.

Then we can say that this needs to be controlled, but how to control it? Now, we will discuss. We are going back to the source. How to control the emissions at the source? One is you can take preventive steps – you can change the fuel, you can increase the stack height, you can increase the exit temperature – that is all you can do but you can certainly do that. Sometimes, we even try that – changing the fuel; for example, if lead was a problem, we changed the fuel to unlead it; similarly, if diesel was a problem, we changed the fuel from diesel to CNG, so we take that step. This is a major decision you have taken but sometimes you have to have the engineering solution to control things. Similarly, what do you do in water treatment and the wastewater treatment? Another two or three lectures will be on how to control, how to counter the engineering control at the source – not preventive control, but the engineering control and how we can put certain devices so that our pollution will reduce.

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We can say what we are going to discuss. The first thing we will talk about is particulate. Whenever you want to remove something, you need some force. If I have to eject you from your chair, I have to use some force; so for control, you need a force. What is that force you apply in your water treatment? Gravitational force, so this can be gravitational force. One can also apply the gravitational force in air pollution control, but this force, which I will show you in some little example, is not so effective – not so powerful and we will see why it is not so powerful.

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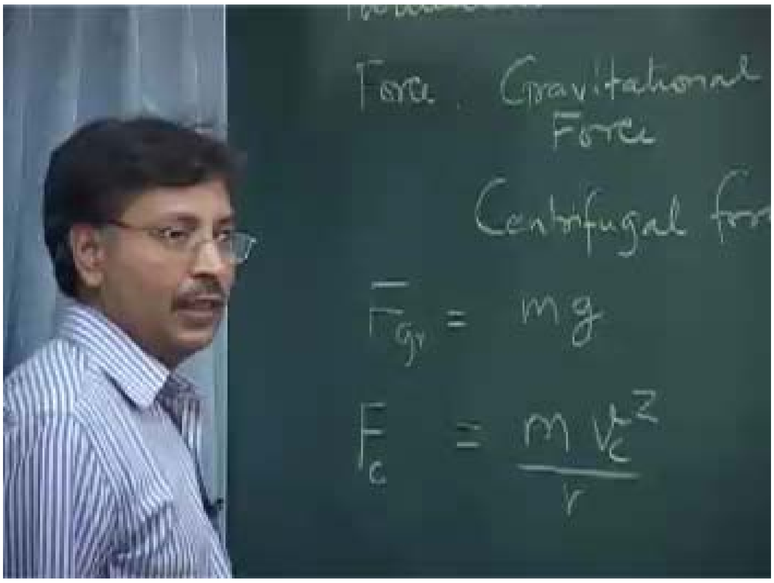

What we do is we apply another force and then we call as the centrifugal force. If we understand centrifugal force, then we can apply it to remove the particle. I want to do some small example and I want to compare the gravitational force versus centrifugal force for the removal of the particle. Let us see which one is larger and which one makes more sense. We are not talking about where the cost involved is more; always gravitational settling will be cheaper because you have to do nothing – gravity is automatically working and we do not have to introduce any kind of outside thing to improve your force mechanism. How do we do it? Let us compare the forces first. Gravitational force $F_{gravity}$, if you like, is mg. Suppose I am providing a centrifugal force and I call that force F_c. What is that if you can recall? m v square by r. Does everyone recall that? Let us call it V_c – centrifugal velocity.

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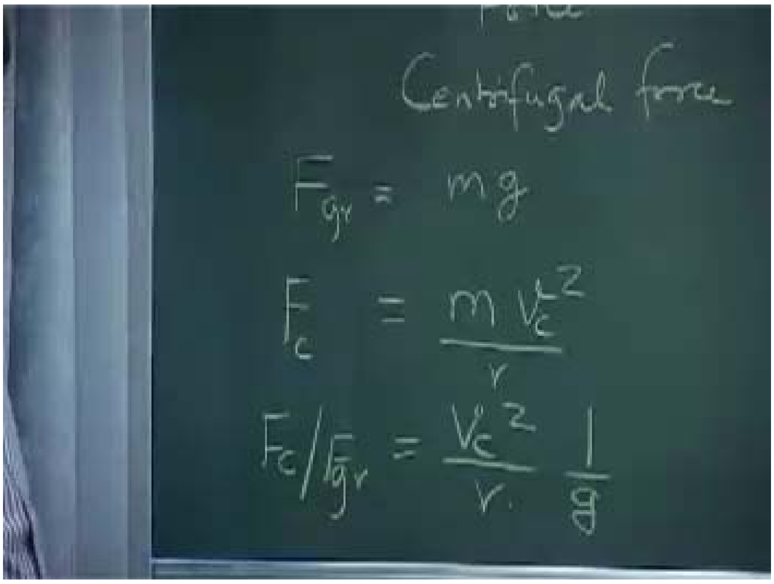

I take the ratio of these two forces or let us say F_c by F_g – this is a little concept, simple thing, but that is what you should know more than complicated things. If I say this, that becomes V_c square by r by g. Suppose I am able to give the centrifugal velocity as 20 meters per second and maintain a radius of let us say r equal to 1 meter, taking g equals to 10, how big is this force compared to F_{gr}? Please tell me. My V_c is at 20 meters per second, take g = 10 and r = 1.

[Conversation between student and professor - Not Audible (07:27 min)]

40 times.

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Just an example to explain as to why we are looking for the centrifugal force for r = 1 and V_c = 20. This ratio F_c is almost 40 times F_g – it makes sense that we should really apply the centrifugal force to remove the particle. Have all of you heard of the centrifuge, which we use in the laboratory? What are we doing? We are doing the same thing – we are applying a large centrifugal force to separate the particles from water and then they quickly settle at the bottom and then you decant it. Same thing, suppose the centrifuge was not there and if you had to use gravitational settling and then maybe you want to decant, you have wait overnight for 24 hours – you have to wait for a long time and hope everything will settle and you do not have such time. Even if you had such time, our processes are continuous and if we have to make water or air stable for many hours, the dimension required for the tank will be very very huge and that also is one of the constraints – not only may it take time but the dimension that you may require may be very very high. I am not saying that we do not use gravitational force, but we apply the centrifugal force in the engineering control of particulate matter in air pollution. Let us see the same thing from the point of the velocity through which the air will be removed.

