Environmental Air Pollution

Prof. Mukesh Sharma

Department of Civil Engineering

Indian Institute of Technology, Kanpur

Lecture No. 21

Examples for Practice

What we will do today is do some examples for some of the fundamentals that we have learned in this course about air pollution and air quality.

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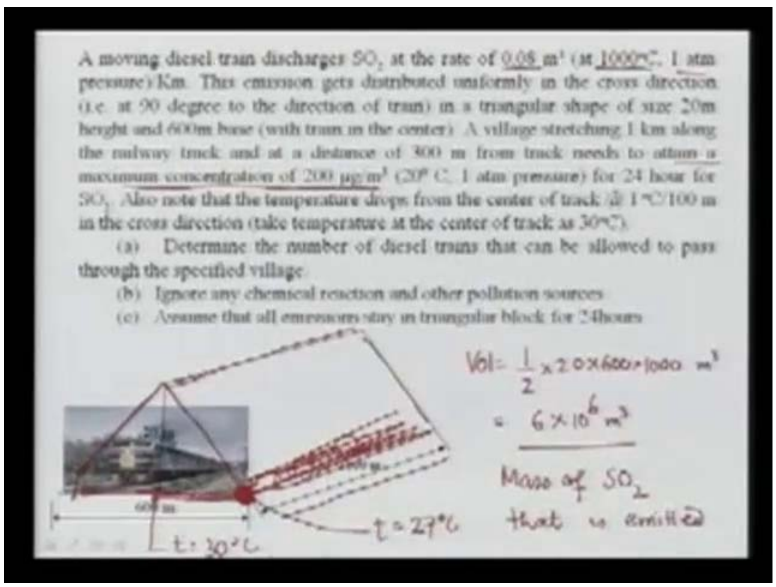

I will read the problem you see on your screen and then proceed to do its solution. A moving diesel train discharges SO_2 at the rate of 0.08 meter cube per kilometer but the condition at which it is discharging this, the temperature of discharge is you can see 1000 degrees Celsius and at 1 atmosphere. The emission gets distributed uniformly in the cross direction – that is at 90 degrees to the direction of the train in a triangular shape of size 20 meter height and 600 meter base with the train in the center.

Now, you can see a picture on your left-hand side. There is a train and you can see it is causing emissions. You can see the black smoke coming out from the diesel. The smoke is dispersing in a triangular area that has a base of 600 meters and height of 20 meters and the train is passing by a village. You can see a village stretching 1 kilometer along the railway track and at a distance of 300 meters – obviously, half of this is 300 meters, so here is the village and the village length is 1000 meters. So whatever emissions take place from the diesel engine, they are completely dispersed in the area that I am redrawing for you. This is the triangular shape and this is dispersed through the entire area of the village.

What is the emission? The emission is 0.08 meter cube at 1000 degree Celsius at 1 atmospheric pressure. Now let us see: a village stretching 1 kilometer along the railway track and at a distance of 300 meters from the track, so this is 300 meters from the track. You can imagine that these are the people and their houses – this is the area where the people are. We need to attain a maximum concentration of 200 microgram per meter cube. So in order for the villagers to be safe, you want to maintain an air quality of 200 microgram per meter cube and the condition for this meter cube is 20 degrees Celsius, 1 atmospheric pressure and the averaging time is for 24 hours.

Also, note that the temperature drops from the center of the track at the rate of 1 degree Celsius per 100 meters in the cross direction. So whatever it says the temperature as we go away from the center, because obviously this little heat here as you can see. As we go away from the center of the railway track, the temperature drops. Also, note that temperature drops from the center of the railway track at the rate of 1 degree Celsius per 100 meters in the cross direction and take the temperature at the center as 30 degrees.

What we are saying is that the temperature here is 30 degree Celsius and as we go away from the center, the temperature drops at the rate of 1 degree Celsius per 100 meters. So you can very easily say that the temperature at this point or the temperature all along the village, that is the temperature at this point, will be dropping at the rate of 1 degree per 100 meters. We are moving 300 meters, so 3 degrees Celsius will be dropped and so the temperature at this point – let us make it a little solid – will obviously be 27 degree Celsius. We have to maintain the air quality for the people living in the village – that is what the idea is. Now, let us try to solve this.

First of all, we know that the entire emissions taking place from the diesel engine are completely dispersed in this volume that I draw. First, let us see the volume in which it is dispersing – that we can very easily find out. It is the area of the triangle – that is 1 by 2 into the height – 20 meters and the base will be the total 600 meters. We have to find out the volume. What is the depth? It is 1 kilometer or 1000 meters. So this is the area in meter cube in which all the pollutants will be dispersed. Let us find out how much this comes out to be. I have a calculator here and I will try to calculate this for you quickly; 20 into 600 into 1000 divided by 2 is 6 into 10 to the power of 6 meter cube. We will remember this number – the air pollutants that are discharging from the diesel train will be completely mixed in this area. Now let us try to find out what will be the mass of SO_2 that is emitted. What I will do is I will rub this or maybe we can go to the next space.

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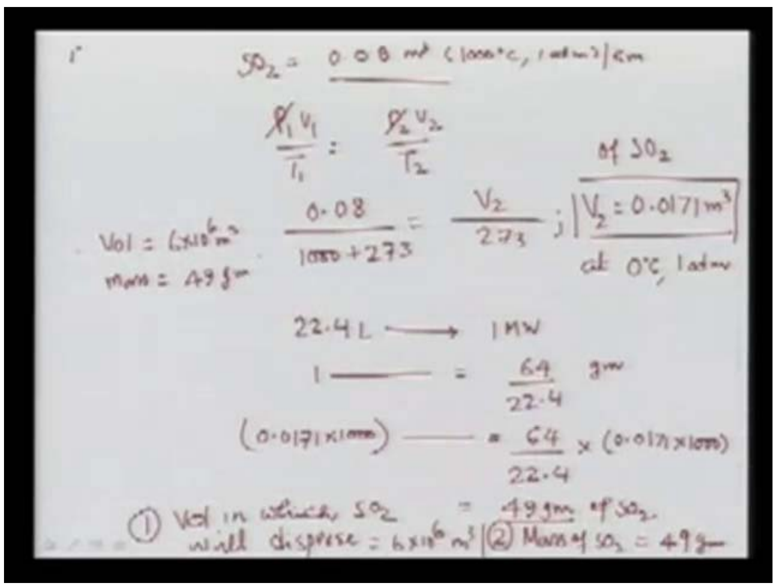

If you remember, what was the SO_2 emission? It was 0.08 meter cube. What condition? 1000 degree Celsius and 1 atmospheric pressure. Let us change this and this was per kilometer and the length of the village was also 1 kilometer. The total emission that we got from the train was this. Let us convert this meter cube first to 0 degree Celsius. If you recall, we have the condition P_1 V_1 upon T_1 is equal to P_2 V_2 upon T_2.

