Environmental Air Pollution

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Lecture No. 23

Examples for Practice – Dispersion Modeling

Today, we will do some examples concerning dispersion models. Essentially, what we will try to do is to develop the relationship between the sources and its impacts.

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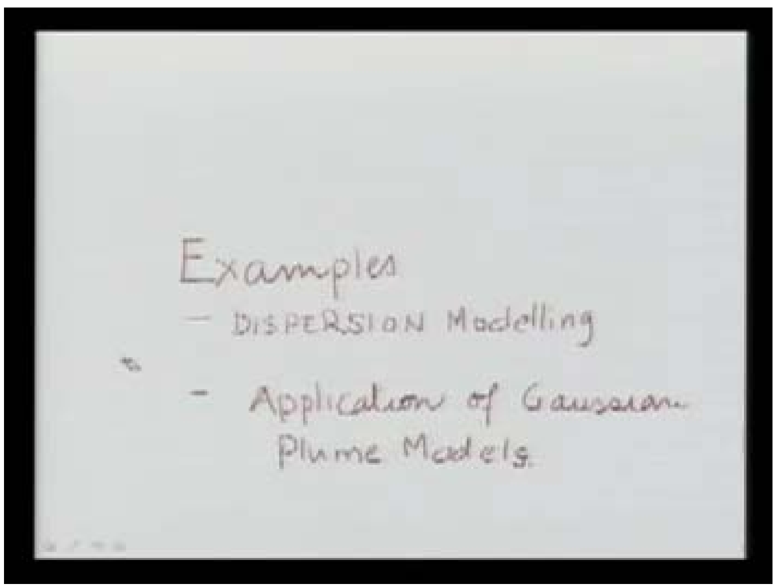

You will recall that you have done dispersion modeling. In dispersion modeling, one of the most popular models that we learnt was the Gaussian Plume model and we did some examples before. Gaussian models can be applied to a point source like a chimney. It can also be applied to a line source like a number of vehicles that are moving on a highway – when we want to see its impact. Gaussian models can also be applied to the area source; when a group of small industries are present, we can also find out the impact of the emissions from such sources in the ambient air. This lecture today is completely devoted to certain examples that we want to do.

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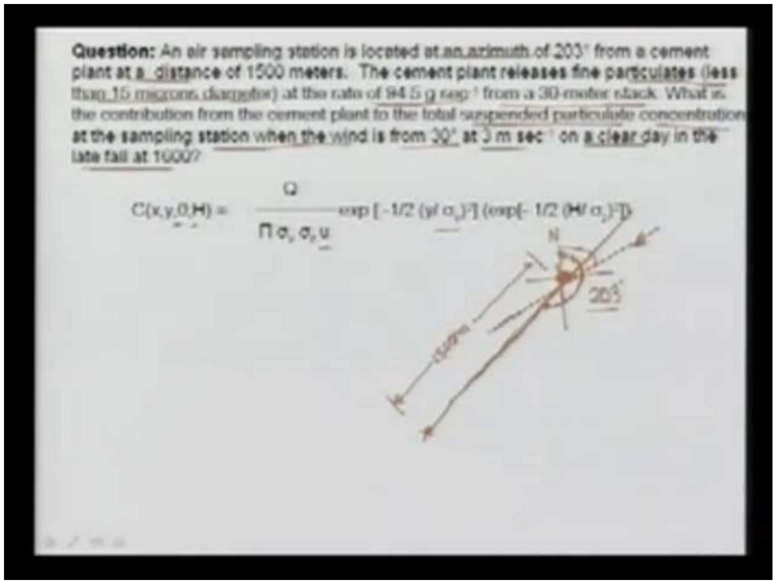

Here is the question and what I would do is that we will read the question very carefully and then we will solve this question right here in the class. You see that I have a calculator here with me – I will be doing certain calculations with the help of the calculators in the process and we will try to write the numbers on the screen. Let us read the question very carefully. The question is that an air sampling station is located at an azimuth – I will explain to you what is the meaning of azimuth – of 203 degrees from a cement plant at a distance of 1500 meters. The cement plant releases fine particulates and the size or the diameter is less than 15 microns at the rate… the emission rate has been given to you as 94.5 grams per second from a 30-meter stack – the stack height is also given. The question is this: what is the contribution from the cement plant to the total suspended particulate concentration at the sampling station when the wind is from 30 degrees and the wind speed is 3 meters per second on a clear day in the late fall at 16:00 hours?

We will try to do this problem. We will be using Gaussian Plume model and for convenience, I have given the formula already for the Gaussian Plume model on the screen as you can see. You would also recall that Q is the emission rate and y is the cross-wind direction, H is the is the is the effective stack height, sigma_z is the dispersion parameter in the z direction, sigma_y is the dispersion parameter in the y direction as you can see here, u is the wind speed, C is the concentration at a distance x, cross-wind distance y, ground level because z = 0 and you can say that the emission is from height H.

We had already derived this formula in our earlier classes, but first of all, before we even touch the formula, let us understand what the question is. The question is telling us that there is a source, so let us draw a source. Suppose this is the cement plant and that has a chimney here and there is a station sampling station. Where? At an azimuth of 203 degrees. Let us see where the station is. If you recall, how do you look at the azimuth? Suppose this is my north, south, east and west, as you remember when we were talking about the wind direction, we said that the azimuth is 203 degrees. We measure the angle of 203 degrees from the north and then we say that my station is located somewhere on this line and this angle is 203 degrees.

As per the question, where is it and how far is it located? The cement plant it is located a distance of 1500 meter. If I go in this direction 1500 meters (let us try to make it as straight as we can), this is where my sampling station is. This distance is 1500 meters – this is the location of the sampling station. In addition, the question says that the wind direction – let us forget about the emission for the time being –the wind is from 30 degrees at 3 meters per second, so 30 degrees is the wind direction. I have to go 30 degrees and show you the wind direction. The wind is going like this. How much is this angle?