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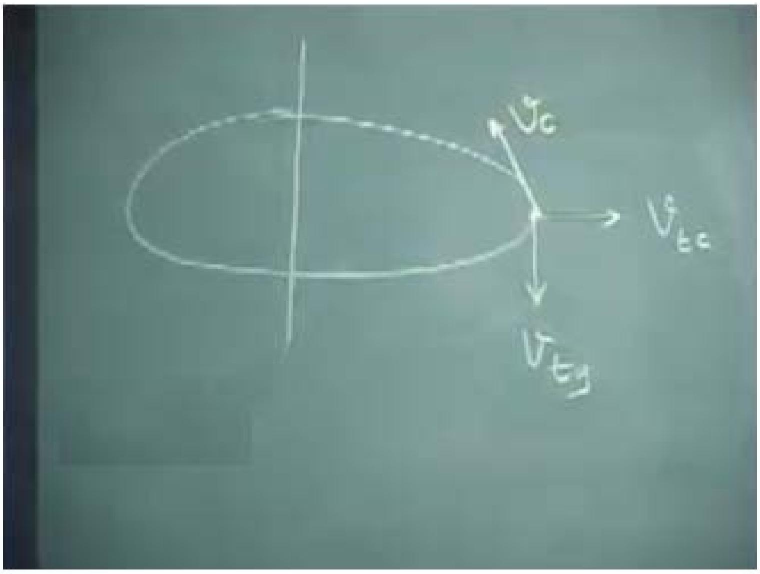

I take this as my axis and this as my circular path through which I am providing the centrifugal force. Suppose I look at this point and this is my terminal velocity due to the gravity part. In which direction will this centrifugal velocity act? It will try to throw it outside. Let us call that as V_{tc} and this is called V_{tg}. Where do I write my V_c? Where do I show my V_c? Tangentially here, right? This is my V_c. Ultimately, things are decided by the velocity apart from the force, so let us compare V_{tg} versus V_{tc}.

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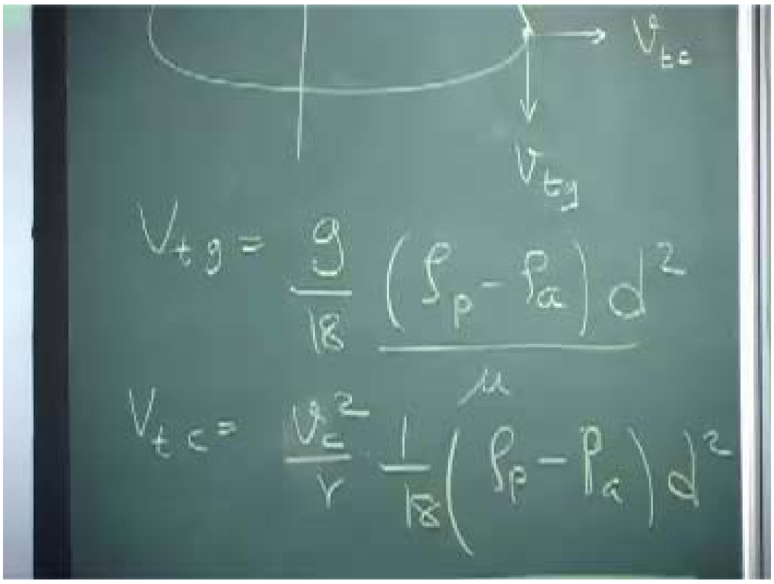

V_{tg} is terminal velocity due to settling. What is that? Which law governs that? Stokes Law. How do we get Stokes Law? What are the forces applied on the body?

[Conversation between student and professor – Not audible (10:38 min)]

Gravity, buoyancy and…? Drag. Drag, three forces and when the three forces are in equilibrium, the particle attains a constant velocity because your acceleration is 0, because the forces are in balance and you can find out this thing. If you recall, this will be… I recall it from my high school time, let us see, I will write g by 18 particle minus the medium, let us write this as p (Refer Slide Time: 11:12), particle… by mu. I have to find out the V_{tc}. My V_{tc} same forces are acting, but the additional the gravity here the acceleration if I replace the acceleration g here with the acceleration, I can get the same equation for the settling or removal velocity with the help of the centrifugal force. What should I replace the g with? Look at this and please tell me. What is the acceleration here? V_c square by r.

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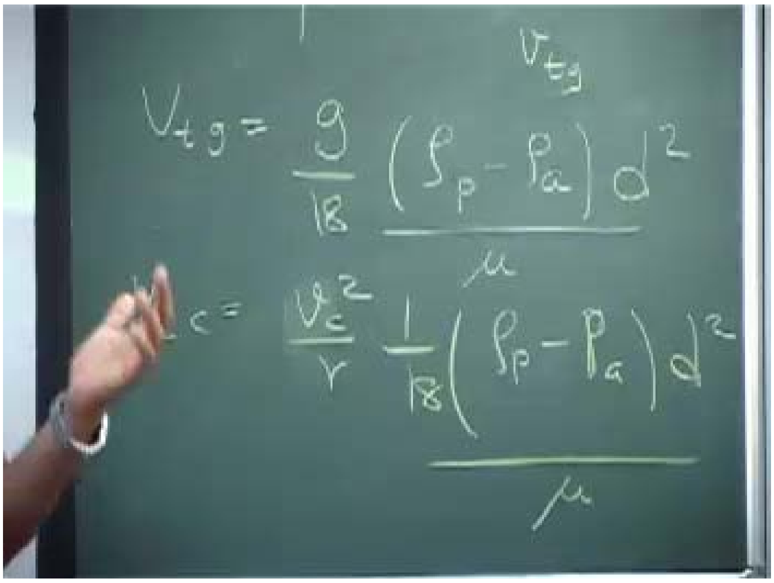

So I can replace g and I can get what will be the velocity of that – simple thing. If you agree, let us write here m, well, I do not have to write m, we write V_c square by r, 18 and the same expression. Suppose I take r = 1 and V_c as 20 meters per second, how large will V_{tc} be compared to V_{tg}? The particle diameter is the same, the viscosity of the medium is the same, this is same (Refer Slide Time: 13:02) and then you see here, I am taking V_c as 20. How much will the velocity be? 40 times, if I take r = 1 – something very similar to what we got; you can really find out in terms of meters per second. You see again that V_{tc} also is very very large. Then why do I not apply the centrifugal force to remove my particles? The device through which we use the centrifugal force to remove the particle we call as cyclone.