Let us say I want to find out…. The pressure is the same, so pressure strikes off. The volume here is 0.08 and what condition is this volume at? 1000 degrees, so make it Kelvin – we add 273. This is the volume I want to find out (Refer Slide Time: 07:21). At what condition do I want to find out this volume? At 0 degree Celsius. So simply, I can put here 273. Therefore, I can find out the value of V_2 – I will do the calculation separately here. 0.08 times 273 goes to this much divided by 1273 and this quantity comes out to be 0.0171 meter cube – this is the volume of SO_2, but remember at what condition? At 0 degree Celsius and 1 atmospheric pressure. Now I want to convert this volume of SO_2 into mass – let us do that. How can I convert this volume into mass? If you recall from the basic Avogadro principle, 22.4 liters of gas – let us write liter of gas – is equivalent to 1 molecular weight or 1 gram or 1 mole or I can say 1 gram molecular weight.

How much mass will 1 liter of SO_2 take? The molecular weight of SO_2 – 64 divided by 22.4 grams. Now, this was for 1 liter. How much volume do I have here? 0.0171. I can find out, I can also convert this into liters: 0.0171 into 1000 liters. How much mass will this give me? 64 by 22.4 multiplied by 0.0171 into 1000 – this is the mass of SO_2. I will do the calculation for you. Into 1000 multiplied by 64 and divided by 22.4 – this came out to be about 49 grams of SO_2.

What have we done? We have done two steps so far. First, we found out the volume in which SO_2 will disperse –we did that last time and that came out to be, if you recall, 6 into 10 to the power 6 meter cube. The second thing we did was find the mass of SO_2 that got emitted and that we found out as 49 grams. You have the mass of SO_2 and you have the volume in which it is dispersed, so you can find out the overall concentration of SO_2 in the volume in which the SO_2 got dispersed. Do not forget that there is a village sitting in the same volume. I will try to remove this and we will write these numbers separately here: 6 into 10 to the power of 6 meter cube and mass 49 grams.

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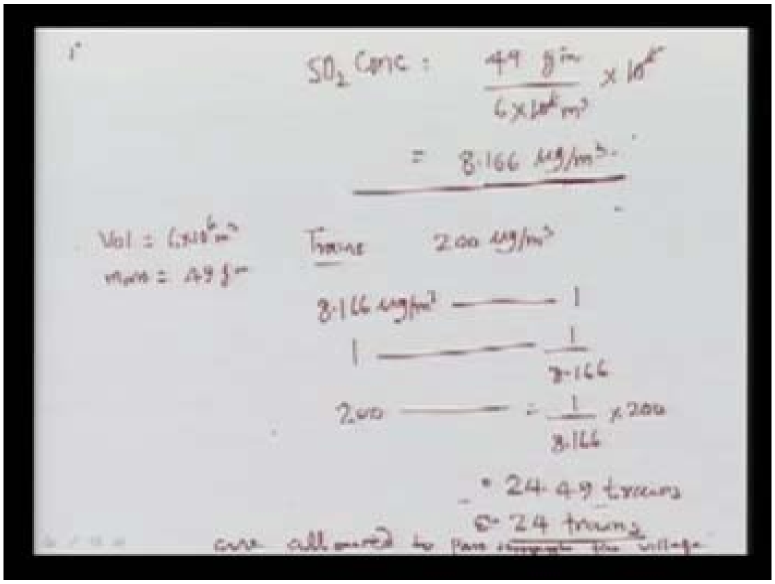

I will rub the whole thing. The next step for me would be to find out the overall concentration. How do you find out the overall concentration? Mass divided by the volume in which it is dispersed will give me the concentration of SO_2 in the region. The SO_2 concentration is this: the mass is 49 grams divided by 6 into 10 to the power of 6 meter cube. I can convert this gram into micrograms, so that comes out to be.… This will strike off, so I simply have 49 divided by 6 – it is the concentration per meter cube but this is not the final concentration. If you recall, our concentration is changing because the meter cube is changing – 1 meter cube is different…

If I can go back to this slide here (Refer Slide Time: 12:43), if you remember, the 1 meter cube at this point and the 1 meter cube at this point are different because the temperature is changing; this 1 meter cube here and 1 meter cube here are just not the same, so I must change this meter cube to the conditions that are at 27 degree Celsius, so let us find out that. How can we find the concentration at 27 degree Celsius? This meter cube you change and as you can see here, this is the overall meter cube.

What will happen is this meter cube will be different at the conditions 30 degree Celsius and at 27 degree Celsius. So we either convert this one or as approximately, because things will not change so much and so we can take the same concentration. Number of trains that can be allowed. What concentration do we need? The required concentration is 200 microgram per meter cube and 8.166 microgram per meter cube is contributed by one train, so 1 meter cube will be contributed by 1 by 8.166. I am allowed to contribute up to 200, so this will be 8.166 times 200 – this will become the number of trains that can be allowed to pass through the village. I do 200 divided by 8.166 and that comes to about 24.49 trains that can pass through here, but the number of trains has to be a full number and so the answer is that about 24 trains are allowed to pass through the village. This is how we can solve a simple problem and try to find out how many trains can be allowed to pass through.

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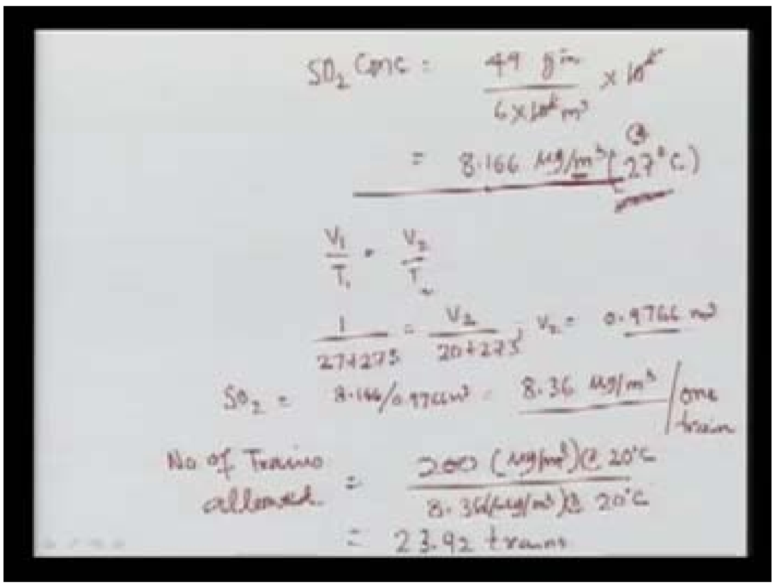

What we did is we found out the overall SO_2 concentration in the triangular area, but what we have to remember is that this meter cube as you are seeing here (Refer Slide Time: 15:47) is really a function of temperature and the temperature within the triangular shape or triangular prism is changing, so I must convert this to the required temperature where my standard is. I will try to go back there. If you recall, what was the standard that we wanted? 200 micrograms per meter cube at 20 degree Celsius. What is my temperature here? 27 degree Celsius. This meter cube really, the point where I want to find out, is at 27 degree Celsius – do not forget that. This is what I was trying to say and here, I am trying to make the sign ‘at’ for you – at 27 degree Celsius, because the village temperature is 27 degree Celsius but our standard is at 20 degree Celsius and so, we must convert this concentration at the 20 degree Celsius.

