Air Pollution Control
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Lecture 46
Practice Examples on Particulate Emission Control Devices

Hello friends. So, as you know we have already discussed several Air Pollution Controlling devices, for example, electrostatic precipitators, baghouse filters or cyclones, even for gaseous air pollutants also. So, today we will have some practice examples related session on particulate emission controlling devices so that you can know how to calculate the size of the particle which can be removed easily or what is the efficiency of a particulate device with a particle size or distribution those kinds of things you will see.

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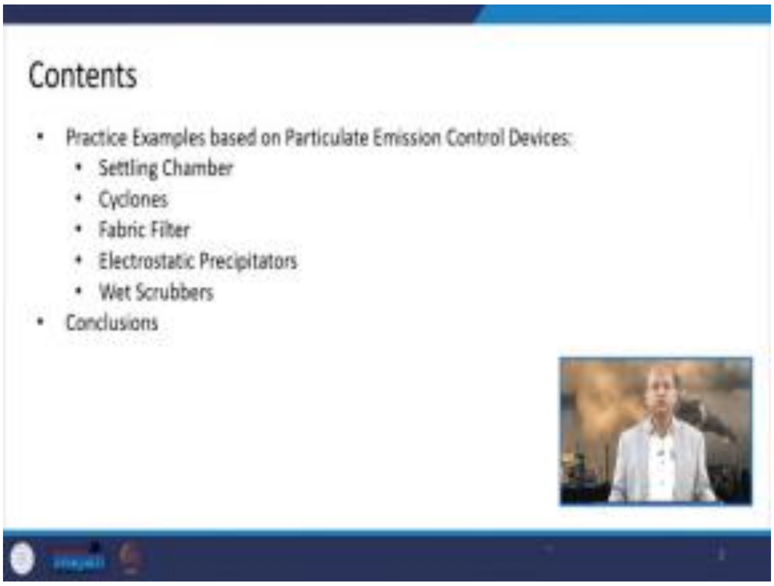

So, we will have this practice example session based on particulate emission control devices like settling chambers, cyclones, fabric filters, electrostatic precipitators, wet scrubbers and then we will conclude.

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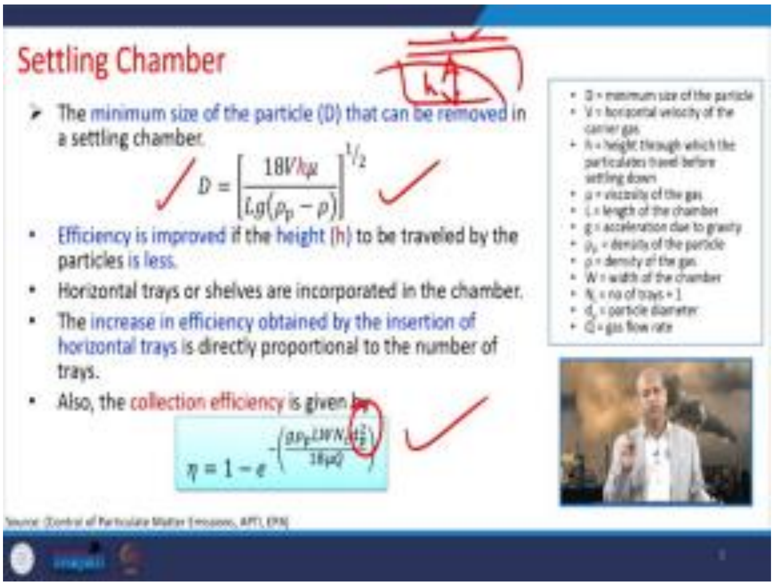

So, as we go for settling chambers as you know the minimum size of the particle diameter which can be removed in a settling chamber is given by this particular relationship where D is the diameter of the particle and then there are other parameters like horizontal velocity of the carrier gas which contains the particulate matter.

Then height through which the particulate matter travels before settling down in a settling chamber, because it moves horizontally and it also moves vertically, when it settles down due to gravity. So, we have this height h also like this is settling chamber. So, particle goes like this so this is the height and this is the length which it travels horizontally and this is the height vertically .

Then there are other parameters like viscosity of the gas where it will settle down, then the length of the chamber, this one and the acceleration due to gravity plus density of the particles and density of the gas and number of the trays, where we have settling chambers with different trays so that height can be manipulated and the particle diameter is there then Q is gas flow rate.

So, those kind of relationships are there for calculating efficiency and calculating the diameter. So, these are the particular relationships which can be used for calculating the diameter of the, minimum diameter of the particle which can be removed, that particular size of the particle can be removed efficiently and the collection efficiency of the settling chamber which can remove this particular diameter of the particle. So, that way this relationship is there between diameter of the particle and the collection efficiency.