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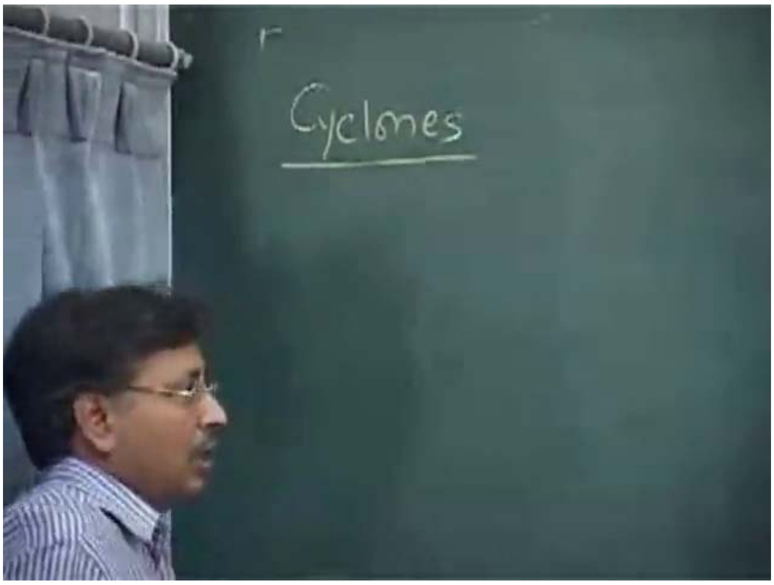

The devices that use the concept that we derived, again in a very qualitative sense, are called cyclones. Now, I will show you a picture of a typical cyclone so that I will save some time in drawing.

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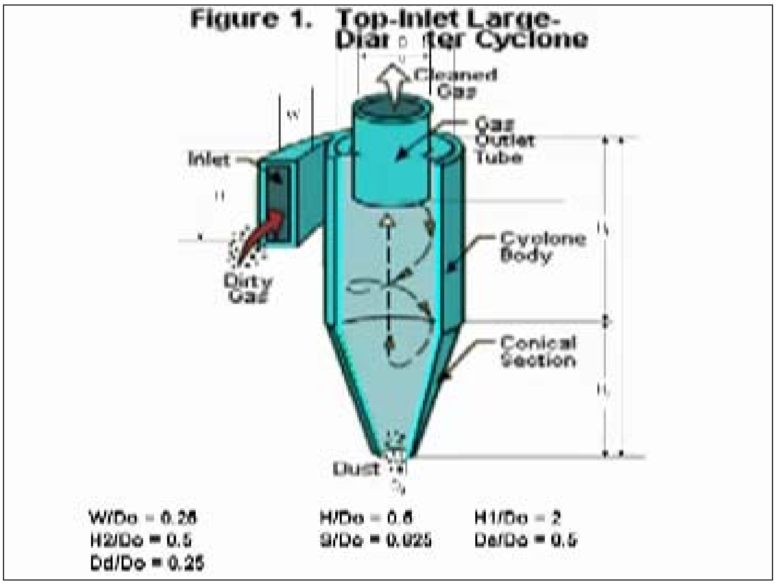

What I can do is I can introduce a high velocity tangentially. This is my inlet and I provide a tangential velocity. The important thing to see is this is H of the inlet, this is W – that is width, it goes tangentially around this one and then there is an outlet here and the gases and the particles will have circular motion. Once they get the circular motion, what will happen? Apart from this picture, I want to show you this thing.

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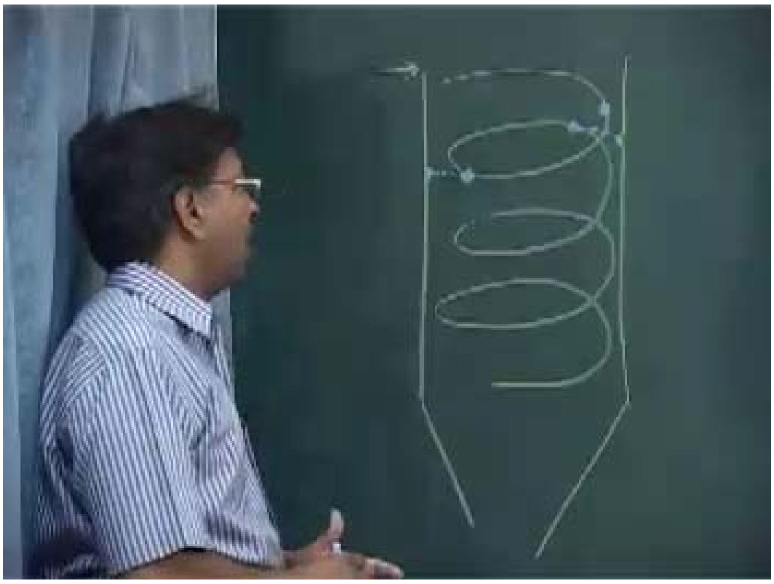

I will not draw the exact picture but let us see how exactly the centrifuge works. You are entering tangentially some gases and the gases will travel in the helical path and let us say the particles are sitting on to that one. Let us say this is a particle (Refer Slide Time: 15:46), this is a particle and let us say this is a particle – they will all go along with the gases. That is what is the helical path that is being shown here. If I talk about this particle, which one will have more inertia? The gas or the particle? The particle will have more inertia. As a result, what will happen? The particle will continue to move in its own direction and leave the stream of the gases. If we can continue with this thing, the particle leaves, this is the path of the gases and because of this tangential velocity, it will come here and hit the wall and with the impact, it will get stuck. Same thing with this particle – because of its own inertia, it will continue to move tangentially and then [16:52].

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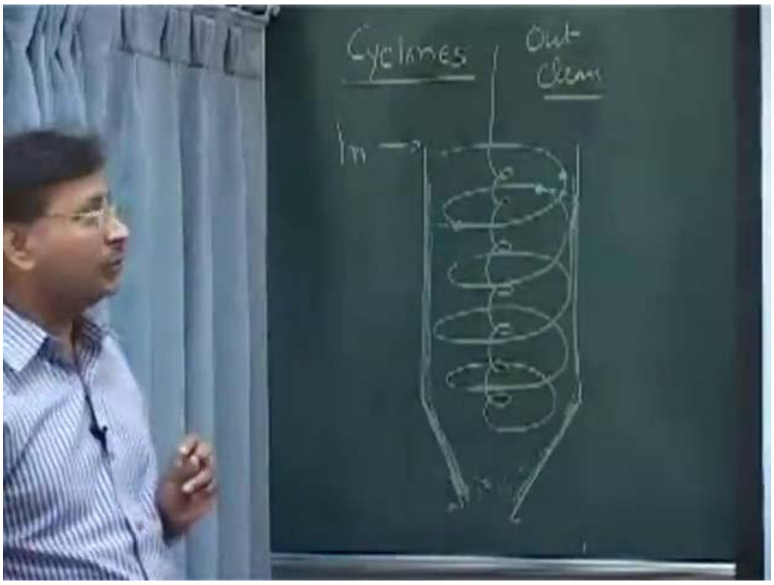

This is how the whole thing will go on – keep on going round and round and finally, when the gas is more or less clean, it moves back with the inner helical to go out. This is in and out and this is clean. You will see that within no time, the particles are depositing here and then you have the layer of the particles here, which then falls back into the hopper. They are the particles which can hit [17:46] and then they fall if we shake it a little bit or it will fall here just because of the cake, as it develops. This is the mechanism through which you remove the particle. One of the ways to remove the particle is to have the cyclone and that is what you see in the picture. I will just scroll the picture up and down and this is what you see. Of course, I will send this one through mail.