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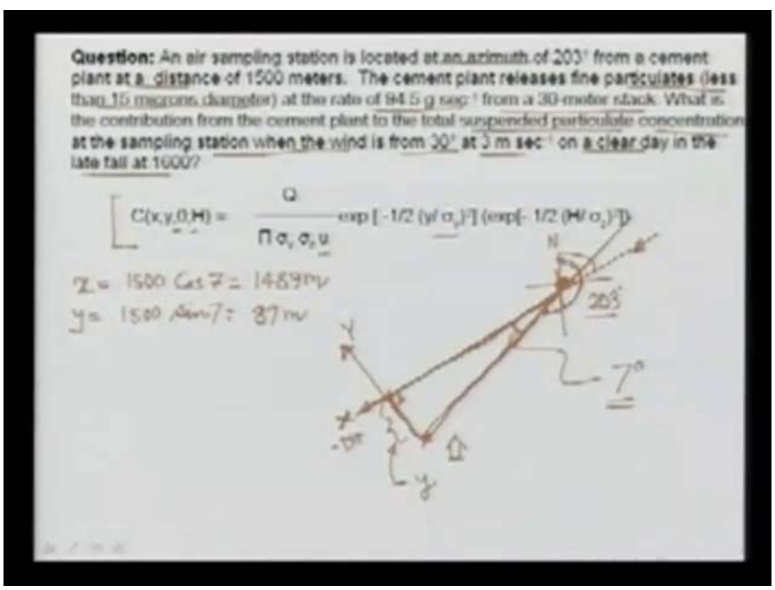

For just a few minutes, I will remove this. This is my wind direction and that is where the wind is blowing. This is my cement plant and here, I have set up a sampling station. I can even show you that my sampling station is located here and the wind is blowing in the direction as you see here. You can find out how much this angle will be– it does not take long. This angle will be 7 degrees – you can see for yourself that the angle between the direction of azimuth at which the station is located and the wind direction is 7 degrees. Let us write it even clearly, so that there is no confusion – this angle is 7 degrees. Now if you recall in the Gaussian Plume model (that is the model you see here), always remember that the direction of the wind is the x direction – this is my x direction.

I need to know the distance from here to the corresponding distance that is the component of this station in this direction. I can draw a perpendicular from the station and then I can find out the distance, this distance (Refer Slide Time: 08:32) because I need to know the distance at the x direction – I can find out this. Always remember that the direction that is perpendicular to the wind direction, which is this direction as you can see here, is my y direction. If this was my x, this is my y direction. Let us make it little better.

Now I can find out what x is equal to, because the total distance from here to here as I am moving my cursor was 1500. Taking the component of this distance or taking this component on x direction, my x will be 1500 cos 7 and if I use the calculator, that comes out to be …. Agree? Similarly, I can find out the y component. We call this as y and my y will be equal to 1500 sin 7 degrees. If I use the calculator, that came out to be 87 meters. If the wind direction and the direction at which the station was there, then we did not have to find out the x and y directions. Since the station was a little bit not along the line of wind direction, we have to find out the x component and y component on the x direction and y component on the y direction. We now understand the meaning of azimuth and we now understand the meaning of wind direction.

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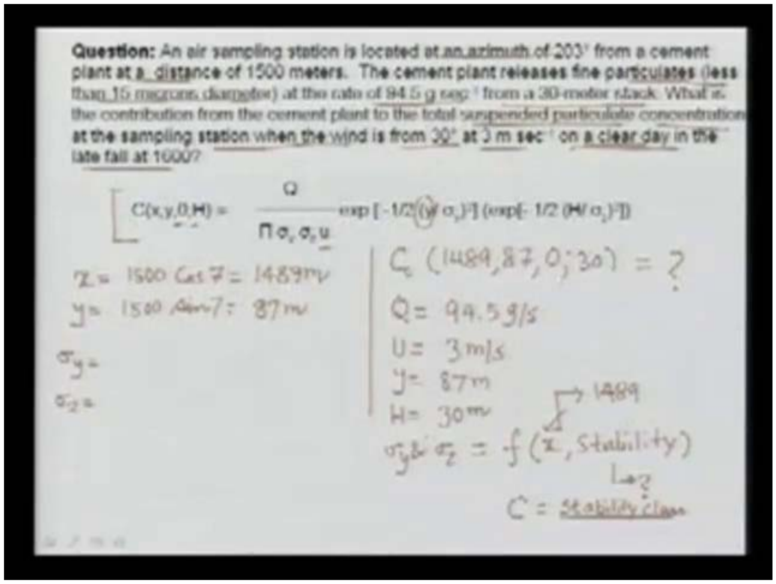

Now, what I will do is I will rub this picture that I have drawn for clarity. Now, what is your objective? Let us see what we need to find out. We need to find out the concentration at x = 1489, y = 87, z = 0 from a chimney, which is my cement plant in this case, located at a height of 30 meters and so, let us write 30 meters. That is what my objective is and that is what I need to find out. Once we know this, life is simple. What we need to do is look at the other things in the formula here – my Gaussian Plume model.

I need to know Q. The Q is given to me as 94.5 grams per second – that information is available to you; this is pi, pi is known to us; we also need to know the u, which is my wind speed. What is the wind speed given? 3 meters per second – that is also known to me. Then, where is the problem? We also need y. y is also known to me – that is 87 meters. Do I need the x? I do not need the x in the formula, but I will be requiring x in some sense and we will see how. We also need to know the H. The H is given to me. Let us read the question – from a 3-meter stack. The stack or the chimney height is 30 meters and so let us write H = 30 meters.

What else do we need? I think we have almost everything except sigma_y and sigma_z – that is not known to us, but if you recall, when we had developed the Gaussian model, you will recall that sigma_y and sigma_z are both function of downwind distance x and stability. What was stability the indicator of? Stability was the indicator of atmospheric turbulence. We need to find out

$sigma_y$ and $sigma_z$ and for that, what do I need? I need x and x is equal to 1489, but if you recall, $sigma_y$ and $sigma_z$ are also function of stability and so I also need to know the stability.

The information given to us is this: clear day, late fall – that is something like October and November, the time is 16:00 hours and so, the stability will be somewhat unstable. You will recall that stabilities were A, B, C, D, E and F. Here, C is the stability. Do not confuse this C versus this C. Let us write in this case C concentration or something C_c and this is the stability class C. Here, C is what I am taking as the stability class. What I will do is now I will determine the value or find out the value of $sigma_y$ and $sigma_z$ as function of two things: x and stability class; stability is also known to me.

I will go to the charts – you recall we had discussed about the charts, then we will go and use the charts and try to find out what are the values of $sigma_y$ and $sigma_z$. Sounds good. What I will do is that quickly I will go to the $sigma_y$ and $sigma_z$ graphs. Bear with some of the things that show up on the screen.

