Air Pollution and Control
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Lecture 16
Gaussian Dispersion Model for Point Source

Hello friends, you may recall, last time we discussed air quality modeling related issues. Within that, this question dispersion model, we just touched its definition, what kind of dispersion model it is. Today we will have detailed discussion on Gaussian Dispersion Model for Point Source, because it can be applied for other sources also. But points for this personal model of Gaussian nature is very important and very interesting.

So, in this particular lecture. First of all, we will see very preliminary info on Gaussian Plume model for the point source, different parameters which affect the concentration of air pollutants, when it is discharged from point source. Then it goes to the air and disperse. Then we will see the derivation of Gaussian plume model, because simplified version of mathematical expressions of the dispersion in Gaussian form is approximation, but it is very fast, very quick and very simple. So, it is very popular.

Then we will see different equations of the Gaussian plume dispersion for different cases, like when certain height is there of the this source of the emissions or the concentration of the pollutant need to be calculated at the ground level, central line or away from the central line at XYZ, something like that.

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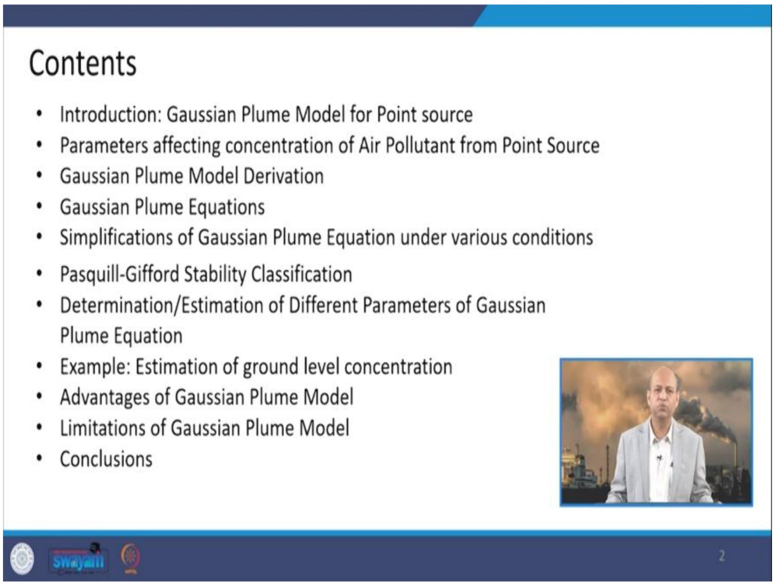

Then we will see the simplifications of these Gaussian dispersion models, so that we can see if there is no stack height. If the plume or the dispersion of the pollutant is occurring from the ground level source, then what will happen? Those kinds of simplifications we will see. Then this Pasquill Gifford distributive classification again we will discuss. Earlier we have discussed it.

But we will see in particular for the change of the wind velocity with respect to the height and with respect to different terrains. Then we will have one estimation of ground level concentration as an example, as a demonstration and at last we will see certain advantages and limitations of Gaussian Plume model and then we will conclude it.

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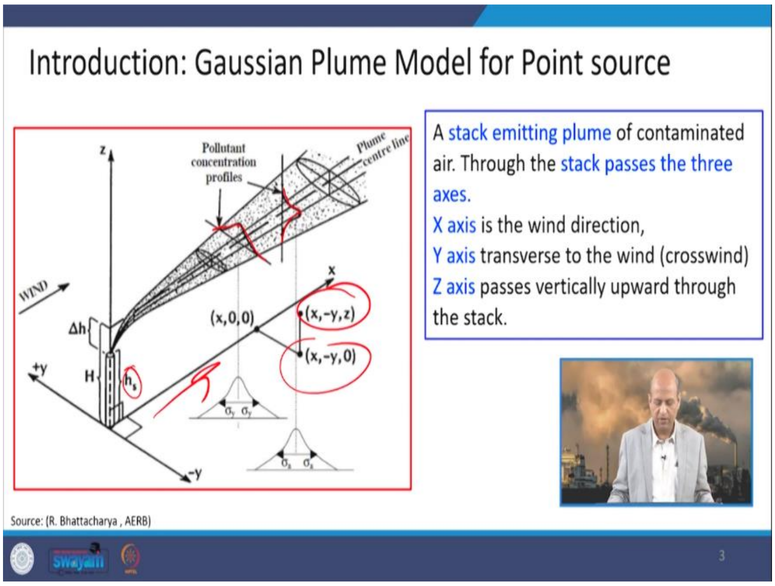