What you see here is the conical section, the cyclone body and things like that. I was wondering if I can make it small and have the full picture. My dimensions are gone. Anyway, we will correct that. Now you see the full picture. We call this the conical section, this is the cyclone body, the gas outlet tube – this one here is the gas outlet tube, this is the entrance. What you see here is this gas outlet tube is projected a little bit inside – if you do not inject it, before these particles go for a circular path, they will just be sucked right here, so this is put a little bit inside and you get the dust collected here. This is typically how the centrifuge works.

A few things I want to tell you are some of the dimensions you see here and what I am saying is important. D0 is the diameter of the cyclone, this is De – you have not mentioned – and that is the exit diameter; this distance is not from there because that is anyway connected somewhere – we do not know, but you see this distance to the outlet pipe first goes inside the cyclone body and it is… where do I write it? I did not write but take this as S. Then, the height from here to the cyclonic body is H1 and the conical section is H2, this diameter is Dd and D0 and d this thing. Every dimension that you see here – H, W, H1, H2 is defined in terms of the diameter of the cyclone; this is a standard practice and it works fine. An important thing is D0 and the rest H, W, H1, H2 and Dd are defined in terms of the diameter of the cyclone and the definition is like this.

Ratio of W (that was width for inlet) to D0 is 0.25 and H to D0 is 0.5. What was H? The height of the inlet. Suppose I am coming with a pipe that is a tangential, it is this height (Refer Slide Time: 21:08), so H by D0 is 0.5. H1 (that is the cyclone body) to D0 is 2 times. H2 is the conical section, you see here this is H2, it is again 0.5. S is the pipe, how much inside it should go into the cyclone to avoid short-circuiting – that is what is S, it is 0.625. De is the outlet – it is 0.25 and the bottom one, which is also important, is at Dd, you see here this is the Dd and this is 0.25.

These are fixed dimensions; somehow, you should come to know about the D0 – that is the diameter you want; the rest of dimensions are fixed. I am sure you must have seen some cyclone somewhere. So that is how the cyclone works. Let us talk a little bit more about the maths or theory of this. What we have defined here is the cut diameter of the cyclone. Cut diameter means the particle diameter that will be removed with 50 percent efficiency – that is how cut diameter is defined. Why we define the cut diameter is that otherwise we cannot define the diameter, because you cannot guarantee that something will remove with 100 percent this thing.

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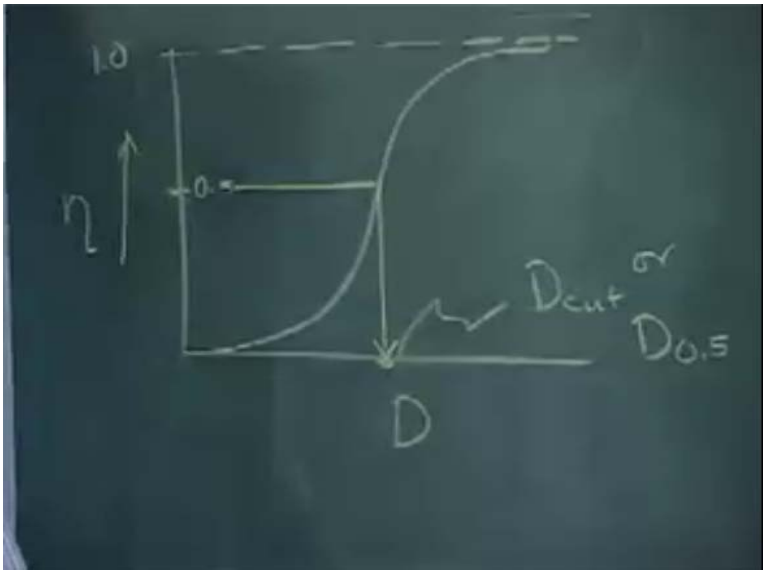

If I draw a graph to explain to you what exactly the D_{cut} is, this is efficiency of removal and I take D – the diameter, the particle will have various diameters, this is 1 (Refer Slide Time: 23:05) – means 100 percent removal and when you see here, this is 50 percent or 0.5, if you like and this is your D_{cut} or in literature, you will find this as $D_{0.5}$ and that is what is important for us to find out what particle will be removed fully. I will explain to you the terms that are there. The particles that are larger than this (Refer Slide Time: 24:03) will be removed like 99 percent, 98 percent and particles that are smaller than this one, they will remove with smaller efficiency. Have you seen our high-volume sampler or respirable dust sampler? You have not seen; it does not matter. Normally for a cyclone, we do not define the particles that will be removed 100 percent. The efficiency of the system, of the cyclone is defined as what is that diameter that will be removed completely with 50 percent efficiency. Here, this diameter as you see will be removed with 50 percent. Larger than this will be with higher efficiency and the lower one is higher efficiency. Now, let me explain what these terms are.

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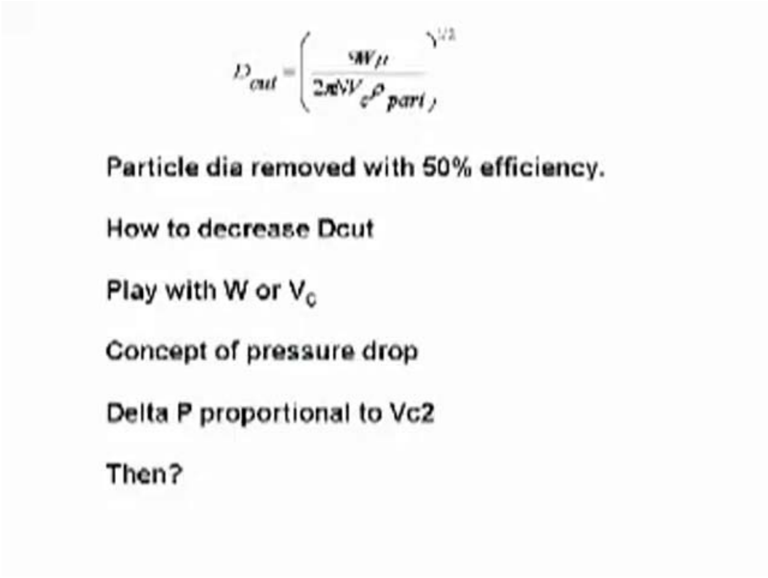

What is W? The width of your tangential pipe which is going to this one, mu is the viscosity of air, V_c is the speed that you could give inside, rho is the particle density and N is the number of turns that the gas stream could make – you see here, the number of turns of the outer helix; do not be confused with the inner helix – we know that in the inner helix, the turns will be very much larger. We have the outer helix in the cyclone, so N is the number of turns that it can make. You will not have calculators but let us discuss the same thing further. If you have decided that this is W, you know the number of turns it will take, you know the velocity that you are giving, you can find out the D_{cut}. Should we do an example? Let us see if we can quickly do it.