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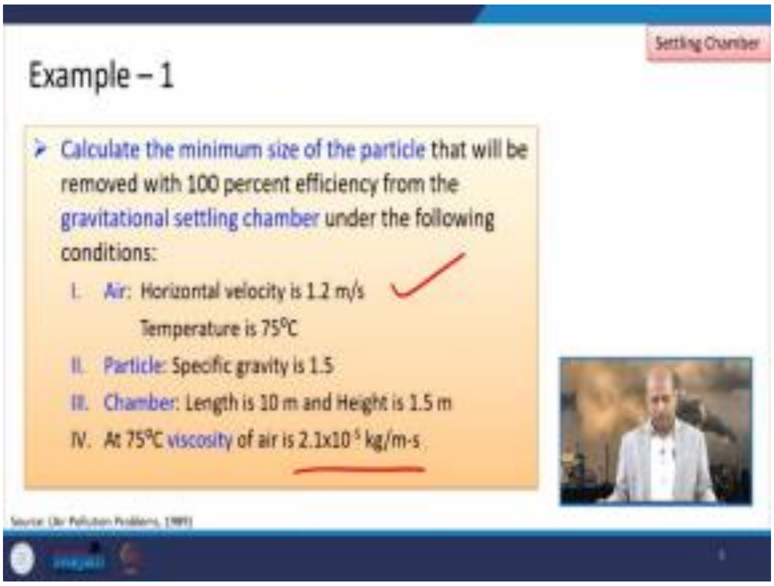

So, we go for understanding this particular relationship how to calculate the size of the particle which can be removed. So, here is the example that we have to calculate the minimum size of the particle that can be removed fully, 100 percent, in this gravitational settling chamber.

Under the following conditions like horizontal velocity, v is 1.2 meter per second temperature is 75 degrees Celsius, particle specific gravity is 1.5 and chamber has the length of 10 meter and height of the 1.5 meter and the 75 degrees Celsius this viscosity at the 75 degrees Celsius viscosity of air is given like 2.1 into 10 to the power minus 5 kilogram per meter second.

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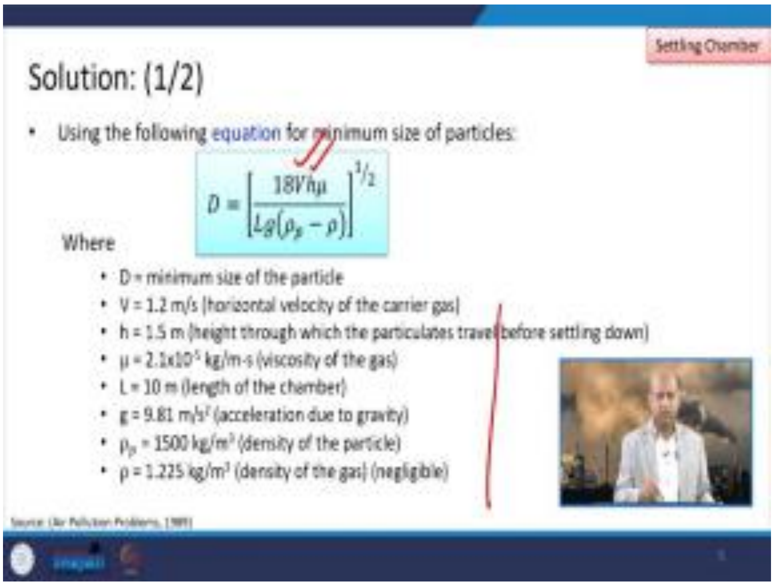

So, we use this particular relationship to estimate or to calculate the minimum size of the particle which can be removed fully. So, this is the relationship, we have all these values, v, h, mu, Lg, rho p(ρ_p) rho (ρ) all these values are there. So, we can put these values in this particular relationship and calculate the diameter.

$$D = \left[\frac{18Vh\mu}{Lg(\rho_p - \rho)}\right]^{1/2}$$

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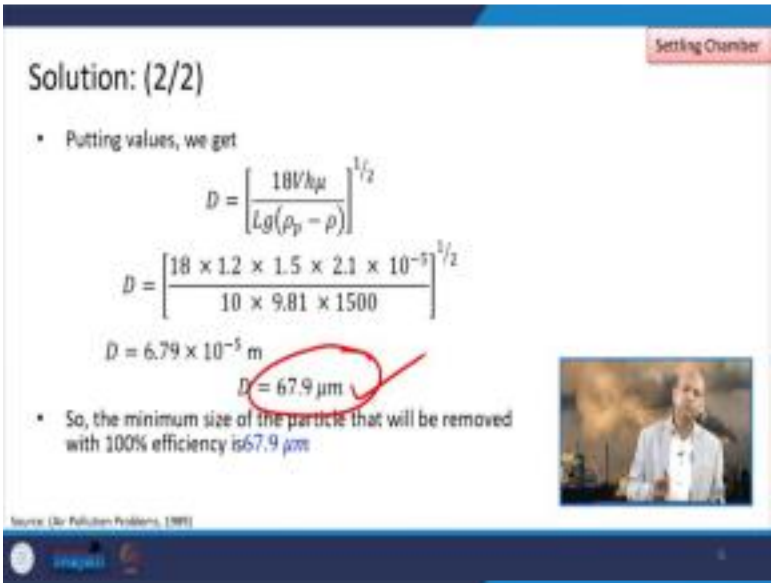