So, this is very important figure for introducing this Gaussian plume model from the point source. So, here point source is the stack. You can see this stack is having stack height h_s, small h_s. This H is the effective stack height. Because h_s is added with the Δh. Δh is the plume rise and plume rise happens, as I repeated earlier also that because of buoyancy.

Because of buoyancy due to difference in the temperature of the exhaust gases, which are very high temperature and it is much higher than the ambient air temperature. So, it has buoyancy, it has tendency to go up right. And then the momentum, because with high speed, it is coming out of the stack. So, it has certain momentum. So, both these parameters momentum and buoyancy decides the plume rise.

It goes up then it disperses along with the wind direction, way in which direction wind is blowing in that direction it goes away. So, this the plume height, physical plume height and this plume rise Δh added and then this H is the effectively stack height which is determined by that, which is used for this Gaussian dispersion modeling. Then there are these coordinates X Y and Z. X is this wind blowing direction.

The wind is flowing in a certain direction which we take as the X direction, then perpendicular to it, we have this Y direction, traversing to the wind crosswind direction you can see and vertical direction is the Z direction. So, X, Y, Z, three coordinates can be seen like here, this is X minus Y, Z minus Y because we have direction, sense of direction.

So, this direction we have taken minus on that direction it is plus. Then the central line, if it is at ground level then X, 0, 0 means certain distance away from the stack point source X. And if it is the ground level point at the central line, then Y is 0 and Z is 0, otherwise it can be X, Y, Z. Similarly, if it is away from the central line, but at the ground level then Z is 0. So X minus Y, 0 this is the coordinate.

So, that kind of coordinate, we can have at any coordinate we can determine the concentration of the pollutant and very simplification this conical shape and the distribution of pollutant from the centerline away, so it reduces because of diffusion. So, diffusion occurs in Y direction and Z direction right, Y direction and Z direction, so, away from the centerline, maximum concentration here is at the centerline.

Then as we go away from the centerline Y direction or in the Z direction, then it reduces. So, you can see here, the maximum concentration, then we go away so, it reduces, it reduces. Similarly, in vertical direction maximum at the centerline when we go away then it reduces. So, this kind of variation is there. So, this is the normal distribution curve, basically, that is why we call it Gaussian normal distribution or Gaussian Plume model.

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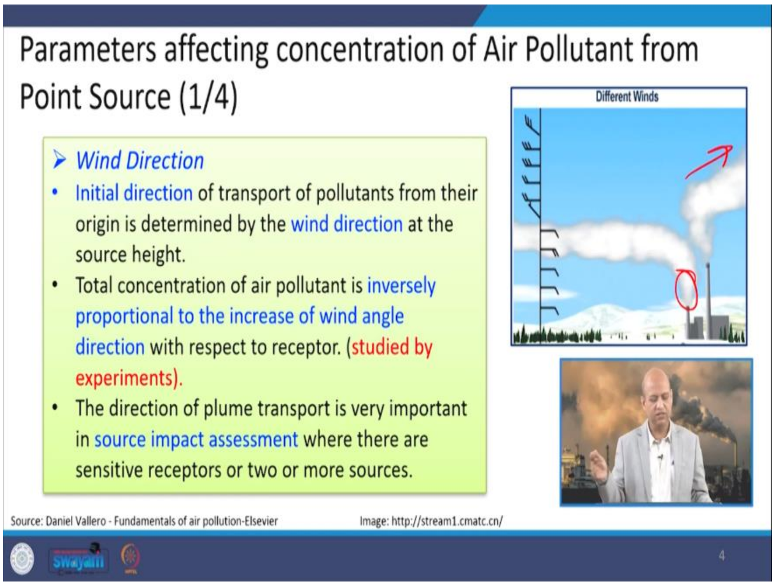