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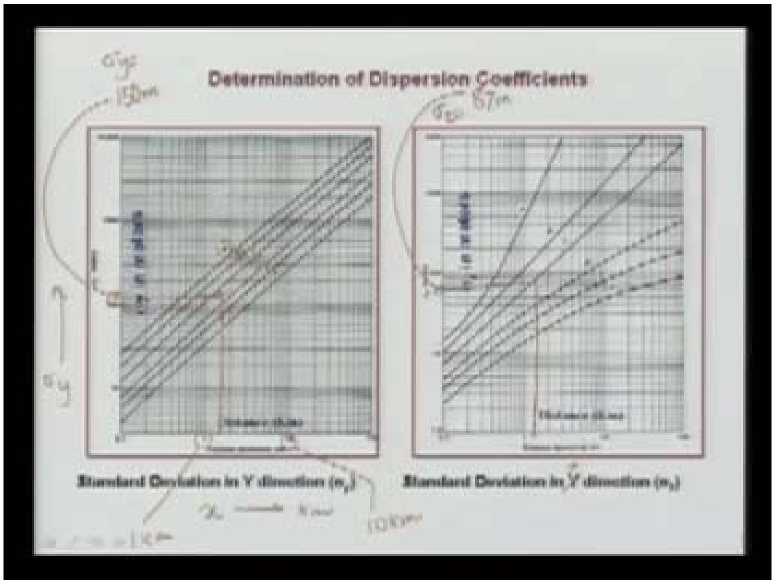

If you recall, these were the graphs that we had discussed when we were talking about the model. This side is my $sigma_y$ and this side is my downwind distance x. You probably cannot see so well but the units here are in kilometer. This is 0.1 kilometer, this is my 1 kilometer (Refer Slide

Time: 16:10) and this is my 10 kilometers. What is my downwind distance? What was my x? 1489. For this 1489…. Here, you are seeing the class A (Refer Slide Time: 16:29), class B, class C and so on and so forth. What was my class? My class was C and my downwind distance was 1489. Let me start from 1489 and let me hit C.

Let us start with 1489 approximately. It will not be so easy for you to do it, but I will do this for you. Let us go and hit C. This is my C graph and then, I can read this value as I go…. This may not be very clear to you but this number if I do the exact this thing, that is coming out to be 150 meters. In a way, I have been able to find out $sigma_y$ goes to 150 meters. Let us do the same thing for $sigma_z$. This should be standard deviation and it should be the z direction. Now, again, I go the same distance 1500 for 1489. The stability class is also the same. Again, let us try to find out what will be the value of $sigma_z$. We go on this graph to find out the value of $sigma_z$. You come here, then you move on to the y-axis, you come here and this is… I can write here 87 meters, so my $sigma_z$ is 87 meters. I could find out the value of $sigma_y$ and $sigma_z$ because I will need to use them again. Let us go back to the slide where we needed the value of $sigma_y$ and $sigma_z$.

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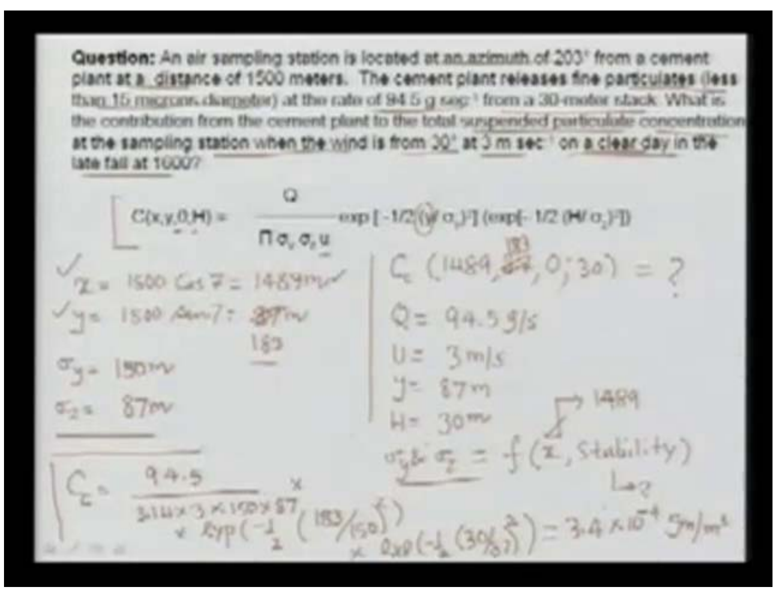

If you recall, what was the value of $sigma_y$ that we got from the graph? That was 150 meters, so let us write it here. If you recall, how much was $sigma_z$? That came out to be 87 meters. Now, more or less, I have everything that I need to know to be able to find out the value of the concentration or the impact of a cement plant on a sampling station. So simply, I can do the C or C_c as I am trying to call it. How much is Q? 94.5. pi is 3.14, u is 3 meters per second, $sigma_y$ is 150, $sigma_z$ is 87 and then the exponential term. I will write this underneath here: exponential of what? —1 by 2 into y. What is the value of y? y value was ….

Now, we made a mistake somewhere. The mistake was this one. In fact, this was 183 and so was this. So let us say 183 divided by the value of $sigma_y$ is 150 whole square bracket close times the value related to H by $sigma_z$ and that is again exponential 1 by 2. What is the value of H? 30. What is the value $sigma_z$? 87. Square and bracket closed. Remember that y was equal to 183 meters. If we run through this calculation (which you can), as I did my calculation on the calculator, that comes out to be 3.4 into 10 to the power of —4 grams per meter cube. Is it clear or not? Let me make it amply clear for you. This is the concentration that I estimated.

I have answered the question that was asked of me. If there was a station that was located at the azimuth of 203 degrees from a cement plant at the distance of 1500 meters and the wind direction and the direction in which the station existed were not coinciding, I had to find out the angle between the direction of the location of the station to the direction of the wind – that came out to be 7 degrees. Then, I found out the x component and the y component and this is 183, 1489 and then, I write down the things available to me. I said $sigma_y$ and $sigma_z$ were function of the downwind distance x, which was 1489, and also the stability – we estimated the stability as class C. We used the graphs to find out the value of $sigma_y$ and $sigma_z$ and once the value of $sigma_y$ and $sigma_z$ are known to me, the final concentration was calculated using the model in which everything was known to me. If that is clear, we will go and do the next example.