What I will do is that I will again follow the method V_1 upon T_1 is equal to V_2 upon T_2. What is V_1? V_1 is 1 meter cube. What was the temperature here? 27 plus 273. At what condition is the volume I want to find out? My standard is at 20 degree Celsius, so let us write 20 plus 273. My V_2 is equal to… I will do this: 293 divided by 300 – that came out to be 0.9766. This SO_2 concentration is really 8.166 divided by 0.9766 meter cube (because my 1 meter cube is really 0.97 meter cube). How much does this concentration become? I will do the calculation for you. Divided by 8.166, so that is marginally changed and it is becoming 8.36 micrograms per meter cube – this is the concentration in the village at 20 degree Celsius.

I will apply this and I will try to find out how many trains can be allowed. The allowed concentration is 200 micrograms per meter cube. This is the contribution by one train – let us not forget that. The number of trains allowed will be 200 (that was my standard that I have to meet) and this was at 20 degree Celsius and the concentration caused by one train was 8.36 micrograms per meter cube – this also I got it converted into 20 degree Celsius. It is very important that we convert both to 20 degree Celsius – the temperature as you see here was at 27 and my standard was at 20 degree Celsius – it is very important that I convert everything to 20 degree Celsius. Then I divide this and then let me see what the answer is: 200 divided by 8.36 comes out to be 23.92 trains that can be allowed to go through.

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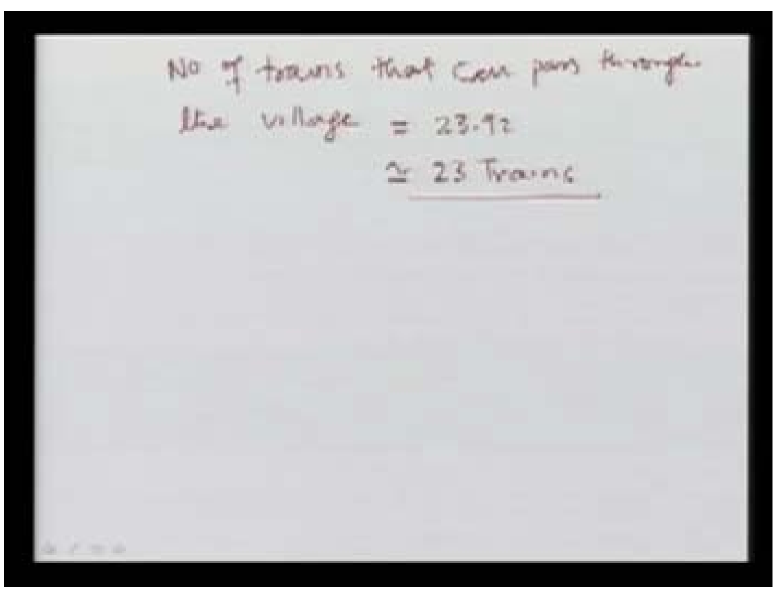

What did the answer come out to be? The number of trains or diesel trains rather that can pass through the village came out to be 23.92, but obviously, the number of train has to be a full number and not a fraction and so the actual answer should be 23 trains that should be allowed to pass through the village. It is really an interesting problem: it involved some practical aspect of what we have learnt and also applying some of the concepts or simple conversions and applying some sense of emission to the air quality standards or air quality norms that we need to attain. What will do is that we will move to the next problem now. You see the problem on your screen now.

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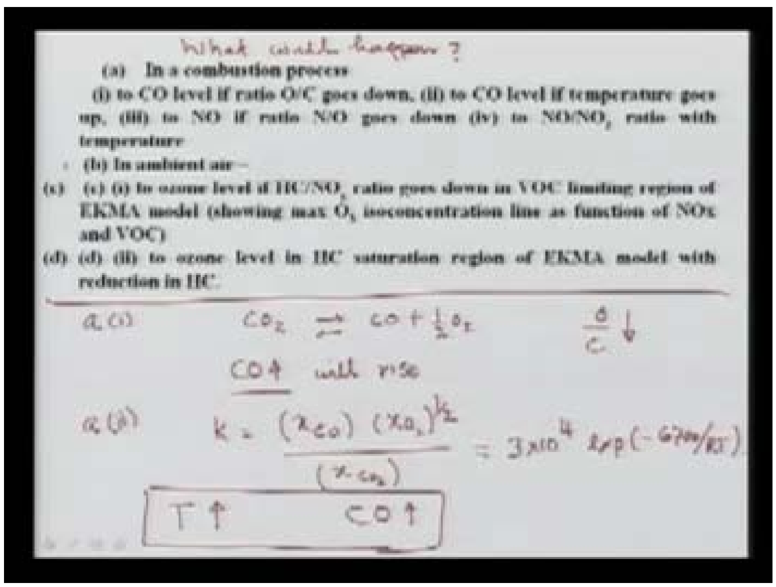

We will try to understand this – you have done this and the background is already there. The question we are looking at is ‘what will happen?’ I think I should write here ‘what will happen’ in a combustion process to the CO level if the ratio of O to C goes down, second thing what happens to the CO level if the temperature goes up, then to NO if the ratio of N by O goes down and to the ratio of NO by NO_2 with temperature. We will do them slowly one by one – let us not worry about that.

Let us do the first part – the (a) and in (a), what we want to do is subsection (i). What should we write? We should write the equation for CO_2. This is a reversible equation: CO plus half O_2 and do not forget that there is also energy – energy will be on the other side. This is the reaction.

What will happen? Of course, we had developed the mathematics but we can also apply common sense: if the O by C ratio is going down, it means my oxygen content is becoming less and less. If my oxygen condition becomes less and less, then the combustion will not be complete and so my carbon monoxide will go up, so CO_4 will rise. I will do it once again for you so that there is no confusion about this. Let us write the reaction again. In combustion, what happens? In the reversible reaction, CO_2 can be CO and oxygen as you can see here. The question says O by C goes down; O by C going down means that oxygen is going down; oxygen going down means that this level is low; then the reaction will be in this direction and so the ratio [23:32], so we will produce more CO. Is that clear?

Now let us try to answer problem (a) part two: what will happen to CO if the temperature goes up? We have to write the stoichiometry and the equilibrium constant. If you recall from the earlier lecture, the equilibrium constant here will be x_{CO} (I will explain to you again what is the meaning of x_{CO}) into x_{O2} by x_{CO2}, where x is the mole fractions. I can certainly write the equilibrium from my chemistry background. This K is equal to, as you will recall, 3 into 10 to the power of 4 exponential minus 6700 by RT.

If you see this, if the temperature goes up, what will happen to CO? Will it go down or it will go up? It will certainly go up because we can see from here that as the temperature increases, my K value will go up and so will the CO value – that is very clear. We have answered that in the combustion process, if we are decreasing the oxygen content, then the CO level will go up and if we are increasing the temperature in the combustion process, the CO level will also go up – that you can very clearly see. What we will do now is we will take…. We have done (a) part (i) and part (ii), so let us go to part (iii) now.