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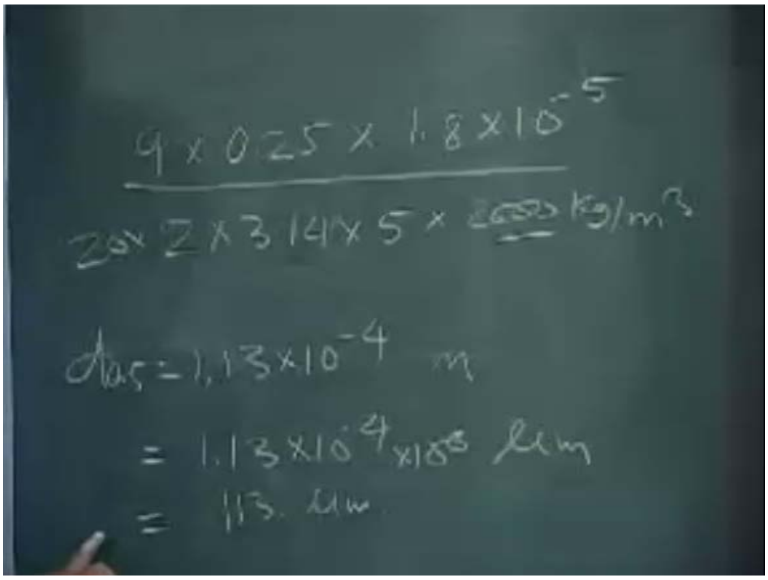

Let us say I take that as 0.25 – that is my width. How much is mu for air? Suppose I am able to give 5 turns for a particle, let us say 2 grams per cc, so I can write this as 2,000 kg per meter cube – it is the rho a; I have to have the V_c and let us say V_c I have to have the V_c two, so this is 20. I repeat: W, mu, V_c, 2, pi, number of turns is 5 and the particle density is 2,000 kg per meter cube. Can we somehow do it quickly or will it take some time? 1.13 into 10 to the power minus 4. 1.13 into 10 to the power minus 4, right? This is meters, very good. This is my D_{50} of this design I am talking about.

I can convert this into micron – we generally measure the particle size in microns, so 1.13 into 10 to the power of minus 4 times 10 to the power of 6 and that becomes micron meter and that will be something like this. It is really a hypothetical number I had taken, but generally, we are able to comfortably remove a particle with the size about 5 micron. Obviously, I have taken this as small – 0.25 meter (Refer Slide Time: 28:32) or this velocity could be increased. You can see that depending on the variables, we can go something like 5 micron meters of the particle and that can be comfortably removed, but then I must define what I mean by comfortable.

Let us see what is the comfort of the system. What is more difficult: to remove the larger particles or smaller particles? Smaller particles are always the problem. If I want to remove smaller particles, I must bring my D_{cut} down because I want the small particle. If I want to bring the D_{cut} down, what are the control variables I have? I cannot control mu, I can control W, I can control N but there is a limit for N because this will become too large, I can control

V_c, I cannot control the $rho_{particle}$. Then what are we talking in terms of the comfort of this or the particle size that can be removed?

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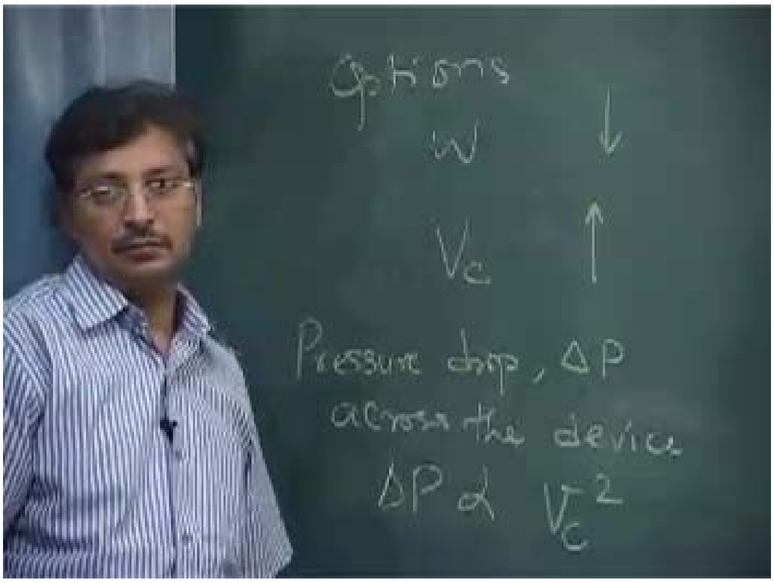

Particle size that can be removed. The options are I increase the W. Increase or decrease? Decrease, bring it down or increase the V_c and suppose N is constrained because of the length, so what do I do? I can decrease the W or increase the V_c. I want to define something important, which you will need to understand at least in qualitative sense: the pressure drop across the system. Before we see which is the better option – is this the better option or is this the better option, we need to define the pressure drop, which is delta P – across the device.

To just give you a feel, if pressure drop is high, what does it mean to you? Suppose you have two devices and one is having high pressure drop and the other is having low pressure drop.

[Conversation between student and professor – Not audible (31:20 min)]

V_c will be very high if…?

[Conversation between student and professor – Not audible (31:28 min)]

V_c will be very high if the pressure drop is high. We agree on that argument but let us not get into V_c. I have a system, leave aside that we have a cyclone, we have a room or we have to do the ventilation part – forget about the cyclone, then I have the pressure drop in the room – as the flue travels, there will be a pressure drop. If the pressure drop is more and I want to maintain a certain velocity, it means that if the pressure drop is more, more is the fan I will need to force the air through the system; if the pressure drop is more, I need a more powerful blower to blow my fluid through the system. If my blower capacity is more, it means my blower is more and the power requirement will be higher; if the delta P is high, it means I need a huge blower, correct? My power requirement will continuously go up. We will talk about this at some other point, but generally, delta P is proportional to V_c square. If I decide in my system that I want to improve my… or I want to decrease my D_{cut}, I can increase the V_c but I cannot increase V_c too much because otherwise, I will need a very huge blower and my pressure drop is high. If pressure drop is high, it means my cost of running the equipment will be high because my power requirement will go high.