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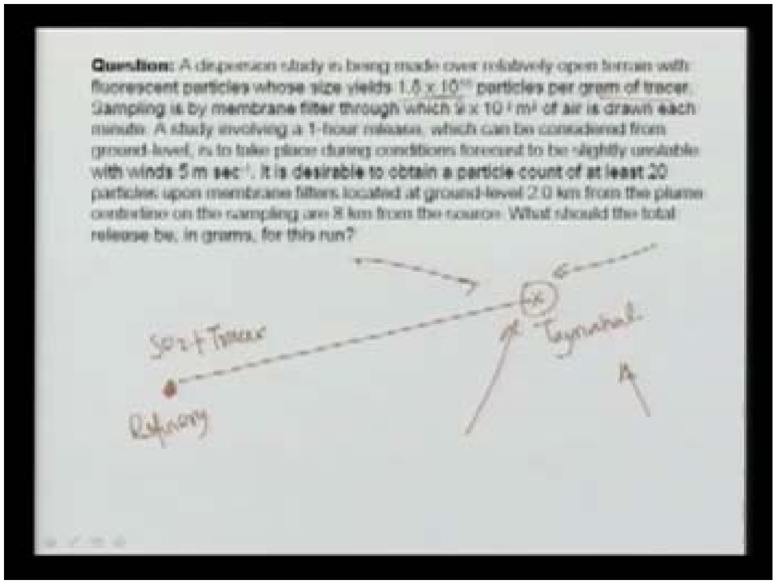

I will not call this example difficult, but it will require some understanding of the problem. The problem reads like this: a dispersion study is being made over a relatively open terrain with fluorescent particles. We are trying to do some measurement of the fluorescent particles whose size yields 1.8 into 10 to the power of 10 particles per gram of tracer. Let me also give a little background of tracer studies and what tracer studies are.

Suppose you have a source and this is emitting SO_2 and you want to see its impact somewhere here – how much is the contribution. For example, this is a refinery and this is some important building, let us say Taj Mahal – it is just an example that I am giving you for explanation. I want to find the exclusive impact of SO_2 from the refinery to the Taj Mahal, but I cannot do it because there are many other small sources that can also contribute SO_2 to the Taj Mahal. So when I am doing the measurement, the measurement is a mixture of SO_2 that has come from many places, but here, I want to find out only the contribution, let us say, from a refinery. What I can do is in the refinery along with SO_2, I can put some tracer and that tracer will be emitted only by the refinery, because I am the mixing the tracer and there will be no contribution of the tracer that will be coming from any other source.

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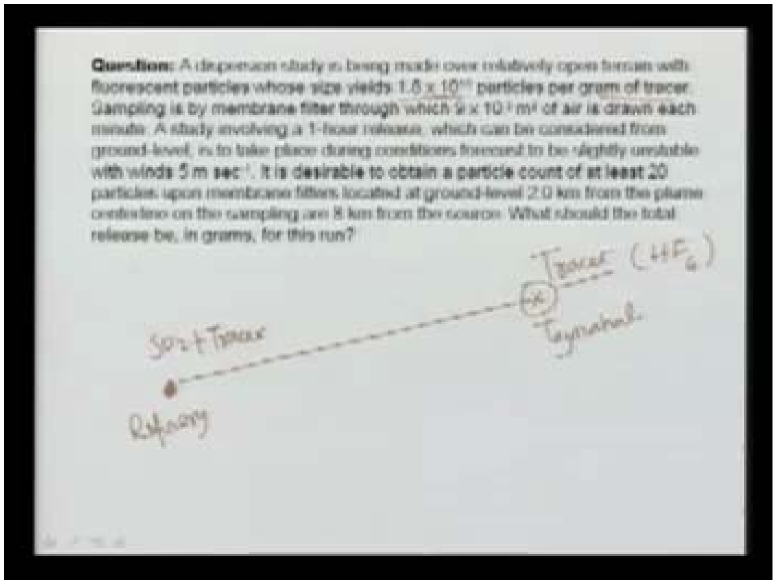

Then if I am looking at the tracer now, there is no question of other sources contributing to the tracer and what I am measuring here is the tracer. This tracer compound, whatever that may be, generally that compound is HF_6. There are studies on what the tracer should be – that is also an interesting thing. But here, we are trying to look at what will be the impact of the tracer. So that is the background of the tracer.

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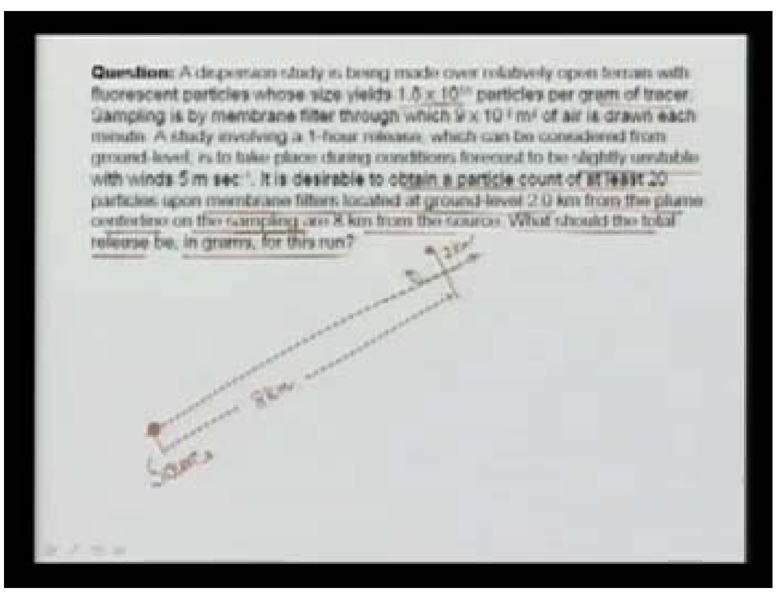

Let us take this one out. What is the question about? Actually, we are planning a tracer study and in that tracer study, we are seeing how much is the tracer quantity that we need to put in the system and that should be emitted out. We will read it again. A dispersion study is being made over a relatively open terrain with fluorescent particles whose size yields 1.8 into 10 to the power of 10 particles per gram of tracer. If I am using only 1 gram of tracer, how many particles will be emitted? 1.8 into 10 to the power of 10.

Sampling is by a membrane filter through which 9 into 10 to the power of —3 meter cube of air is drawn each minute. A study involves 1-hour release. 1-hour release of what? 1-hour release of tracer, which can be considered from the ground level. If I am considering the ground level, it means my H is 0. The study is to take place during conditions forecast to be slightly unstable (you recall that slightly unstable means the stability class is C) with wind speed of 5 meters per second.

It is desirable to obtain a particle count of at least 20. Wherever I am doing the sampling, in order to get a good tracer amount on my filter paper, I must ensure at least 20 particles are captured at the sampling site – 20 particles upon membrane filter located at ground-level 2 kilometers from the plume centerline on the sampling are 8 kilometers from the source. What should be the total release in grams for this run or for this study? What we are trying to say here is that there is a source where we are releasing the tracer and we are doing the measurement here. This distance is 8 kilometers and located at ground-level 2 kilometer from the plume centerline. This is my plume and this is my 2 kilometers. If that is the case, I have to find out the total quantity that I need to release.