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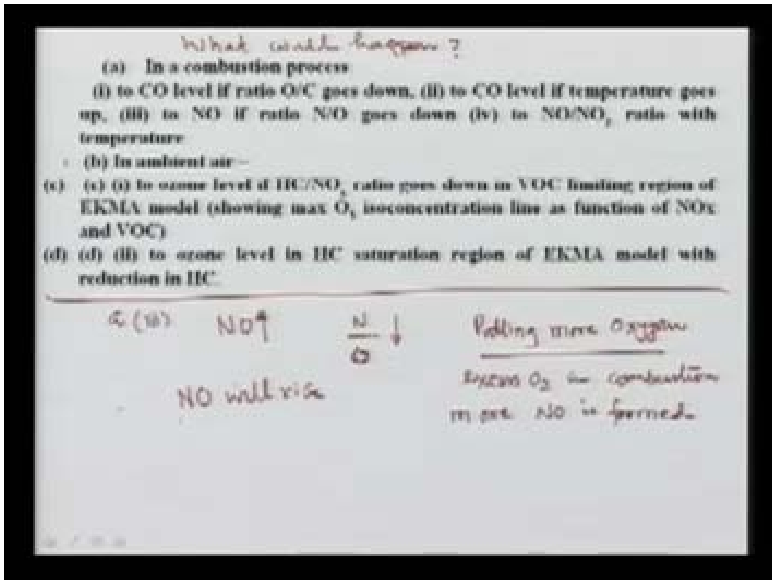

Let us do question (a) subsection (iii). The question is what will happen to NO if the N by O ratio goes down? If my N by O ratio is going down, it means I am putting more oxygen. We all know that if there is excess oxygen in combustion, more NO is formed. Recall what that NO used to be called – we used to call it as thermal NO. So the answer is if this ratio is going down, it means NO is going up – the answer is that NO will rise under this condition. Now, let us do part (iv) of the section (a). I will remove this.

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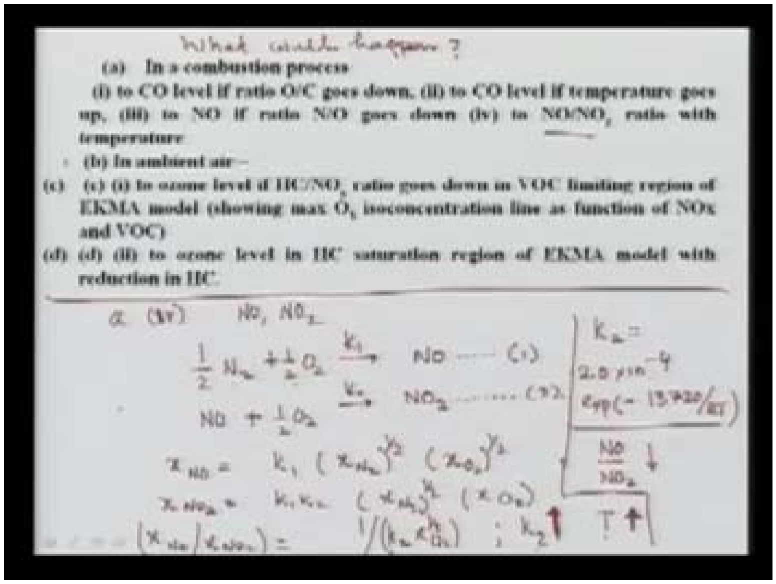

(a) and part (iv). This is a little interesting because it involves both NO and NO_2. What will happen to the ratio of NO to NO_2 with temperature? As the temperature is rising, what will happen to NO and NO_2? For this, we will have to write some equations and I will do that here for you. What was the formation that was producing NO? Let me write this equation as (1). This NO can further convert into NO_2 and let us write this as equation or reaction (2). What I will do is that I will write separately the equilibrium constant for equation (1) and equation (2).

Suppose the equilibrium constant for this is K_1 and for this is K_2. What I am interested in really is the ratio of NO over NO_2 and so I can write the equilibrium reaction in the form of NO and NO_2 using the equations (1) and (2). From reaction (1), I can write that the mole fraction of NO will be equal to K_1 times (x_{N2} to the power of 1 by 2) into (x_{O2} to the power of 1 by 2) – I am sure everyone can write that; I am just using this equilibrium constant and trying to write what will be the mole fraction of NO. Similarly, I can write the mole fraction of NO_2 using equation (2) but this time, both the constants are involved because reaction (2) depends on reaction (1). I can write x_{NO2} is K_1 times K_2 into (x_{N2} to the power of half) into x_{O2}. This is what will come.

I want to find out the ratio NO by NO_2. So I can find out the ratio x_{NO} by x_{N02}. K_1 will cancel, this will cancel and then I will have 1 by K_2 times x_{O2} to the power of 1 by 2 and this K_2 is the function of temperature. What happens? You can recall that as the temperature goes up, the K will go up – we all know from basic chemistry that the K will go up. I am sorry, this K_2 will go up. So if K_2 goes up with temperature, what will happen to the ratio? The ratio will decrease. I can try to give you the value of K_2. K_2 is equal to 2.5 into 10 to the power of —4 times exponential (—13720 by RT). As the temperature goes up, the value of K_2 will also go up and as K_2 goes up, the ratio will come down. We have not written the final answer, so let us write the final answer here. When the T is going up, K_2 is going up and this means this ratio is coming down. So with the rise in temperature, the ratio of NO by NO_2 will come down. Is that clear?

Let us go to the next problem now. We will do another problem and this is problem about the internal combustion engine. No, I think we need to answer something else before we do this. There is part (b) also of the problem – we did not look at part (b), so let us write part (b) also. We will rub this and let us make it (b) here. The (b) part says in the ambient air. This was inside the process combustion process and now this is in the ambient air. What will happen to the ozone level if the hydrocarbon to NO_x ratio goes down in the VOC limiting region of EKMA model? Do you recall the EKMA model and the results of EKMA? I can do it again.

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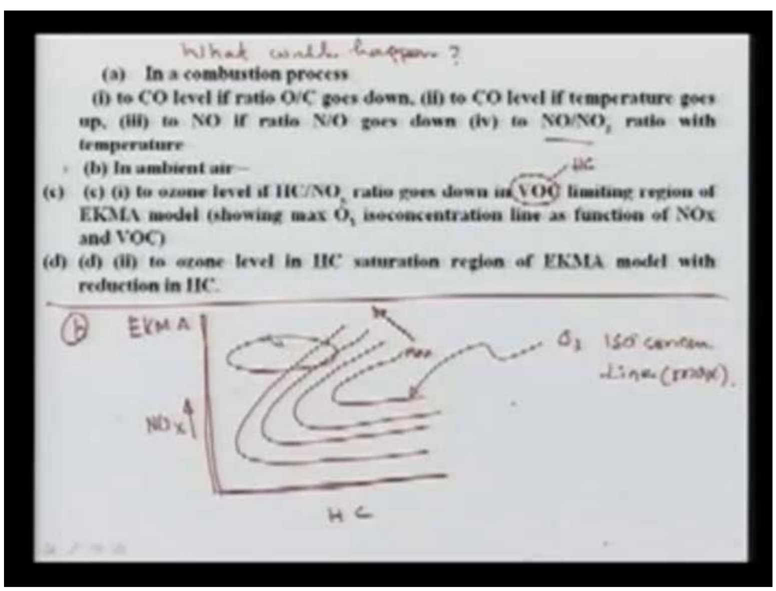

What was here? We had the hydrocarbons on this scale and NO_x on this side. We had plotted the levels of maximum ozone concentrations something like this – it was maximum and then the concentration will reduce in this direction (Refer Slide Time: 33:58). Once we have this EKMA, let us try to answer question (i) – what will happen to the ozone level? These are all ozone levels – do not forget. What are these? Ozone iso-concentration lines – of maximum concentration. Then as we go in this direction, it will reduce. Let us look at the problem – what will happen to the ozone level if hydrocarbon to NO_x ratio goes down in the VOC limiting area. Which was the VOC? Let us understand VOC – it is the same as hydrocarbons, so let us not get confused about this. So which area is the VOC limiting area? This region (Refer Slide Time: 34:57). Why VOC limiting? It is because I have high level of NO_x here and the VOC is low. We can even draw one more picture.