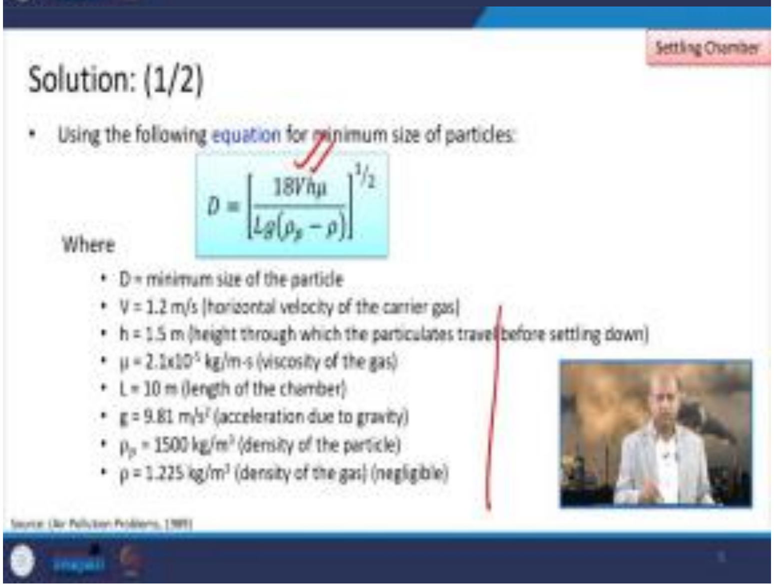

And this diameter is like around 67.9 micrometre. So, we can say that up to 67.9 micrometre size of the particles will be removed fully in this particular chamber of a given size with all these values, these values is governing like this rho p or the viscosity or the length of the chamber, height of the chamber all these within this particular condition, this is the diameter of the particle which will be removed completely.

Beyond that some percentage will be there, not 100 percent, but up to this means this is the minimum size of the particle which can remove fully, otherwise larger particles will also be removed but up to this size we can remove. Smaller particle will be difficult to remove in that way.

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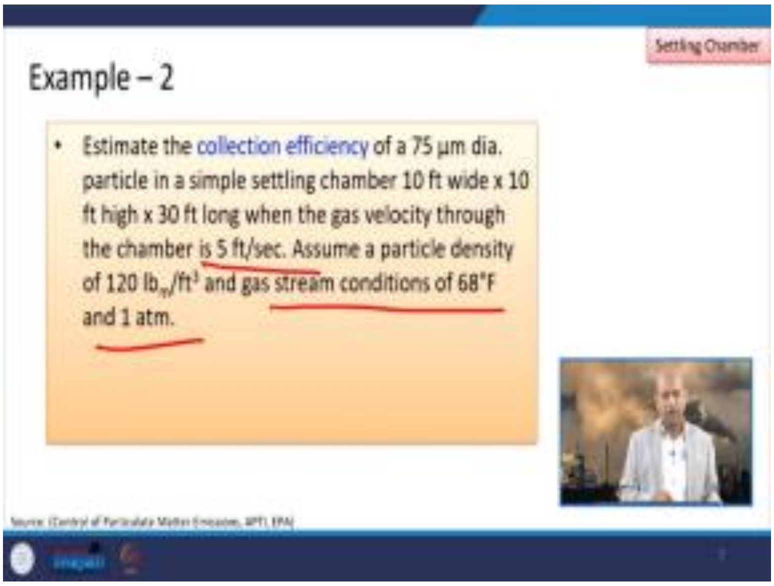

The next is estimate the collection efficiency of 75 micro diameter. If we say that 75 micrometre diameter is their sides in the particular particulate matter emission, so what would be the efficiency of the collection of this particular size diameter particle, in simple settling chamber where 10 feet is the wide and 10 feet is the height and 30 feet is the long one.

So, this is the chamber like 30 feet long, 10 feet wide and 10 feet is high. So, those are the dimensions. 5 feet per second is the velocity of the gas in the chamber and the particle density is around this 120 pounds per cubic feet, So, gas system conditions at 68 degrees Fahrenheit and 1 atmospheric pressure all these conditions are given.

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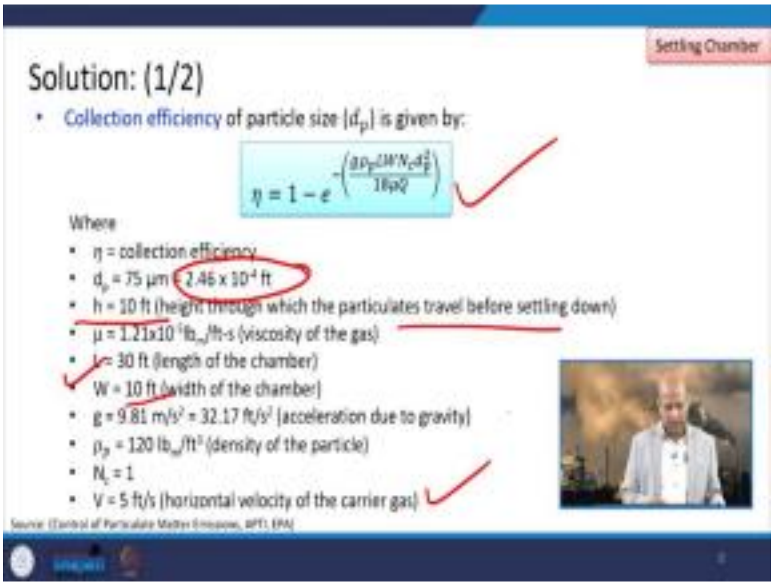

So, we use this particular relationship which we have seen that this efficiency is 1 minus e to the power of these parameters and these parameters are already given like diameter of the particle is 75 micrometre and we calculate or we convert it into feet because all other dimensions are in feet. So, that particular unit you have to use.

$$\eta = 1 - e^{-\left(\frac{g\rho_p L W N_c d_p^2}{18\mu Q}\right)}$$

Either you convert all those units into this meter, etc. or you can calculate only this diameter of the particle is in micrometres. So, it is easy to calculate it in feet and then other dimensions are given in feet. So, we go for this like length 10 feet width is 10 feet height is also 10 feet through which the particles travel before settling down.