Now, if we see other parameters like, for example, wind direction, so, the wind direction changes from point to point in the time period. Basically, wind is not static it changes direction; it changes its value or absolute value. So, we have to have the direction as well as the value, so, wind speed and wind velocity you can say. For example, at this site, if the wind direction is in that direction, so, plume will go away in that direction, at lower height wind is blowing in this direction, then plume will blow in that direction after this plume rise, certain plume rise and then dispersion takes place.

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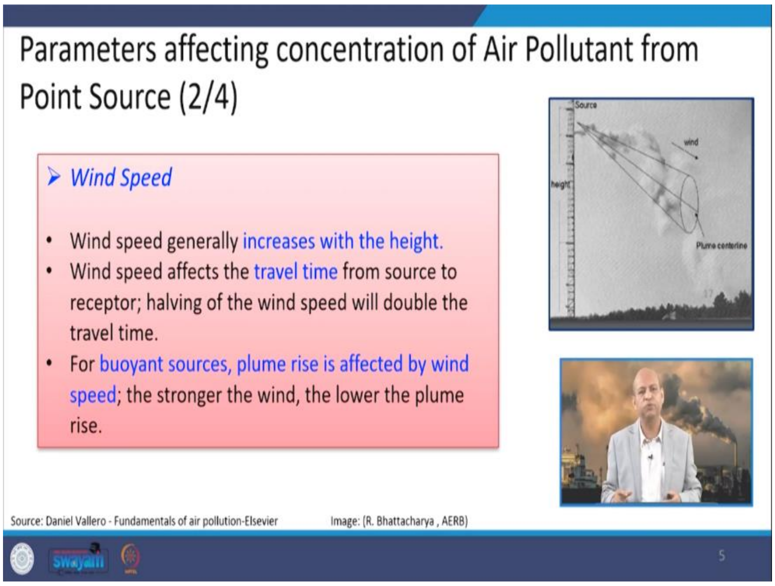

Now, if we see this wind speed, so, it has like it affects the travel time from source to the receptor and having the wind speed like half of the wind speed, then it can double the travel time. Those kinds of thing happens. That is very simple relationship. Then there are like for buoyant sources, plume rise is affected by wind speed because it takes away from the source point. And the stronger the wind the lower the plume rise because it will not rise full to the maximum possible, the wind will take it away from the point source.

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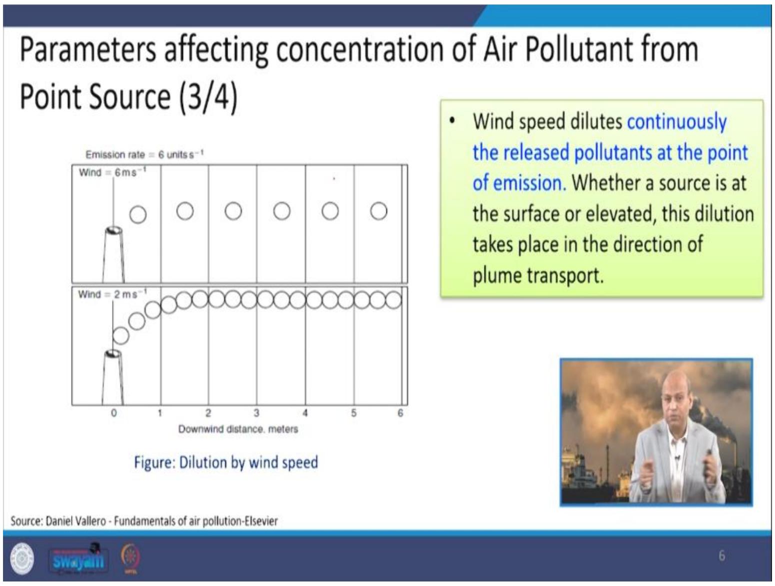

When we look at the air pollution concentration for the point source. So, wind dilutes it continuously, it dilutes continuously. So, it depends on the wind speed. If wind speed is slower than the dispersion is slow. You can see here, this is 2 meter per second; this is 6 meter per second, right. So, you can see this is pictorial representation. The concentration is high here; here concentration is low because dispersion has happened very quickly and very efficiently.