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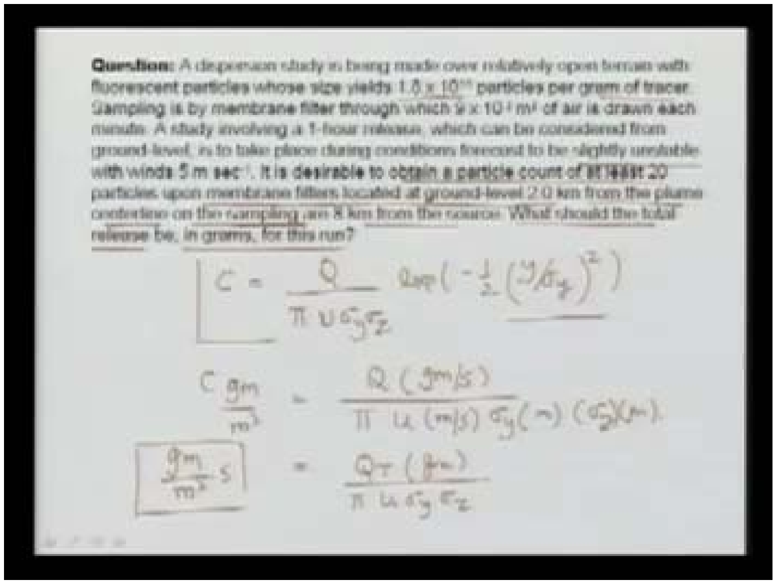

We will remove this for the time being and try to write the model once again. C was equal to Q (quantity of the emission rate) by pi u sigma_y sigma_z into exponential (minus 1 by 2 into ((y by sigma_y) square)) and there will be no H term, because H is equal to 0. Why is H = 0? It is because this source is at the ground level. This is the formula that we need to use. Let us be a little bit careful about the units here. C is in… whatever units you want to take, now you take something like grams per meter cube, my Q is in grams per second, pi is unitless, u is meter per second, sigma_y is meters, sigma_z is again meters and this will be unitless (Refer Slide Time: 29:35). Does it make sense dimensionally? Yes, it does.

If I say the quantity that I am releasing is for 60 minutes, here in place of Q, I can write Q_T and then it was for 1 hour.… All right. What I can do is I can take this unit – seconds on this side and I can write this as grams per meter cube second. I can write this Q this is as Q_T, which is the exactly is the mass that I need to emit, and rest of the things can be simply the same. I need to find out this quantity.

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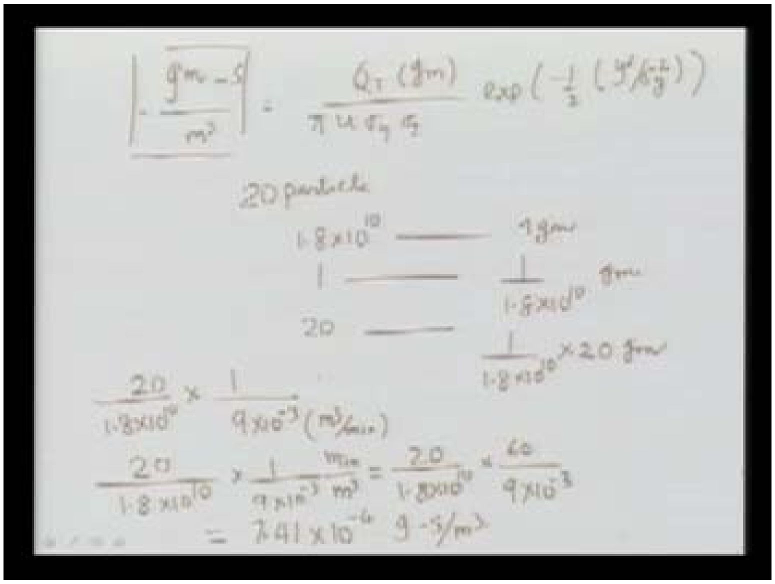

I need here the unit grams per second per meter cube – this was my Q_T (only the mass and that is gram) by u sigma$_y$ sigma$_z$ and let us not forget about the pi and exponential of (minus 1 by 2 into (y square upon sigma$_y$ square)). This is what I need to find out. The condition given to me is that I need to capture 20 particles as per the question. What will be the mass of 20 particles? If you recall from the question, 1.8 into 10 to the power of 10 particles are released when the mass is 1 gram.

Let us do from the basic principle. If the particle is 1, then mass is 1 by 1.8 into 10 to the power of 10 grams. If I want to capture 20 particles, how much is the mass that I will capture in the filter paper? 1 by (1.8 into 10 to the power of 10) times 20 – that is the mass that I want to capture on my filter paper, but here, I want the units to be grams per second per meter cube. If I divide this gram – my 20 by 1.8 into 10 to the power of 10 by the flow rate of my sampler….

Let us go back and see that. What is the flow rate at the sampler? Where is the flow rate? Filter through which 9 into 10 to the power of —3 meter cube of air is drawn each minute. Let us go up and 9 into 10 to the power of —3, so this is my 9 into 10 to the power of —3 and the units will be minutes per meter cube. I can convert this into seconds; for seconds, I need to multiply by 60. Now, finally the overall unit I am getting is grams second per meter cube.

I did this calculation and you can also check such a calculation. No, we made a mistake again – we need to divide by the flow rate, so this should be 1 upon what was the flow rate? 9 into 10 to the power of —3 meter cube per minute, so this will become meter cube and this will become 20 by 1.8 into 10 to the power of 10 minutes, which we can convert into seconds, upon 9 into 10 to the power of —3 and that will come out to be equal to.… I can use the calculator here to find it out and this value comes out to be 7.41 into 10 to the power of —6 grams second per meter cube.