Then other parameters are there like Nc is number of the plate is 1 only because there are no other plates in between, 10 feet is only the single size of the this particular chamber and V is the velocity, horizontal velocity of the carrier gas which contains the particles.

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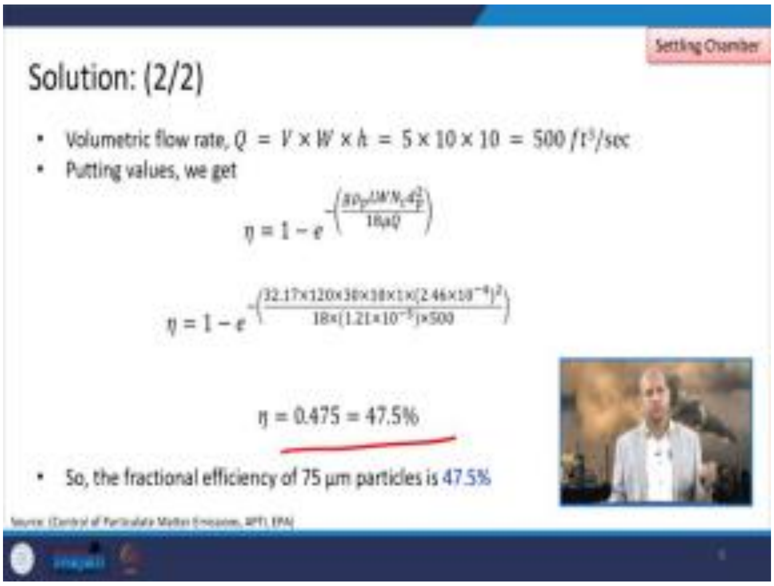

So, we put all these values and we calculate this efficiency and it comes around 47.5 percent. So, you can say that the fractional efficiency of 75 micrometre particles is around 47.5 percent or 48 percent. So, that much it is removed others may just bypass you can say like that short circuit kind of thing.

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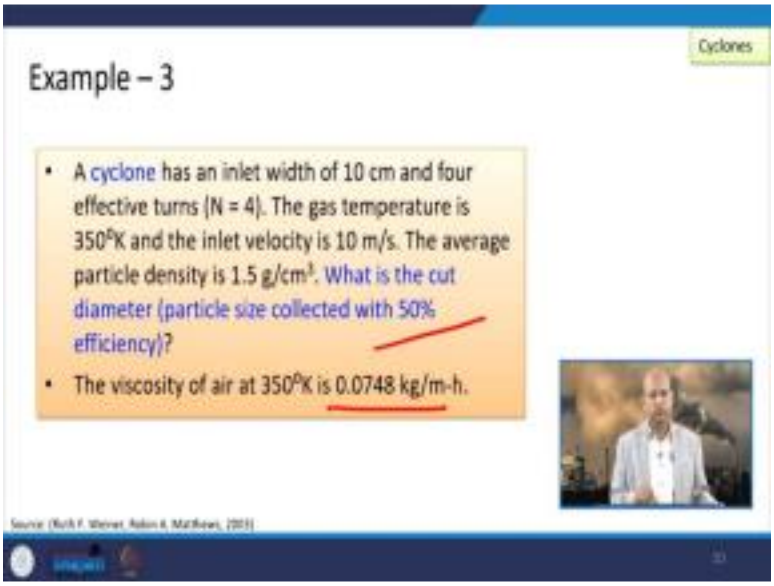

Well, then there is the example 3 for cyclone. So, a cyclone has been given which has inlet width of 10 centimetre and four effective turns like before this settle down, so, number of turns of the gas or this particle laden gas goes on before it goes up within the cyclone. So, these are number four. The gas temperature is around 350 degree Kelvin and the inlet velocity is 10 meter per second.

And the average particle density is 1.5 grams per cubic centimetre. So, what is the cut diameter particle size collected with 50 percent efficiency that is known as the cut diameter. So, you have to remember this particular this is not the minimum size which we have just seen. This is cut diameter which has the efficiency of 50 percent removal and the velocity of the air at 350 degree Kelvin is, this is viscosity of the air at 350 degree Kelvin is 0.0748 kilogram meter per meter per hour. So, this is also given.