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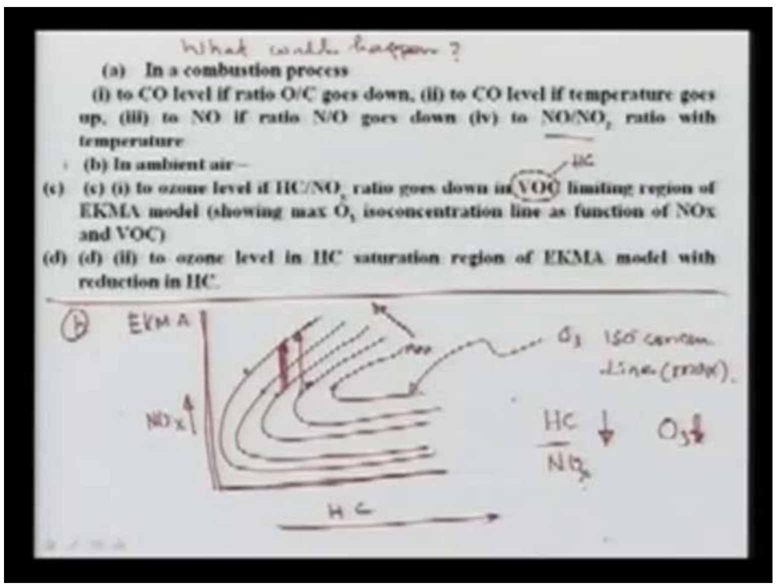

Let us remove this and let us make one more. This area is my limiting region of VOC – VOC limiting, because here VOC is very low and as I am going in this direction, my hydrocarbon is increasing, so this is the area. Now the question is what will happen to HC to NO_x? What is happening to this? It is going down. How can it go down? I can increase NO_x and so I am increasing the NO_x. If the ratio has to go down, I have to increase the NO_x; if I am increasing, I am moving in this direction and as I am move in this direction, my ozone levels are dropping because this is the maximum ozone concentration; then smaller, then smaller, then smaller, then smaller – by increasing the NO_x, I will reduce the ozone level. Somebody can argue that I can reduce this ratio by decreasing hydrocarbon. Let us consider that also.

At least we understand that if we are decreasing this ratio, my ozone level is also decreasing. Why decreasing? I repeat: in order for this ratio to go down, my NO_x must increase. I am increasing the NO_x – as you can see, I am going from down to up and my ozone level is going down and I put the down arrow here.

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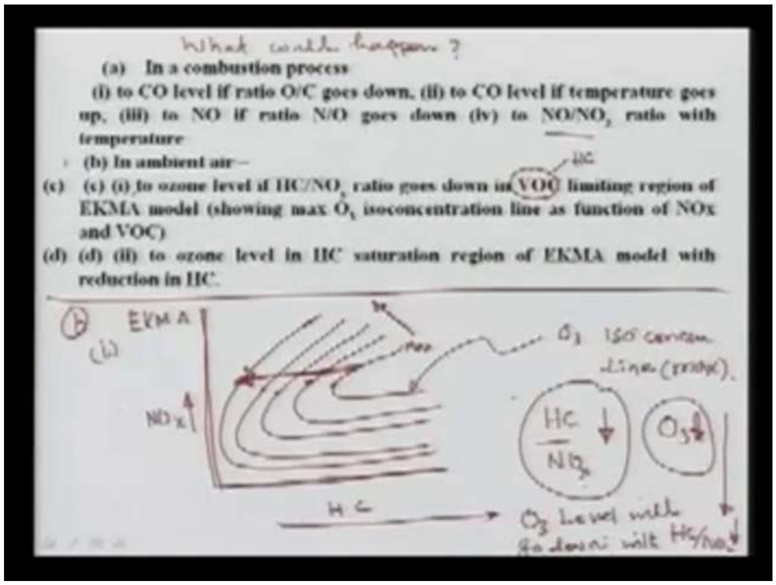

I can also decrease this ratio by decreasing the hydrocarbon. Let us see if I can remove this. I can decrease this ratio by decreasing the hydrocarbon. It means again I am moving in this direction (Refer Slide Time: 37:12). If I move in that direction, what does that mean? Again, my ozone concentration is dropping and so I can conclude that as this ratio goes down, my ozone level will also go down. The answer is that the ozone level will go down with the ratio of HC to NO_x – that is the answer that I will give to problem (b) section (i). We have answered this one. Let us quickly also answer the next part.

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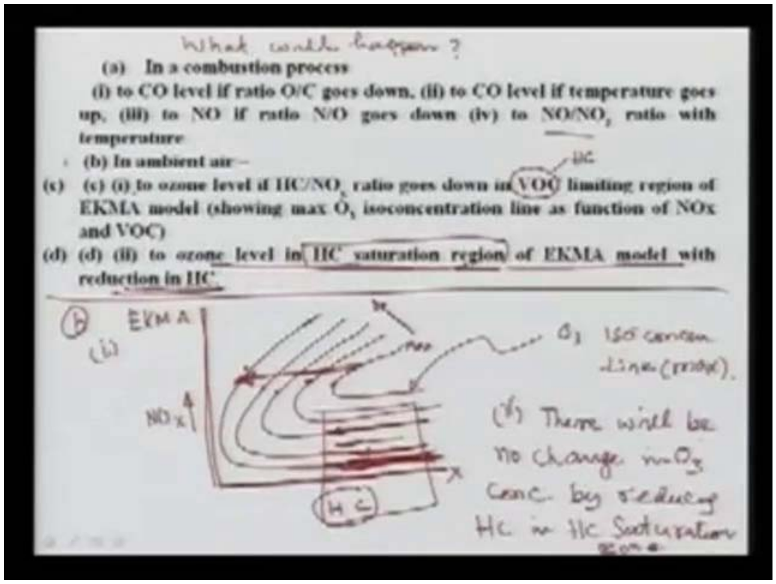

What I will do is I will remove this. That is fine, but let us remove this. We are still looking at the EKMA model. The question is what will happen to the ozone level in the hydrocarbon saturation region of EKMA model with reduction in hydrocarbon? We have to again look at this figure. I am reducing the hydrocarbons and I am moving in this direction (Refer Slide Time: 38:30), I am reducing the hydrocarbons and I am moving in this direction and I am reducing this hydrocarbon.