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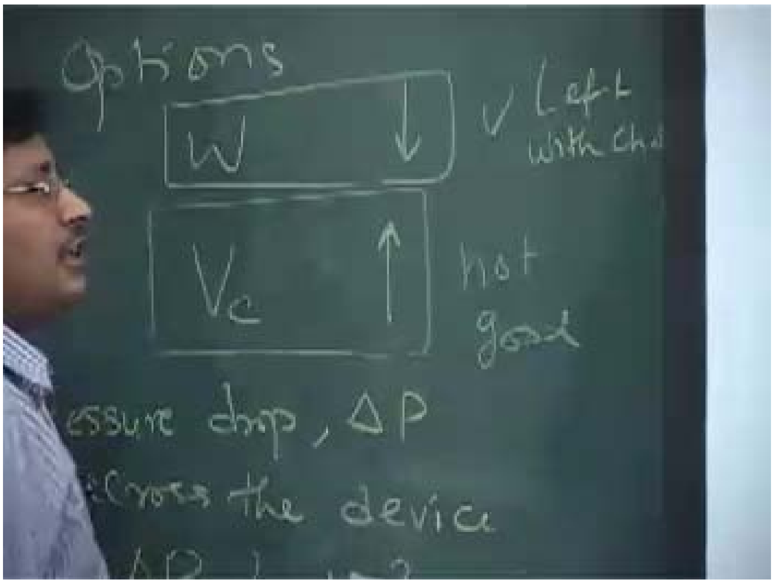

Of course, in the industry or wherever you are, the cost of power is a major consideration – the size of the blower is a major consideration, so generally this choice is not good (Refer Slide Time: 33:31). Then the choice I am left with is this: I can decrease W. If I decrease W, what happens to my cyclone? By the way, I want to maintain the same V_c because I am not handling the V_c – I do not want to change V_c. If I reduce the V_c, then again my D_{cut} goes up, so I am keeping this constant and I am reducing W and my cyclone becomes small. Then, it means I should have many cyclones to maintain the same V_c and reduced W. That system where we apply this concept, where we are reducing the W for the same V_c because we do not want to disturb V_c because of the pressure drop, such system is called multi-clones – multi-cyclones or multi-clones. Then by virtue of going multi-clones, I can reduce the particle size to a still reasonable extent. Remember I have more cyclones placed but I am not increasing my power requirement nor am I increasing my blower capacity. That is what is the thing and something I am sure you will see here. The same thing which I talked to you, that we have agreed and that is what you see.

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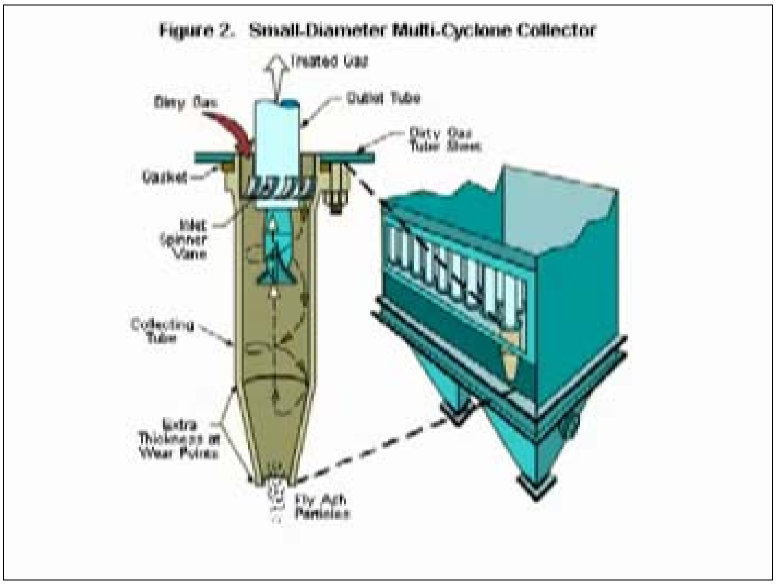

I am sure I can show you the picture and the concept of multi-clones. Here, we have many small cyclones. What you see here is that earlier, we were only designing one, but now what we do is we can design many of the cyclones. We can maintain V_c the same because we do not want to play with V_c and you see here, the W here, which is in some other form; somehow, you have to introduce the tangential velocity – you can cut the veins rather than provide the tangential. You can cut the veins and then you come here with the [36:00]. You get the cyclonic motion, fly ash or whatever the particle I have removed and this goes off.

What you see here is that the dirty air is introduced somewhere here and the whole thing is filled with dirty air and since it is tightly packed, the dirty air will be forced to enter into each of the cyclones and then the clean air will go up and the outlet of the clean air will be outside this ceiling. The outlet will be here, outlet will be here, outlet here, so the clean air goes out. Do you understand the concept? We call such things as multi-clones. Small, small one but there is a little problem. What is the problem? An important thing that you should write and understand is the pressure drop across each of the little cyclones that you see should be the same. If some cyclone has little lesser pressure drop, wherever there is less pressure drop, all air will go through that. Wherever the pressure drop is less, it means there is an open area and the fluid would like to follow the path of least resistance. Then, one of the cyclones will be loaded heavily and the others will not get the gas going through and that becomes a little tricky. You have to somehow ensure that the pressure drop across each of the tiny cyclones you see is the same – that is the key for operating multi-cyclones. Maybe you will not find so much detail in the book, but you can still read and the concept is like this.

They have some mechanism which is some kind of thing that they can measure the pressure drop across each of this thing and they have to maintain the same pressure drop. What does maintaining the same pressure drop mean? Maintaining the same V_c and you have to have identical dimensions – you cannot have one cyclone bigger and one smaller. You will find this in many plants; whether this is air pollution thing or you are just cleaning certain things within industrial processes, this is very very commonly used. Now you have got the concept of multi-clones and the reason why we need to go for multi-clones and why we need to maintain certain things in the multi-clone to ensure that it functions properly.