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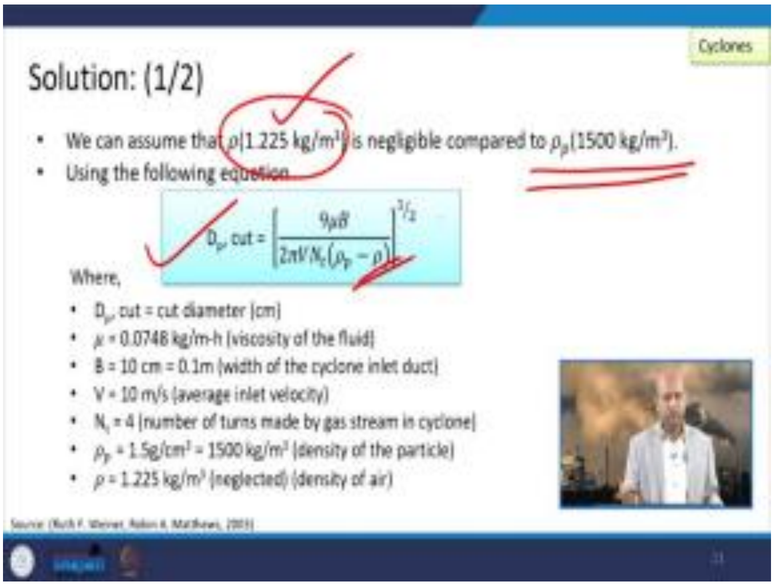

So, we use these values in this particular relationship, diameter cut, we calculate, we put these values of the density which is air density is negligible in comparison to the density of the particle which is 1500 kilogram per cubic meter. So, you can put here and you can ignore this parameter basically and all other values are given here.

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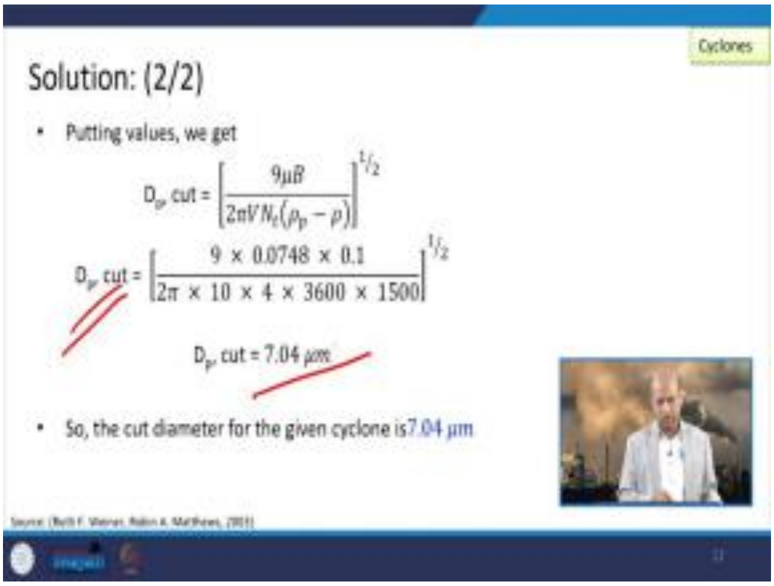

So, you use these values in this particular relationship and then calculate the cut diameter and this is around 7 micrometre. So, the cut diameter of the given cyclone is 7 micrometre, 7.204 7 micrometre. So, this particular diameter of the particle which will have the 50 percent removal efficiency.

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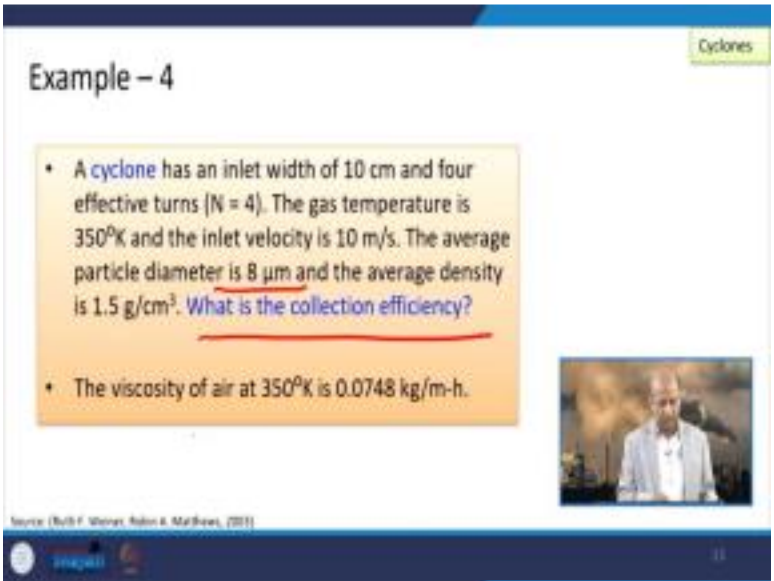