What is happening to the ozone? The ozone more or less remains constant. Why does it remain constant? This is because these lines as you can see them essentially appear to be and they are parallel to my x-axis on which I have plotted hydrocarbon. The answer for part (ii) is that there will be no change; when I say no change, it really means no significant change – no change in ozone concentration by reducing hydrocarbon in the hydrocarbon saturation zone. You see here that this was the key part – in the hydrocarbon saturation region. So you can see that this is the region – lots of hydrocarbon (Refer Slide Time: 39:40). Even if I take this window in this region and if I am reducing the hydrocarbon moving from right to left as you can see, there is no change in the ozone – it is funny but this is true. Let us go to the next problem because we are doing problems today.

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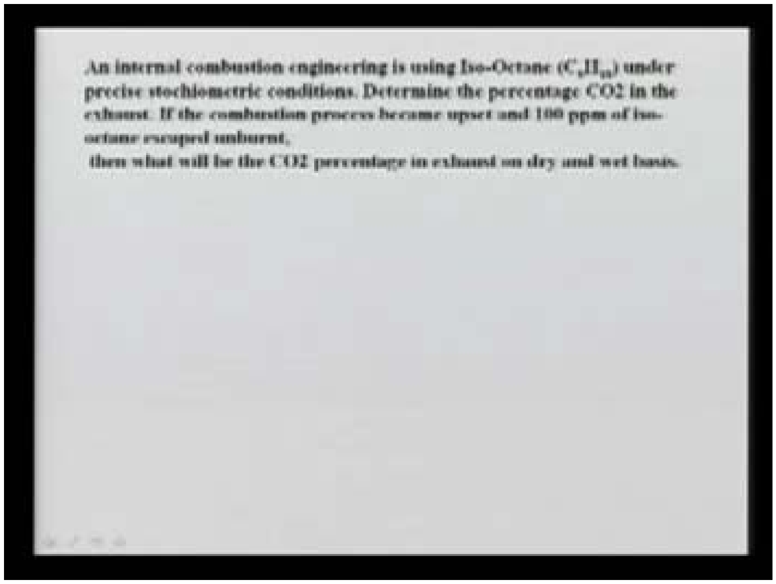

Now we are moving to the internal combustion engine. The problem is an internal combustion engine is using a kind of fuel called iso-octane (that is C_8H_{18}) under precise stoichiometric conditions – you understand that. Determine the percentage of CO_2 in the exhaust – that is the question or the part one. It also says that if the combustion process becomes upset and 100 PPM of iso-octane escaped unburnt, then what will be the CO_2 percentage in exhaust on dry and wet basis? We will do this. In order to do this, we have to invoke the combustion fundamentals or combustion engineering. Let us draw a line here and if you recall, any hydrocarbon fuel has carbon and hydrogen and if it burns…. I will quickly write the [41:02] equation for you.

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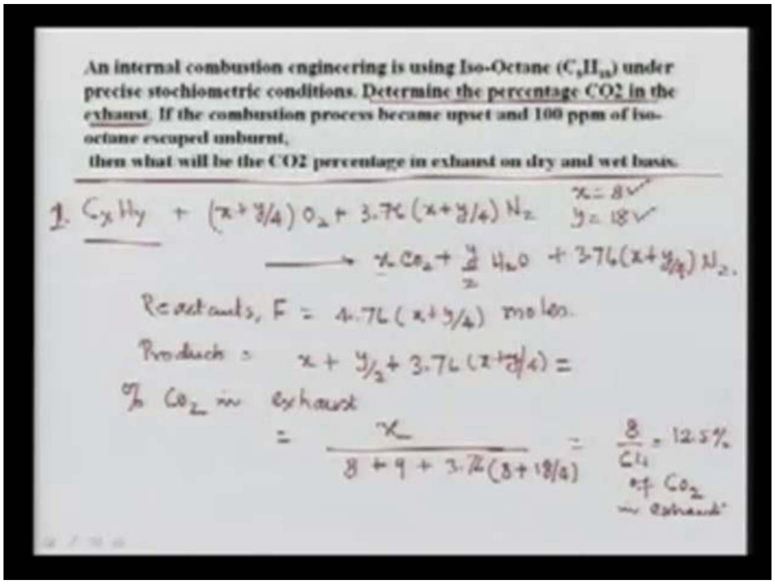

Oxygen plus do not forget the nitrogen that comes in and this gives rise to your x moles of CO_2 plus y by 2 moles of water plus 3.76 into (x plus y by 4) moles of nitrogen – that is the complete combustion under stoichiometry. If you say for 1 mole… let us not forget that here it is just 1 mole. What are the reactants for 1 mole? Let us call the reactants R – this we have done before but I will do again it for you. Let us call the reactants as F – I used it last time and I must use the same thing.

How many moles? This plus this, so I can say 4.76 into (x plus y by 4) moles – these are the reactants. Look at the products. I can also write the moles of the products – for products on this side, so x moles of CO_2. Agreed? y by 2 moles of H_2O plus 3.76…. These are the total moles on my product side. What is the percentage of CO_2 in exhaust? How many moles are there for CO_2? x divided by the total moles that I have here in the exhaust. I can find out this right here (Refer Slide Time: 43:37). What is my value of x? x = 8 and y = 18, so I can find out the moles. x is nothing but 8, so let us write 8 plus y by 2 and y is 18, so that is 9 plus 3.76 into x plus y by 4 and x is 8 plus y is 18 by 4. This came out to be 8 by 64 – that is 12.5 percent of CO_2 in exhaust. That is my answer to my problem ‘determine the percentage CO_2 in the exhaust’.

I repeat: I wrote the general combustion equation (reaction equation), balanced it and then found out the product side. The product is x moles of CO_2 – let us not forget x moles of CO_2 – and y by 2 moles of water, 3.76 x plus y by 4 moles of nitrogen. I could find out the total moles because my x and y are known: x = 8 and y = 18, so I can find out the product. The moles in the exhaust of CO_2 is x divided by the total moles – that is 8 by 64 and that is equal to 12.5 percent. This is what you will find generally – the CO_2 concentration is generally around 12 percent in normal combustion process; it can vary but that is the general value.