Then, I want to come to something else. But there is a limit to which you can do. Then again, we should think of applying some more force. The centrifugal force will work up to some level, but you see in combustion processes and many other processes, we encounter particles even in micron size – particles that could be 1 micron, 0.5 micron, 0.2 micron and they are more dangerous than the [39:09]. So if you are having the particle size larger, you should go ahead with the cyclone and be happy but that is not easy. Sometimes, one of the forces that additionally we applied is electrostatic force.

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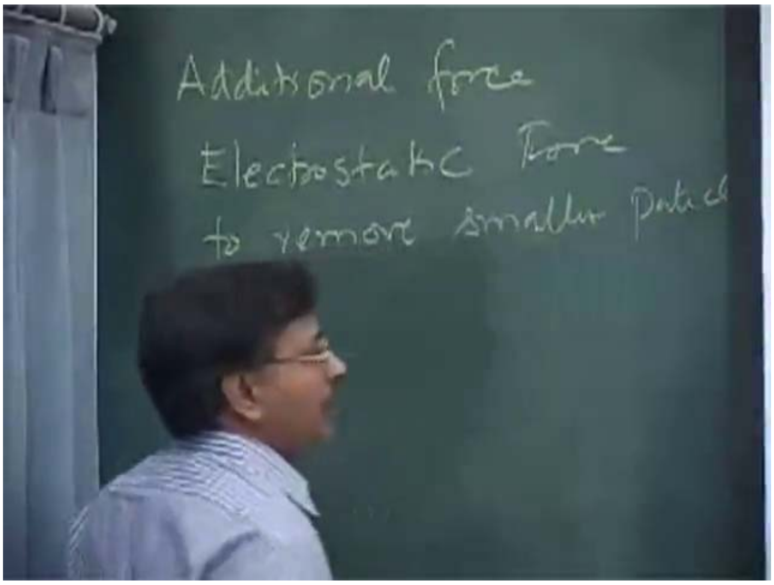

We will call it additional force – electrostatic force to remove smaller particles.

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Let us make some physics of this one as to why electrostatic force would be a better thing to do. Again, we are not talking about the ESP. Suppose I am driving the particle to come and get removed and I apply various kinds of forces. One force is the gravitational force or centrifugal force and there is a particle that is resisting; it does not want to come with this one or there is someone stopping him to be removed – that is normally the drag force. Let us try this, I will just see if I can try this, the drag force in terms of the diameter because we are focusing on the diameter. The drag force is proportional to diameter of the particle. If I say driving force, which may be gravitational force or centrifugal force, what is that in diameter? What is it? Square of the diameter? Square root of the diameter? Or cube of the diameter? Mass is the same. It is cube, right? Do you agree? This is d cube. What are the forces you take? There is mass and what is mass related to? More is the mass, then this is related to d cube, so it means it is proportional to d square.

In the case of electrostatic force, this is more like a surface phenomenon, so the ratio of this driving force to the resisting force… and this is surface phenomena – electric charging, electrostatic thing and it is d square by d, that is d. If I want to enhance this force when I am going to the smaller particles, my diameter will reduce by the square because now I am going from higher particle to the lower particle. If my diameter is reduced, it means my driving force is reduced effectively, because this will reduce with the square of the diameter. My d has become let us say now 0.5, so this ratio will be 0.5 into 0.5 is 0.25 and so it means my driving force is 0.25 and suppose I am using electrostatic this thing and if d has gone from 1 to 0.5, how much is the driving force now? Proportional to 0.5. My d has become 0.5 d, so my driving force is 0.5 d and here the force was reduced to 0.25 d. It means if I go with the concept of the electrostatic precipitators, with the same force, I can reduce much smaller particles.

Of course, you can do the mathematics part, writing equation, design even with the handbook but this is what you have to understand, because if I use the electrostatic force, then I can even go into smaller particles and I will still have my driving force, which is more compared to my gravitational settling or centrifugal settling, because my driving force will reduce here with the square in the diameter. From d whatever my force was there, I want to go for half of the size of the particle, so this force is 0.25, whereas here it will become only 0.5 and when I go smaller and smaller, it becomes more meaningful to go for electrostatic force and then use electrostatic force. Do you understand?

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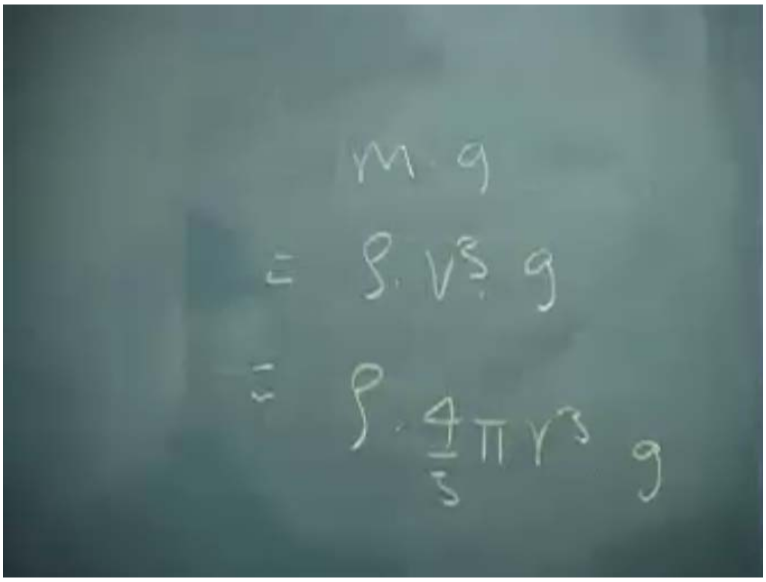

Those of you who have not understood why this force is proportional to d cube see here, because I saw someone quite blank. I am making the concept clear as to why the driving force was d cube. In m g for example, m I can write as rho V cube and rho times V, suppose it is a sphere for example, I can write 4 by 3 pi r cube, which is nothing but d cube, so that is where the d cube has come from.