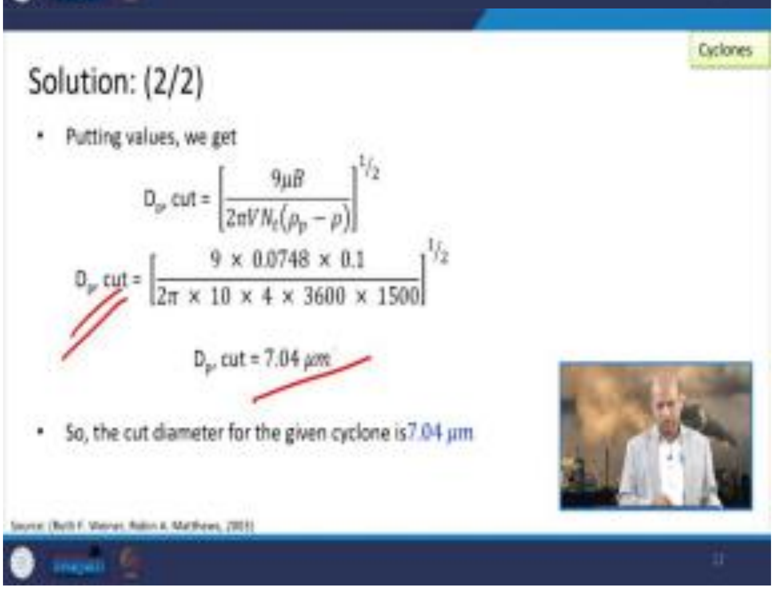

Well, next example is like a cyclone has an inlet width of around 10 centimetre and four effective turns. The same example is there the gas temperature and other parameters are already given. So, what is the correction efficiency for particle diameter 8 micrometre? Another viscosity again the same value is given.

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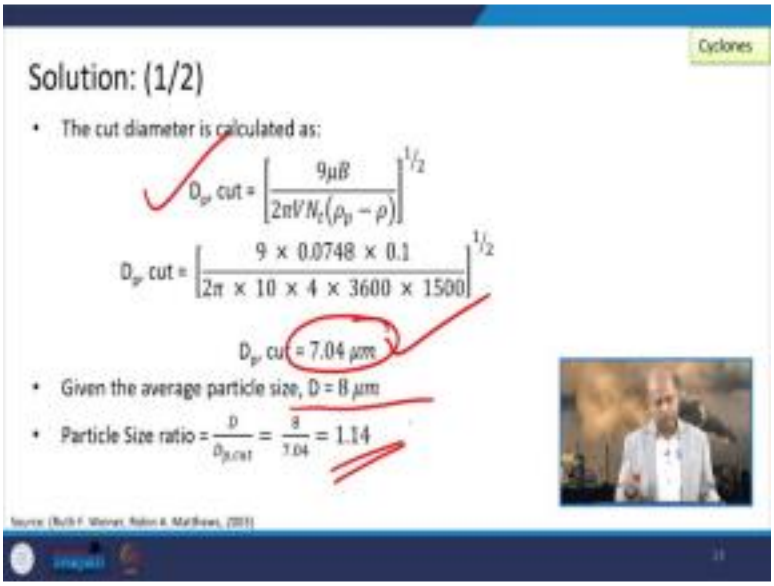

So, we go for calculating this using this particular relationship where this is the diameter cut diameter and then other values are their width etc. So, we put all those values and this is 7.04 micrometre cut diameter and the given average particle sizes 8 micrometre. So, we see the ratio how much this particle size ratio between D and D_{cut}. D_{cut} we already calculated 7.04. So, 8 divided by 7.04 is around 1.14. So, this is the ratio of the particle size which is to be removed and the cut diameter.

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And with this we use this particular graph to calculate the or to estimate the efficiency. So, 1.14 is given here in this particular particle size ratio and we go up and then go left and we calculate that this is around 55 percent. So, you can see 7.04 diameter particles is having 50 percent efficiency. When it is 8 micrometre, then the efficiencies 55 percent. So, expected collection efficiency is about 55 percent in this case.

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So, that way means as this particle size ratio goes up and then the collection efficiency increases of that particular size particles because size particular increases and it is easy to remove it. Then we come to fabric filter related example. So, this is one particular example where a fabric filter has around 2000 square meter of the filter area, total filter area and it treats 15 cubic meter per second of here carrying a dust concentration of 0.015 kg per cubic meter.

Assume these parameters like K_1 = 25 kilo Pascal second parameter K_2 = 10^5 per second. If the filter must be clean when the pressure drop reaches around 3 pascal kilopascals then what period must be there for cleaning these filter, baghouse filter or fabric filter you can call. So, that we need to estimate.

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So, what is given? Filter area is given 2000 square meter air flow rate is also given 15 cubic meter per second, then filtration velocity we can calculate easily because 15 cubic meter per second divided by this area. So, this is around 0.0075 meter per second. This is the basically filtration velocity. So, overall pressure drop across the fabric delta Pt, delta PR is conditional residual pressure drop, this is the air Delta Pc pressure drop due to dust cake.

So, these particular parameters we use. Delta P_t delta P_R Delta Pc, then this is particular relationship which we use and it can be written in simple way K_1 V + K_2t. So, we can use this particular relationship because K_1 and K_1 are given.

$$\Delta P_T = \Delta P_R + \Delta P_C = V\mu_g \left\{\frac{x_R}{K_R} + \frac{x_C}{K_C}\right\}$$

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So, you can see here this given value is 25 kilo Pascal second per meter so, we can write it as 25,000 Pascal. Similarly, delta P_t is 3 kilo Pascal. So, it is 3000 Pascal basically. So, these values we can use in this particular relationship.

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And we can calculate that way this t means how many what will be the time gap before this particular filter needs cleaning because otherwise it will choke and the pressure drop will increase. So, for the given pressure drop this relationship can give us the time, the frequency where it needs to clean.