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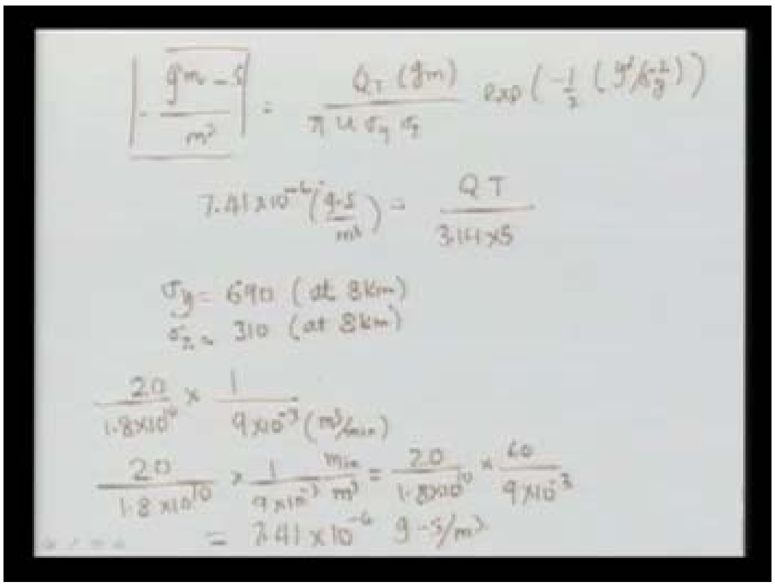

I can remove this and then I can write here 7.41 into 10 to the power of —6 grams second per meter cube. I want to find out Q_T. What was my pi? 3.14. Do you remember how much the wind was? 5 meters per second. Again, I need to find out $sigma_y$ and $sigma_z$ at what distance? At 8 kilometers, so I will use the same graphs. I have found out $sigma_y$ equal to 690 meters. At what distance? At 8 kilometers. For $sigma_z$, I will again use the same graphs as we did last time. At what distance? At 8 kilometers. If you have any doubts, we can quickly check.

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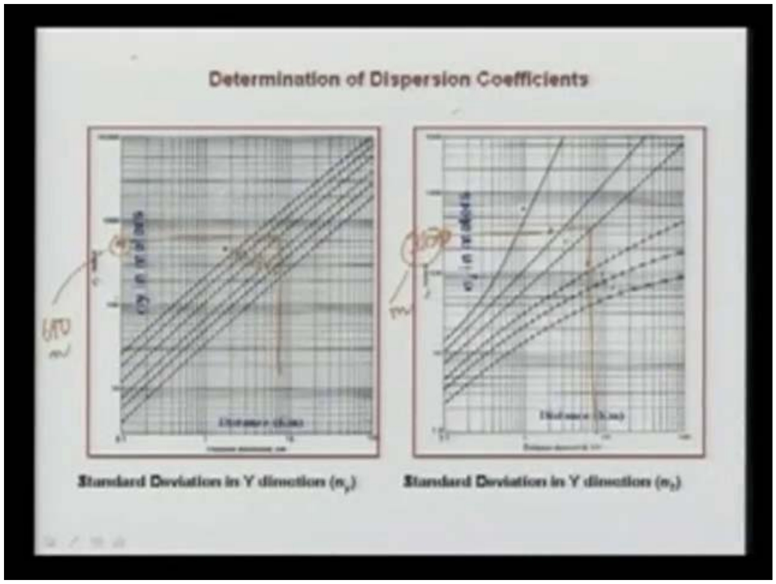

sigma$_y$ at 8 kilometers. This is the distance, this is 10 kilometers, this is 9, 8. You go along 8 kilometers and hit C here and then come in this direction. Then, you will find this value here is 310 meters. Similarly, for sigma$_z$ at 8 kilometers 10, 9, 8, hit C somewhere here and that value comes out to be…. Actually, I am sorry, this came out to be 690 meters and this is also meters.

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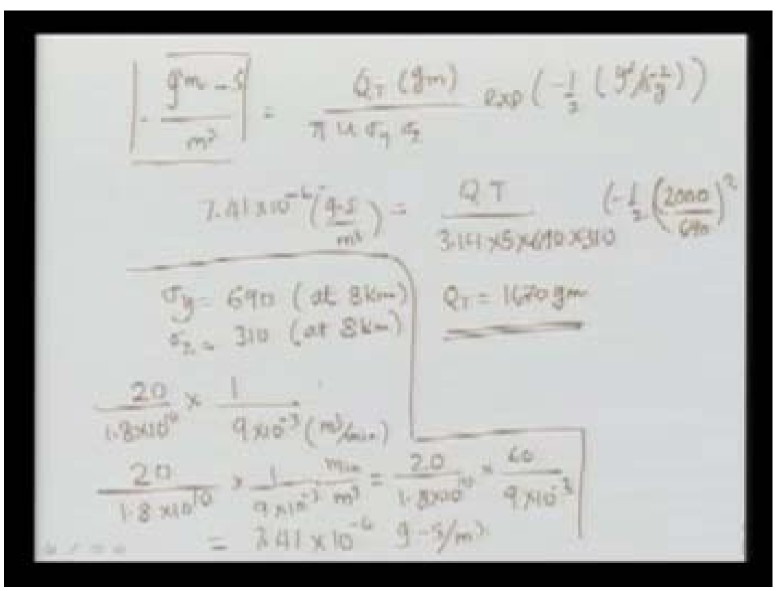

We have sigma_y as 690 and sigma_z equal to 310 into minus half into what was the value of y? 2 kilometers, so that is equal to 2000 meters divided by sigma_y. How much was sigma_y? 690 and the whole thing square. Solving for Q_T, that came out to be 1670 grams. The answer to the question is that we should put so much of grams of the tracer in the process so that it will be emitted and once we are capturing it at a distance of 8 kilometer downwind, 2 kilometer cross-wind, we will be able to capture at least 20 particles of the tracer, which was fluorescent particles. That answers the question.

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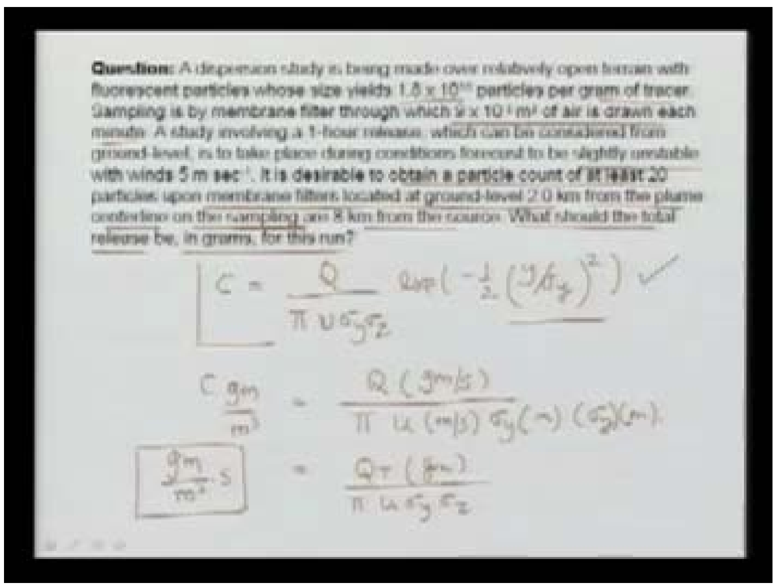

We can quickly take the recap of the whole thing. This is my standard Gaussian formula. I need to find out the quantity Q_T, which I need to release. In this step, what I did is I just put the units for clarification and then I said this is what is the total quantity that I need to know. The seconds I sent to this side and this is the quantity I want to estimate first and then I want to go on to Q_T.