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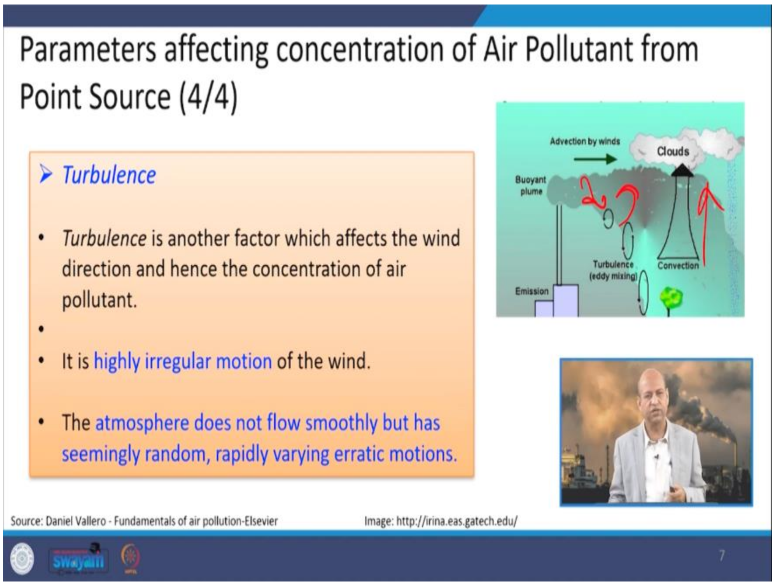

Then the turbulence. Turbulence is the parameter like normal direction is there in which wind is flowing. But turbulence is within that wind, pockets of the wind, they have different direction, away or other than the main direction, like these the eddies, it goes up, it comes down, a lot of turbulence occurs in the fluid motion, whether it is here or water something like that.

So, if it is going, this is the advection by wind, horizontal movement, convection in the vertical direction because of temperature gradient and this the turbulence, the eddy mixing, because this air goes like this, then it comes down, that kind of churning occurs. So, that also adds into dispersion and diffusion of the pollutants and dilution of the pollutant.

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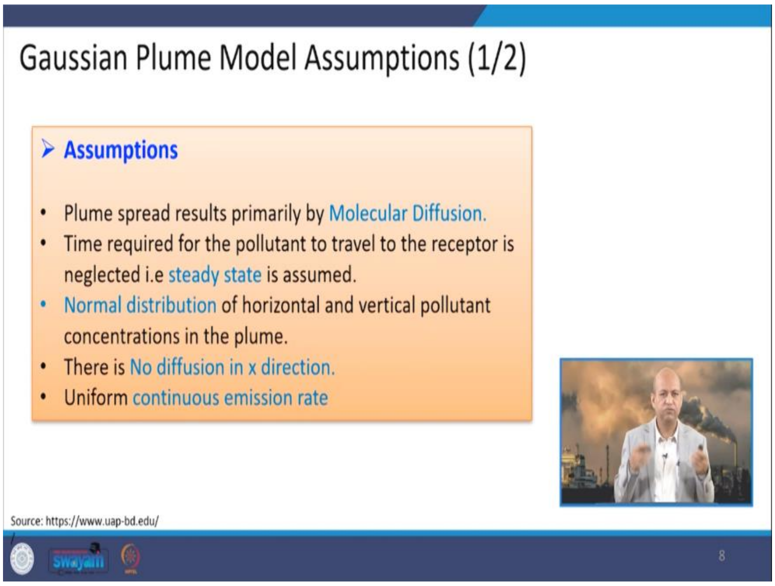

Then there are certain assumptions, basically, because this Gaussian dispersion model is not the true representation of, what is happening in the atmosphere with the pollutants. Because pollutants have several things. For example, it may mix, it can react with each other, it can act or it can react with atmospheric constituents.