[Conversation between student and professor – Not audible (46:00 min)]

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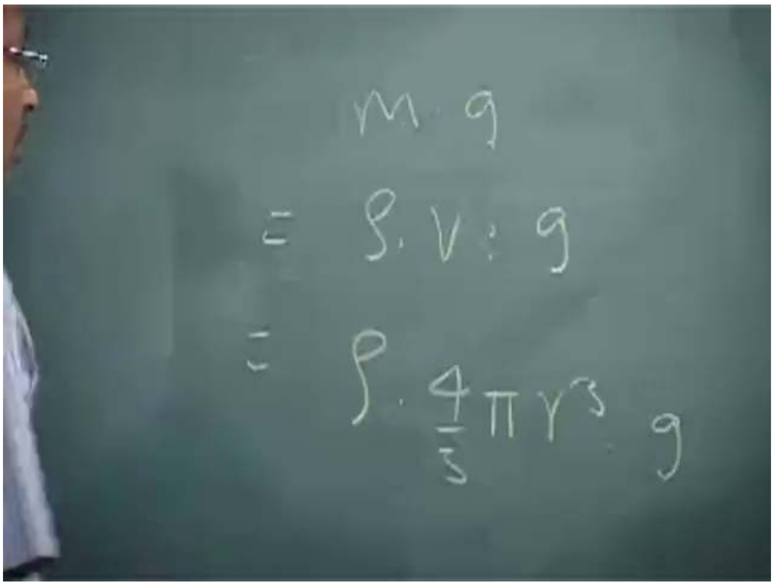

Oh, I am sorry. Now is this point clear as to why I wrote d cube here? This point is clear, so we can use electrostatic force and the system that uses the electrostatic force to remove the particles of the smaller… when we are interested in removing very small particles, we apply somehow the electrostatic force and the devices that use it are called electrostatic precipitators and the electrostatic force will be a surface phenomena.

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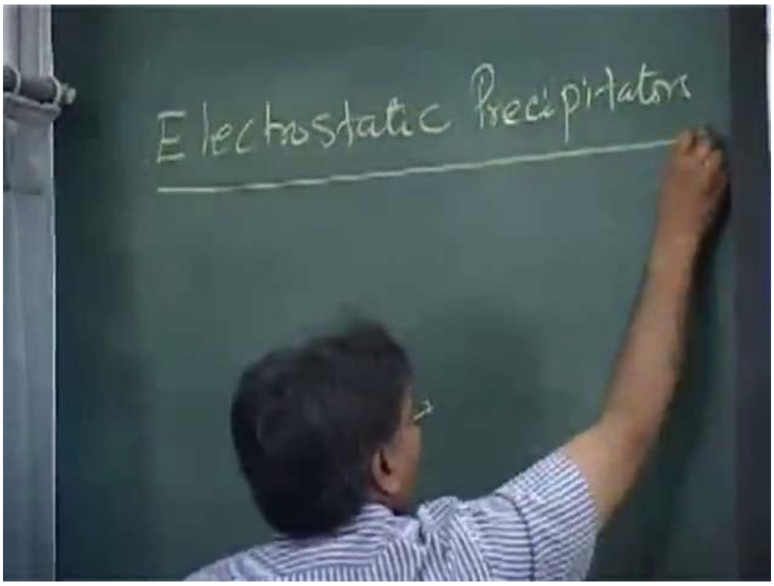

We will be discussing I do not know in the next class.…

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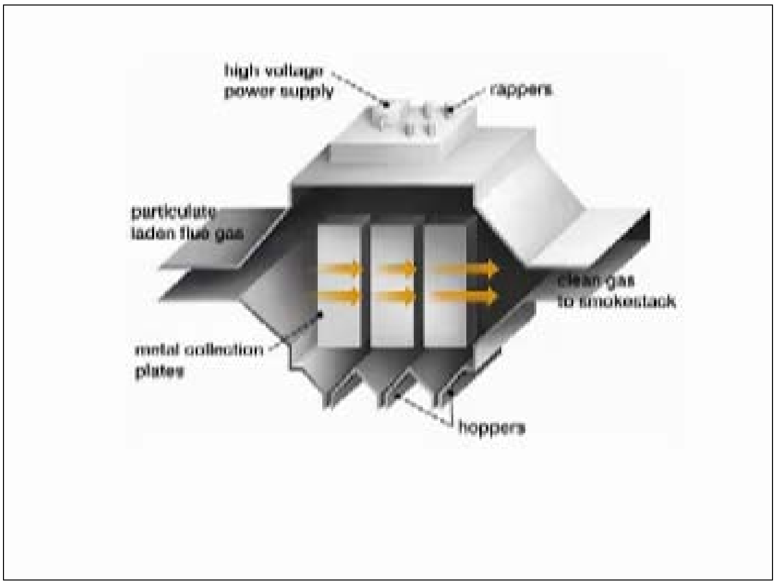

Electrostatic precipitators look something like this. I will explain you from inside what it is. See here, it is the dirty air that goes in there and I am not sure if you can see there are multiple plates [47:21] and within the plates, there are gaps, so this dirty air goes through them.

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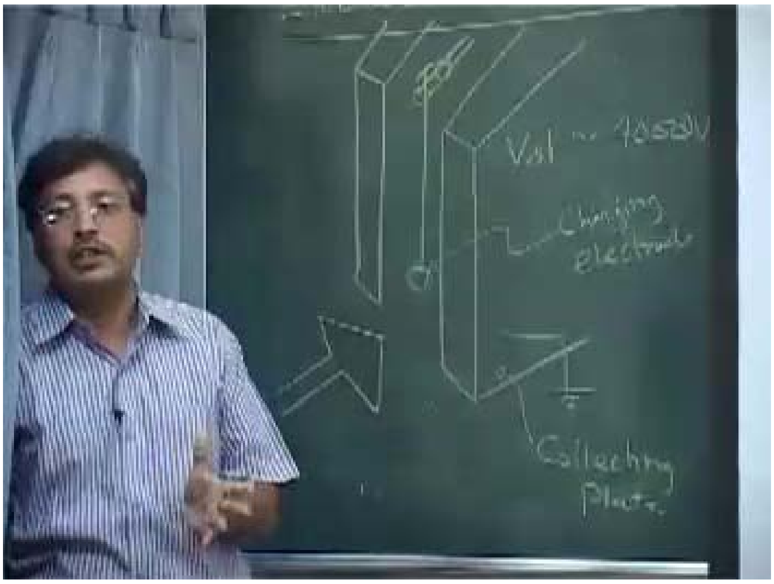

Just to make you understand, I will draw two plates and at comparatively much farther distance. I am drawing the same plates exactly but in three dimensions. Your air is entering from here, the dirty air is entering between the two plates and within the plates, what you have is a charging electrode; I have a rod here (Refer Slide Time: 48:32), which has a wire and that wire hangs like this with a heavy weight here – between the two plates, there is a pendulum that is hanging and you cannot see that here. There is some pendulum, which is a heavy weight so that it can stand; these plates are grounded. Then, you apply a DC voltage across the plate and the charging electrodes. This is what we call as the collecting plate and this one is the charging electrode and the voltage that is applied is of the order of 40,000 Volts and it is a DC voltage. Now what happens is once it comes through this one, these are some… and generally, this is negatively charged – this charging electrode is negatively charged. If we see from inside, there will be…

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If I can change the things here, let us see. Let us take the blowup of that thing. I think we will stop it here.