So, this is around 9.26 hour. So, every 9.26 hour we need to clean this fabric filter otherwise its efficiency will decrease because pore size will be clogged by the particulate matter and the pressure drop will be very high that way energy will also be need more to push the air which is polluted air with the particles.

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Next example is like if the process gas exhaust rate is given around 4.72 into 10 to the power 6 cubic centimetre per second, around 10,000 cubic feet per minute and the filtration velocity is 4 meter per second and the air cloth ratio is 4 to the 1.

So, what would be the cloth area? Then the next problem is like further calculate the number of bags required in the baghouse filter that fabric filter. If the bag diameter is given like 0.203 meter or 8 inch and back height is 3.66 meter or 12 feet. So, both units both systems are given for the units, but you can use whatever system is there.

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So, the air cloth ratio is this $(A / C)_{gross}$ is $Q_{maximum} / A_{total}$. So, A gross you it is given 4 centimetre per second or 4 is to 1 you can use this particular relationship then 4.72 this value is given for $Q_{maximum}$ is this one. A total fabric area we need to see.

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So, we can calculate because this ratio is given air to cloth ratio 4 and this Q maximum is given. So, the A total can be easily calculated with this relationship. It comes around around 118 square meter. So, the required cloth area for that particular flow rate with that ratio is around 117.98 or 118 square meter.

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Well, next is the number of bags we need to calculate. So, here is the relationship of bag surface area, this A = πDL and then diameter is there 0.203 meter of the bag diameter that is used in the fabric filter, then length is around 3.66 meter of the bag and area this relationship can be used. So, diameter is given, length is given area can be calculated that is 2.33 square meter.

So, the number of bags required because the total area we have calculated already how much it is around 118 square meters. So, this 118 square meter 117.98 divided by area of one bag. So, number of bags can be calculated this is around 50.65. So, the number has to be full, we cannot have fraction half bag or like that, so the 50.65 means 51 bags we can have.

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The next is the baghouse filter is having around 20 compartments and 360 bags per compartment. So, this is a huge setup and each bag have diameter 11 meter and the bag length is 30 meter with a gas flow rate of 1,200,000 cubic meter per minute. So, we need to calculate the gross and net air to cloth ratio and we need to assume that two compartments are out for service when calculating the net air to cloth ratio. So, that is also given, that condition is there.

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So, given gas flow rate is there and then there are 360 bags per compartment number of bags is given and the 20 compartments are there. Within one compartment 360 bags are there, then bag diameter is also given. So, diameter is twice of the radius bag length is given. In circular fashion when bags are there, so if we open that bag basically the width will be the 2 πr or you can say πD.

So, that is why this height will be the length you can say. So, πD into h will be the area. So, this is h and this is πD. So, πD into h will be the area of the one single bag, this is around 1036.73 square meter, then total fabric area because 20 compartments are there one compartment has 360 bags, so 20 into 360 into 1 bag's area which just we calculated. So, it is around this 7.46 into 10 to the power 6 square meter.

Now we calculate gross air to cloth ratio. So, $(A/C)_{gross} = Q_{maximum}/A_{total}$. $Q_{maximum}$ is given we already know, so divided by this total area which we calculated. So, how much is there? This divided by this particular value it is around 0, 0.161 meter per minute. So, the gross air to cloth ratio is around 0.161 meter per minute.

Now, we want to calculate the net air to cloth ratio, the net fabric area is calculated by subtracting out the those compartments which are not in filtering service as , this is given that two compartments are out of service for service purpose. So, we can say that 20 minus 2 will be the net area, 20 minus 2 into 360 into this 1 bag's area. So, this is the net area.

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So, again we calculate this A/C. So, A net rather than A total we use A net. So, this value divided by this net area it arrives around 0.178 meter per minute. So, the net air to cloth ratio will be 0.178 meter per minute. So, that way we can calculate.

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Now, next is how to find the collecting plate area and the number of plates which are used for that surface area which can be used in a horizontal flow single stage electrostatic precipitator which is handling an average gas flow of 2.5 cubic meter per second from a pulverized coal fired boiler. The required collection efficiency is also given of that electrostatic precipitator which is 98 percent and the drift velocity is also given 12 centimetre per second.

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So, we use this particular relationship for calculating this area, available collection area because this omega value is given Q and efficiency is also given.

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So, we calculate area is around 81.5 square meter. Then, since the width of the ESP plate is generally between 0.5 to 1 times of the height, so, let us consider the plate. It will be of 4 meter wide and 5.2 meter height. So, the collecting plate area of the one surface is around 20.8 square meter and the total area we calculated is 81.5 square meter.

So, if we divide this total area with the area of one plate is this is 3.92 or you can say the four surfaces are needed because one single surface could be of the full value. So, the four surfaces we need and four surfaces can be here like one surface and the two surface of this plate two on either side; or the inner part inner side of the plate three.

So, the total four surfaces are there and the number of plates for this particular requirement of the four surfaces could be (4 – 1) = 3.

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Now, the next example is related to collection efficiency of a horizontal flow single-stage as it is given for this ESP and consisting of two sections found by plates of 4 meter wide and 6 meter height on 25 centimetre centers holding a gas flow of around this 2.5 cubic meter per second and we have to assume migration velocity is 12 centimetre per second.