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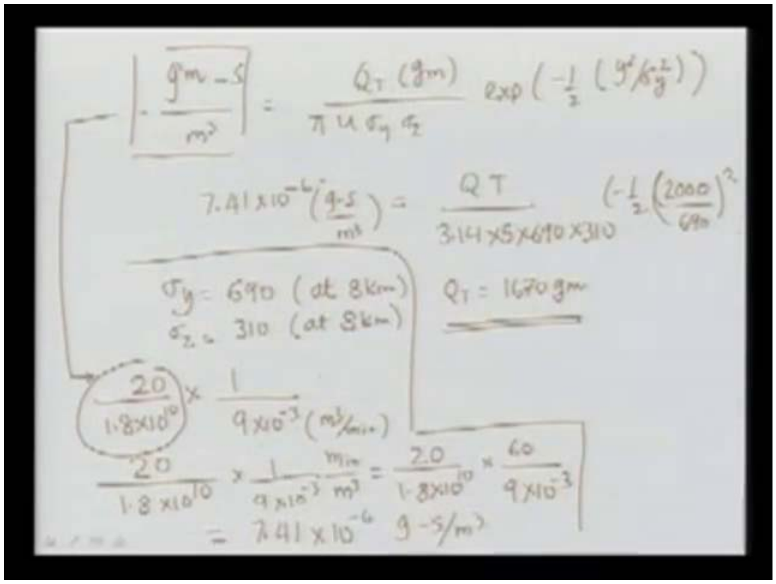

The next step what we did was we tried to estimate this quantity and for this quantity, we did the calculations, which are here (Refer Slide Time: 39:46). For 20 particles, this will be the grams – so many grams for 20 particles that I want to capture, this is the flow rate and this flow rate I converted into seconds here. The final answer came out to be 7.41 into 10 to the power of —6 grams per second per meter cube. I use this information here and then I estimate for Q_T and everything was known to me.

I calculated sigma$_y$ and sigma$_z$ using the graphs that were depending on stability and the downwind distance. The downwind distance was 8 kilometers and y is 2000 kilometers, because the station was located at 2 kilometer or 2000 meters cross-wind of the wind direction. This is how I can find out the quantity of the tracer. We will do another example, again trying to estimate the impact of the emissions of vehicles on the point of our interest.

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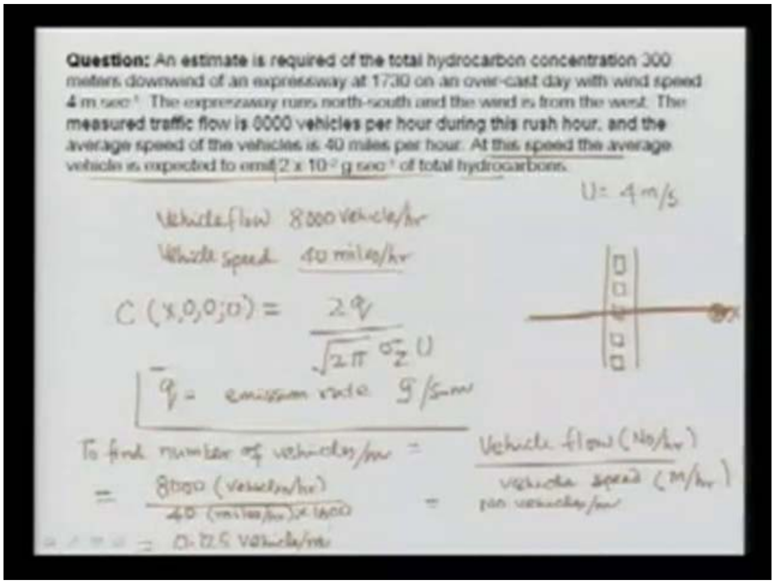

Let us read the question properly. An estimate is required of the total hydrocarbon concentration 300 meters downwind of an expressway in the afternoon 17:30 hours on an overcast day with wind speed of 4 meters per second. Let us see. U is given to me as 4 meters per second. The expressway runs north-south. Suppose this is my north-south, the road is like this and I have many vehicles going on the road. The expressway runs north-south and the wind is from the west. We say that the wind direction is like this – wind is from the west.

What else does it tell us? The expressway [42:04] from the west. The measured traffic flow is 8,000 vehicles per hour – the vehicle flow is 8,000 vehicles per hour and the average speed of the vehicle is 40 miles per hour. We will change this 40 miles into meters, let us wait for a moment. The vehicle speed is 40 miles per hour and it is also given that at this speed, the average vehicle is expected to emit so much grams per second of the total hydrocarbons, that is, each vehicle will emit so much.

If you recall the formula that we used or that we developed for the expressway or for the line emissions, the concentration was C at any distance x, y =0. Why y = 0? It is because where I want to find out the concentration is also coinciding with my wind direction, which is my x and so, my y on this line is all 0, so y is 0. We want to find out the ground-level concentration – that is 0 and my height of the emission is also 0 – I can consider the source to be at the ground level.

If you remember, that was 2 q root 2 pi – this formula we had derived earlier – $sigma_z$ U. $sigma_z$ you understand but here, the q is the emission rate. In what units? Grams per second per meter. What is the information available to you? 2 grams per second. I need to find out the emission in terms of grams per second per meter – that is my requirement and so, I have to be a little careful in finding out the….

What I will try to do is this. It might be a good idea to find the number of vehicles per meter –I can do that very easily. It will be the vehicle flow, which will be in numbers (number of vehicles per hour), divided by the vehicle speed and let us say that speed I have in meters per hour. So what will my final answer be? The number of vehicles per meter and that is what I need to do; let us try. The vehicles flow or the number of vehicles per hour it is 8,000, so let us write here 8,000 – that is the vehicles per hour. How much is the vehicle speed? Unfortunately, it is in miles – 40 miles per hour, but I can convert this into meters approximately if I multiply by 1600 and this will be meters per hour – the final answer will be in meters per hour.

I can remove this and this thing will come out be equal to…. I have to do some calculation here and that comes out to be… I will do the quick calculation here because I am using the calculator here. Interesting. Vehicles per meter. Now, we are all set and we can use the information here.