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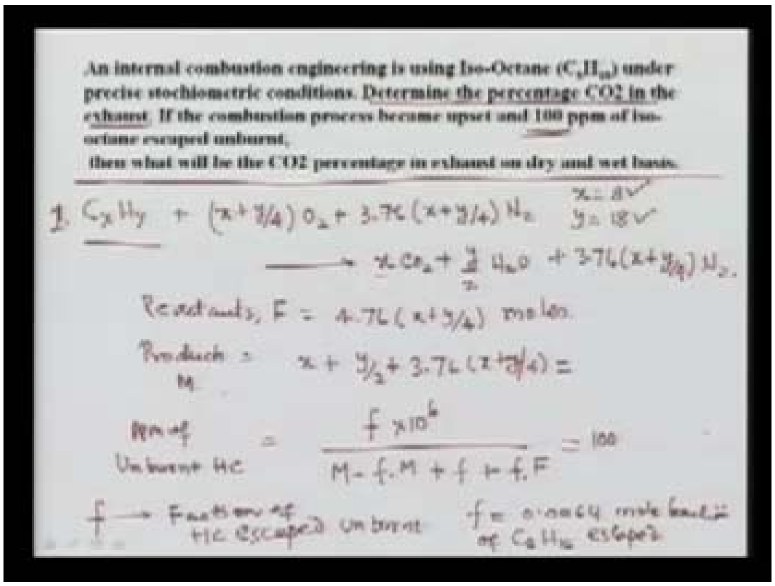

Suppose I call the products as M. You recall we gave a formula to you that PPM of unburnt hydrocarbon was f (I will explain to you what is f) into 10 to the power of 6 upon M minus f times M plus f plus f times capital F. What is f? f is the fraction of hydrocarbon escaped unburnt. How much PPM of unburnt hydrocarbon in the exhaust have I been given? 100 PPM. I can put this equal to 100 and then I can find out what will be the.… What is unknown to me? My F is already known to me, my m is already known to me and what is unknown is f – I can find out the f. I will not do the calculations here, but if you run through this calculation, the value of f will be equal to 0.0064 mole fraction of C_8H_{18} that got escaped. This is one thing I got.

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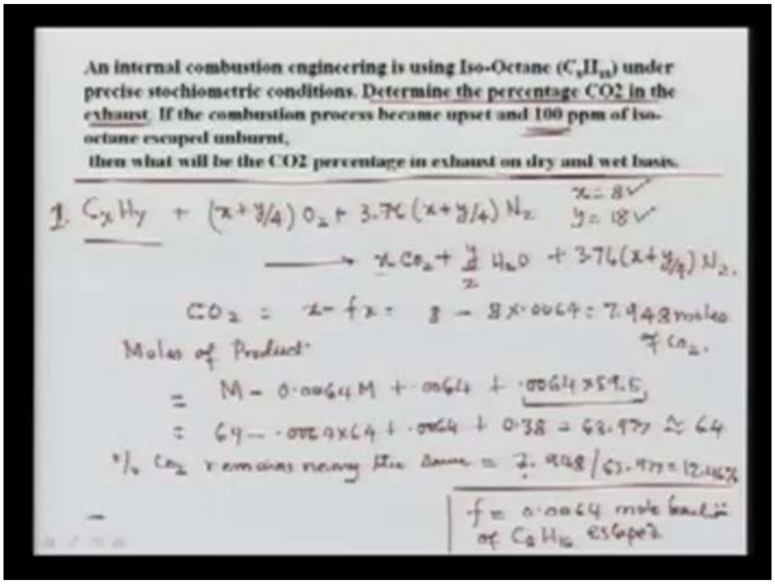

Now, what I want to do is again I want to find out the CO_2 in the exhaust. I will remove this and I will use this information. When something is escaping unburnt, CO_2 will be less, so under the condition something is going unburnt, CO_2 will be equal to x minus fx – that is 8 moles of CO_2 minus 8 into 0.0064 and that will be equal to 7.948 moles of CO_2. Now, the moles of products will be equal to M minus 0.0064 times M plus 0.0064 plus 0.0064 into 59.5. M was the total product when everything got completely burnt, but this time it is not completely burnt because something is escaping.

If you recall, what was my moles? M was 64 minus 0.0064 times 64, this is the portion which is showing up in the exhaust – I will simply add this up, this is the portion that is coming out from the reactant side (Refer Slide Time: 50:01) because the reactant did not completely convert into CO_2 and hydrocarbon – those portions of the reactant will come up as such, this becomes 0.38 and the whole thing comes out to be 63.977, approximately 64. The percentage of CO_2 remains nearly the same or there will be a slight change actually because what we have to do really now is…

That answer will be 7.948 divided by 63.977 and that came out to be… I can show you that number: 7.948 divided by 63.77 came out to be 12.46 – almost the same as the last time. Now, the other part of the question says exhaust on dry basis. This was the wet basis because we had considered the moisture. If you do not consider the moisture, then what will be the values?

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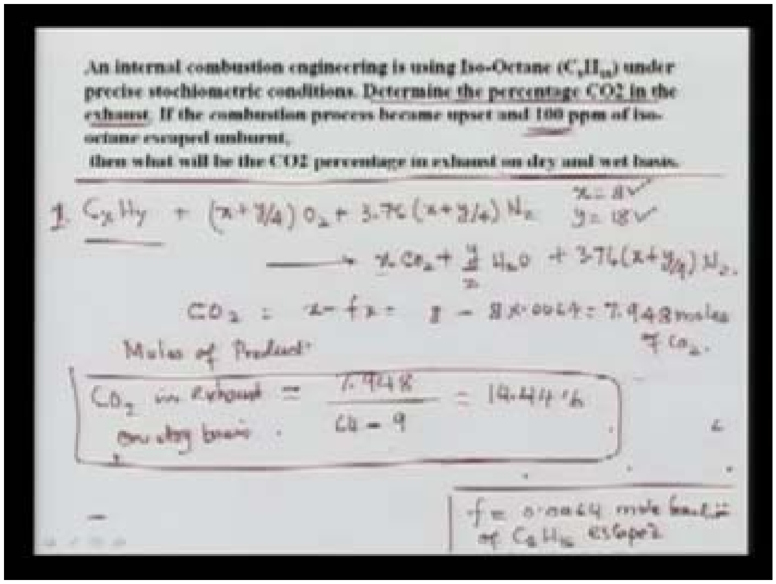

I can remove this now. I will not consider the moisture and I can find out only on the dry basis. In the exhaust, CO_2 is the same, 7.948 and total was 64 minus the moles of water. How much will the moles of water be? y by 2. y was 18, so by 2 is 9; that comes out to be around 14.44 percent – that is the CO_2 in exhaust on dry basis. What is the difference that we have done? We are not considering the water and that is the 9 moles. Where are the 9 moles coming from? y by 2. What is y? y is 18, 18 by 2 is 9 and so in the exhaust, we are not considering the moles of water – it means whatever the concentration is, that will be on the dry basis. Sometimes as air pollution engineers, we need to report something on the dry basis. You have learnt from this example that we can report the CO_2 concentration on the wet basis, on the dry basis and also under the condition when some part of the hydrocarbon got escaped unburnt – that is another example that we have done. What we will do is that we will do one more example of a different kind.