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So, we know these values, 12 centimetre per second is the given this value omega and then A is 4 x 6 x 2 because those dimensions are given and then Q is we can calculate it flow rate per section 2.5 per by 2 because two sections are there. So, 2.5 / 2 = 1.25 cubic meter per second in each section.

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Now, we go for the efficiency. So, the efficiency relationship as , we give those values of the area like 48 which we calculated here and then 1.25 is the Q value which we already calculated here. And then we know this efficiency by this particular relationship this is around 99 percent. So, the collection efficiency of this particular device is around 99 percent.

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Now, if we find this migration velocity of an existing ESP or electro precipitator in which collection plate area is given 110 square meter gas flow rate 2.5 cubic meters per second collection efficiency is 99.5 percent.

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So, again we use this particular relationship which is very simple. Eta equals 1 minus e to the power minus omega A by q. So, given 99.5 percent efficiency is given. Q is already given 2.5, cubic meter per second. Area is given 110 square meter. So, we put those values efficiency and this Q value A value, so we can calculate this migration velocity or drift velocity omega. So, omega is around 0.12 meter per second.

$$\eta = 1 - e^{\left(-\frac{\omega A}{Q}\right)}$$

$$0.995 = 1 - e^{\left(-\frac{\omega \times 110}{2.5}\right)}$$

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So, now, next example is around this ESP again but we need to calculate the corona power that due to potential corona power for an electrostatic precipitator which is designed to treat around 9000 cubic meter per minute of the gas stream which is having this pollution of particulate matter with a collection efficiency of 99.8 percent.

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So, we go for this value Q is given 9000 cubic metre per minute. So, it can be estimated like in cubic per meter because this particular graph is given in corona power ratio which is having W per 1000 cubic feet per minute and then efficiency relationship is given. So, we need to calculate first in cubic feet per minute, we can convert this.

Collection efficiency 99.8 percent is given. So, using the below graph for this 99.8 percent we go to then come to this. So, around 330, 330 watt per 1000 this cubic feet per minute. So, this is there. Then this Pc / Q, so 330/1000 and into this particular value we can use. So, around 110,000 watt or 110 kilo watt Corona is required for this, Corona power is required for this particular device of ESP.

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The next example is how to collect the collection efficiency of 5 micrometre diameter particle with a density of 2 gram per cubic centimetre in a counter current spray tower, spray tower we have used a spray tower for even removing gases and for particles. Here we are removing the particulate matter that is why this diameter is given.

The tower site is 2.5 meter high and the gas flow rate is around 200 cubic meter per minute and the water flow rate is 150 litre per minute. Gas velocity is also given 100 centimetre per second and this droplet diameter is also given around 800 micro meter. So, that droplet diameter is also given. We need to assume the temperature of 20 degrees Celsius. And this factor correction factor is there 1 and flow to be a potential use droplet terminal settling velocity around 327 meter or 327.5 centimetre per second.

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So, this is the relationship for this collection efficiency of single size particle which was developed by this Calvert for counter current spray tower scrubbers. So, overall efficiency is given like this 1 minus exponential of these particular parameters these parameters are given here. So, those values we have taken from the given example.

$$\eta_{overall} = 1 - exp\left[-\frac{3}{2}\eta_I \frac{Q_L}{Q_G}\frac{z}{d_D}\frac{V_T}{V_T - V_g}\right]$$

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And then the relationship is there, impaction number and impaction collection efficiency that also we will use because impaction number first we can calculate why this relationship. So, this relationship can be used for calculation of impaction number when we know the efficiency. Eta 1 which we have efficiency due to impaction which we can calculate from this graph when we know the N1. N1 can be calculated by this particular relationship.

$$Impaction\ Number,\ N_I = \frac{d_p^2 \rho_p K_C (V_p - V_D)}{18 \mu_g d_D}$$

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So, first we calculate the N1value. This is around 0.439. So, from 0.439 we go up and see this sphere experimental potential flow go to left side and around 31percent is the efficiency of this particular spray tower.

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So, then we put those values and eta overall because this relationship eta overall here this particular. So, eta 1 you have calculated from this particular graph. So, we put these values of eta 1 here and other values VT VG etc. and we calculate the overall efficiency around 79.2 percent. So, that is the collection of overall efficiency of this spray tower to remove those particulate matter of the given size.

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So, this is the way to calculate either efficiency of a device or a particular size of the particle which can be removed efficiently. You can play with those values and you can learn this is the application of those relationships which are given for different parameters for a particular device, whether it is efficiency, whether it is diameter of the particle to be removed or the size of the device like the baghouse filter or number of plates required surface area required all these things you can estimate by using those kinds of relationships.

So, this is just to give a feeling that how we calculate different parameters when we are given certain values. So, we can see that using appropriate relationships which we have just discussed, the removal particle size collection efficiency of device and useful dimensions of particulate matter controlling devices such as number of bags in a fabric filter, area of the plates in electrostatic precipitator all these can be calculated when other values are given and some unknown values are there. So, this is all for today.

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Thank you for your kind attention. These are the references for additional exercises which you can practice in your free time. So, again, thank you and see you in the next lecture. Thanks again.