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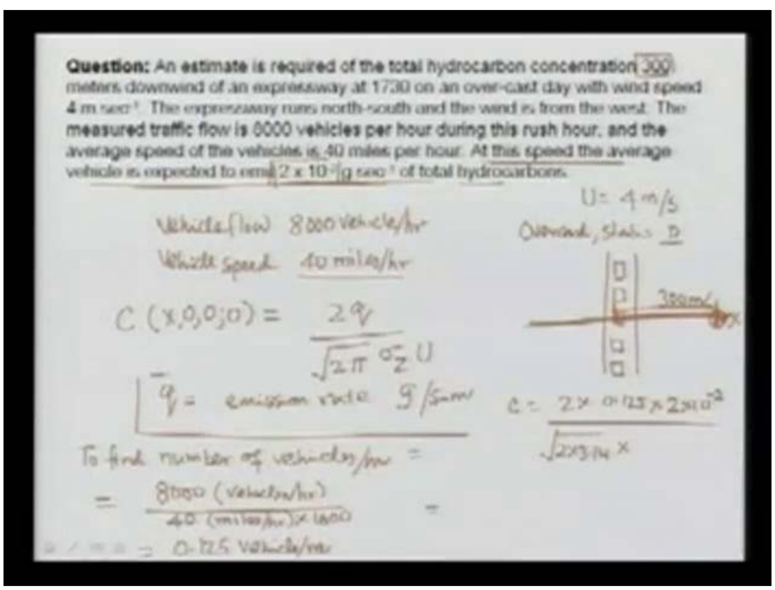

C is equal to 2 times q, which is 0.125 vehicles per minute and how much is each vehicle emitting? 2 into 10 to the power of 2 grams per second. So each vehicle…. I have only 0.125 vehicle, so I multiply this by 2 into 10 to the power of —2. This is what essentially I have got and this is my q, divided by 2 into 3.14 times sigma$_z$. I need to find out the sigma$_z$. What was my stability class? I need to know the stability. Did it say anywhere? Overcast condition. Overcast means… If you recall, we had explained to you that overcast conditions means the stability is equal to D, so let us take this stability. What is the distance from here to here, x distance? I forget. Let us see what the distance is. Expressway runs north-south, wind is from the west, the measured flow is… and concentration is 300 meters, very good, so this is 300 meters.

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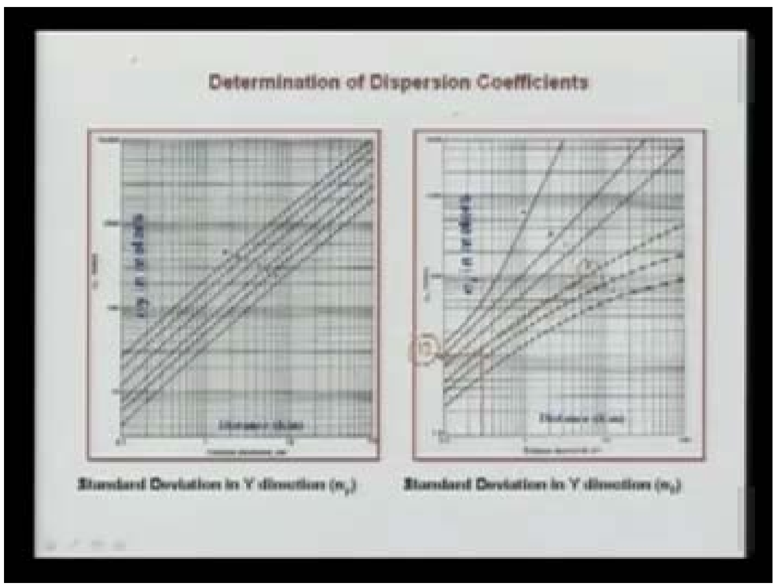

I need to go to my graph and this time, I am only interested in sigma$_z$ and so, let us find out the sigma$_z$ as we have been doing in the past. sigma$_z$ is here and my distance was only…. This is 1 kilometer and my distance is only 300 meters. This is 0.1, 0.2, 0.3, this is my 2, 3, so I go here and keep going along this line till I hit D. This is D, so I am hitting this graph. I go this way and find out and this comes out to be 12.

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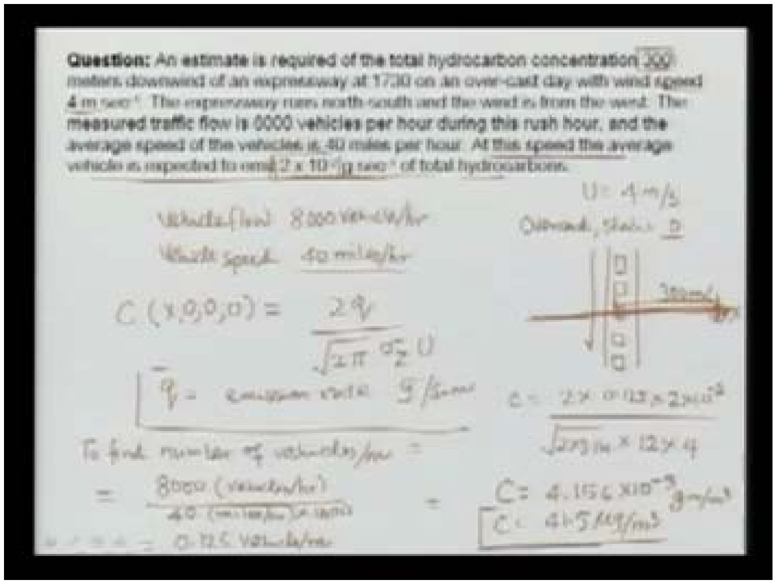

We go back to our calculation site and then we say sigma_z was 12 and what was the value of U, the wind speed? The wind speed was 4 meters per second, so this is 4 meters per second and now, we have to simply do the calculation. Let us see how much that is coming out to be if I do the calculation. 2 times 0.125 times 2 exponential 2 is so much and divided 2 times 3.14, take the square root of that, multiply it by 12, multiply it by 4, so much and it comes out to be 4.15.

C is equal to 4.156 into 10 to the power of —5 grams per meter cube – that is the impact of the highway. I can also say that this is approximately 41.5 micrograms per meter cube. This is what is my final answer and that is the impact of the vehicles on 300 meters in the perpendicular direction of the flow of the vehicles – that is the final answer. This way, we can utilize the models to find out the impact of any source – it can be a chimney, it can be a power plant or it can be vehicles.