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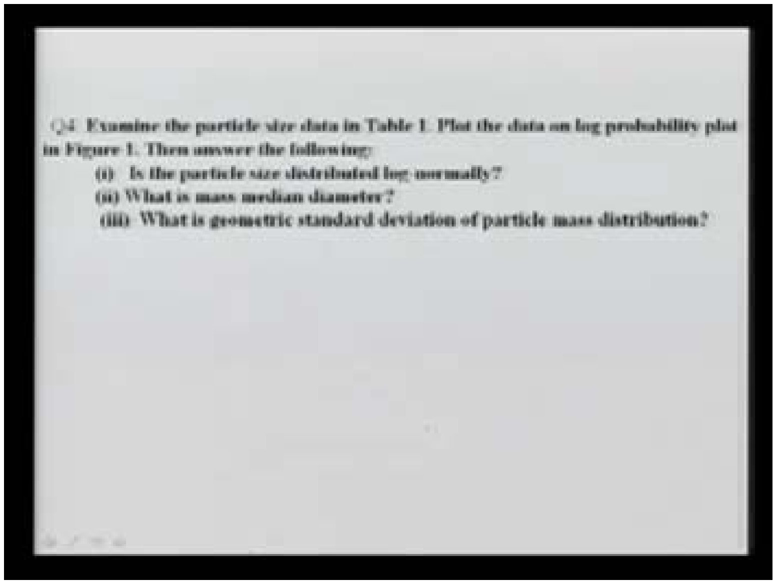

The problem four that we are doing is: examine the particle size data given in table one. I will show you table one in a moment. Plot the data on the log probability plot in figure 1 – I will give you the figure 1 also – and then answer the following questions: is the particles size distributed log-normally, what is the mass median diameter of the particle and what is the geometric standard division of particle mass distribution? This information we require a lot in terms of looking at the particle size distribution in the ambient air. What we will do is go to the next one.

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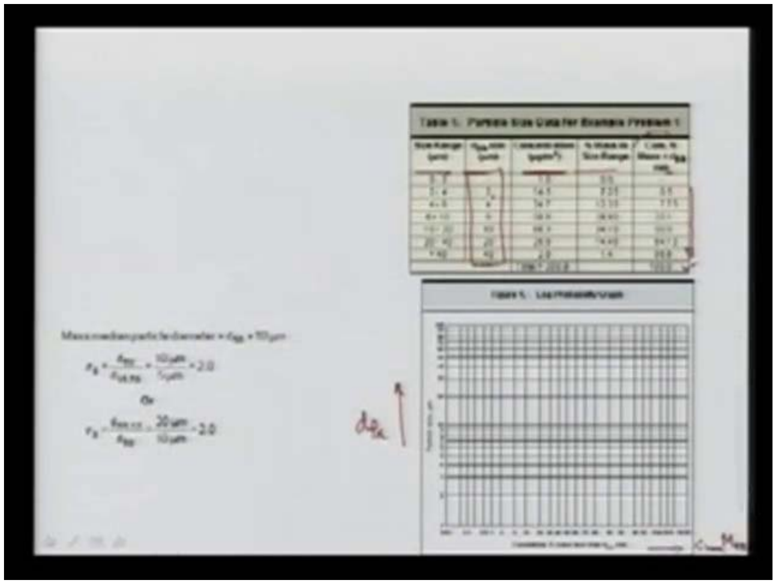

Here you see the data that is given to you in the table 1. What people had done was sieve analysis. This is the range of the particles and you can see what was the concentration in this particular range; you can see the mass in the range – how much was the mass; and this is the cumulative mass. So between the particle size, let us say 2 and 4, the mean minimum diameter was 2, the concentration in the particle size range 2 to 4 was 14.5 and the mass size of the particle in this size range was 7.25 – it was the percentage mass.

The cumulative mass was 0.5 and then what you can do is that you can…. The cumulative masses are shown here – they will increase and finally should add up to 100. Then, what we have to do is plot the whole thing on the log–log probability plot because you want to find out if the distribution of the particle size is log-normally distributed. What we have done here is on this side, we have plotted dpa – the particle size or this column (Refer Slide Time: 55:45) and on this side, we have plotted cumulative…. No, but this is the other around way we have done. On this side we have plotted the particle size – that is my dpa and on this side, plotted cumulative mass, which is this column.

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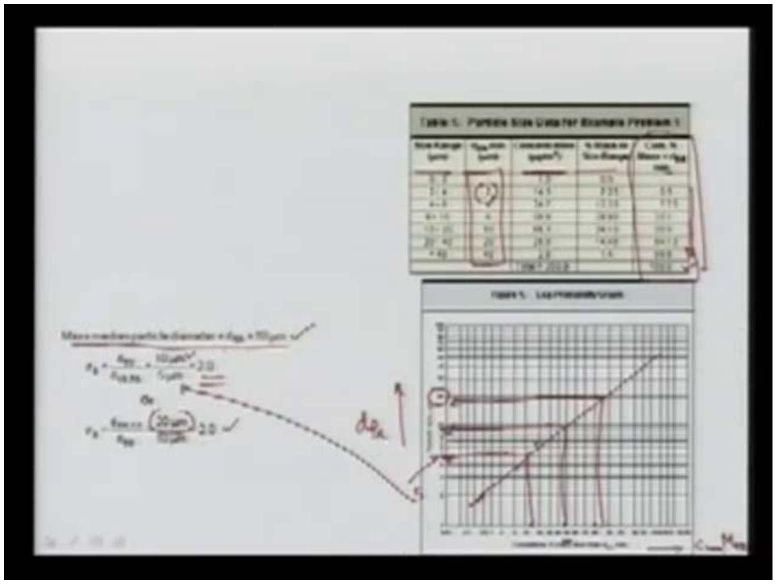

Now let us plot this one for example. See here: the dpa is 2 – so this value is 2. What is the cumulative mass? 0.5, so I go from 0.5 and plot this point at this dot. Let us go to the second point 4. Let us say 4 and that 4 is the cumulative mass 7.75. This [56:41] 7.75 will be somewhere here (Refer Slide Time: 56:52). Then go and plot the point let us say 6, then you can go for 6 here; for 6, I have the cumulative mass as 20.1, so this is 20.1 and then I am plotting this as 7. Finally, let us plot the condition here – 20; for 20, the diameter is 20, so we go on 20.

How much is the mass? It is 84.13. This is something like 80, then 84.13, so it comes here. When I join these, I will get a straight line more or less – this is what my log-log plot is. Since it is coming in a straight line, I can certainly say that this is the data or the particle size is log-normally distributed. I want to find out the median diameter or the mean diameter, so I should go over the cumulative value equal to 50. This is my 50 point – you can probably see this 50.

Then, I go here on the 50 line and go this side and I can find out my mean diameter. You can say d_{50} or the mass median particle diameter is 10 microns. The cumulative is 50, then I can go here, this. I have to find out the geometric standard deviation. This is the relationship we discussed in the class: d_{50} by $d_{15.78}$. How much is this d_{50} value? 10 – we just now got that this value is 10. At $d_{15.78}$, I have to go 10 and between here; so I have to go here and then plot here 15.78 and then get the value somewhere here – that is close to 5, as you can see here; this is 5. Then, I can take this value 5 and I can find out the geometric standard deviation as 20.

You can do on the other side also – you can take d_{50} (M) and or 84.13. If I take 84.13, that also will give you the same thing. This is 80 here as you can see – this point, this point is 90, so in between and this you are getting as 20 – you can see here 20. So I can take the 20 here, 20 by 10 – that will still give me the same answer. What we have done is we had the data and we could say the particle size distribution of log-normally distributed and the mean, the mass median particle diameter was 10 microns as you can see here and the geometric standard deviation was 2.