So, like SO_2 conversion to SO_3 or H_2SO_4, those kinds of things. But, for the sake of simplification, because otherwise complexity will increase and given so much uncertainty in monitoring and modeling, maybe we don't have those great benefits, if we make it more complex. So, for simplification, we assume certain things, which are not true, but still we assume, because of simplification.

So, first, like we assume this plume is spread like by molecular diffusion. So, whether then this wind velocity at least in Y direction and Z direction, diffusion is the most predominant phenomena. Otherwise, in X direction, in a transportation of plume is taken by the wind. Then we look at like a steady state concentration means the uniform concentration is achieved at certain point of time, so, it does not change with respect to the time.

The normal distribution is there, whether in horizontal Y direction or in the vertical direction. So, at the centerline maximum concentration as you go away, the concentration lowers down. Then there is no diffusion in X, direction only diffusion in Y and Z direction. And uniform continuous emission rate we assume, like from the stack, whatever emission is coming out then it is coming with the constant speed, which is again not true in real sense, but still we assume. We have some average value.

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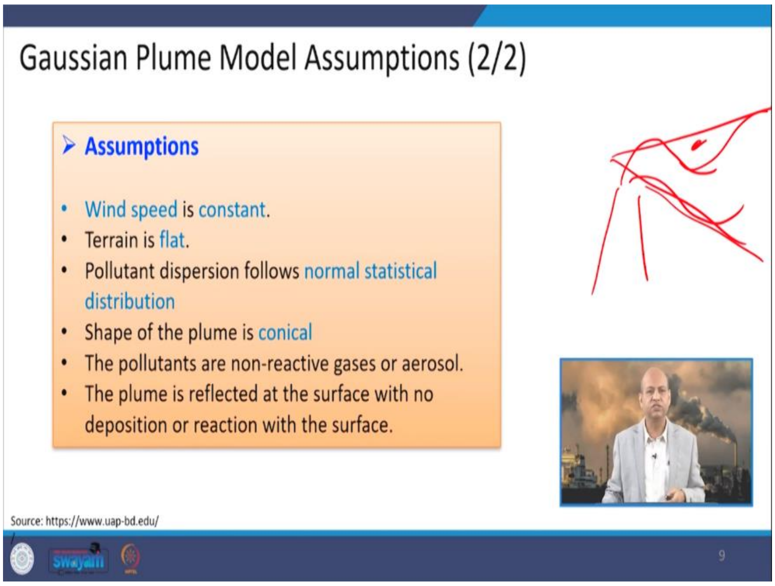

Similarly, like wind speed, we assume as constant, otherwise wind changes from minute to minute, but still we assume, we take some average wind speed. And we assume that the terrain is flat where the dispersion is occurring, otherwise undulation may be there. There may be certain buildings of different heights or undulations of the trop, this topography may also be there, but we assume that terrain is flat.

Then we also assume that this pollutant dispersion follows the normal statistical distribution, as we have seen, maximum at certain point and then decreases like with σthat is the dispersion coefficient. And shape of the plume is conical. So, like funnel kind of thing it takes otherwise, like, if it is coming out of a stack, it can go like this and disperse.

So, we assume like conical shape. So, even if there is no concentration we assume here some uniform concentration is there such conical shape is there. Then we also see like non-reactive pollutants we assume. As I said SO_2 NO_x etc. They can react with the moisture, but we do not assume here any reaction.

We assume whatever pollutant is coming, it is there in the same form, they are non-reactive, right. So, those kinds of assumptions are there. Also like if pollutant is coming to the surface, then it bounces back, it is reflected, it is not like dry deposition, where deposition occurs in real sense, but that we do not consider, we assume that whatever pollution is coming to the ground, it is coming back and giving the complete contribution to the point, where we are estimating the air pollution concentration.

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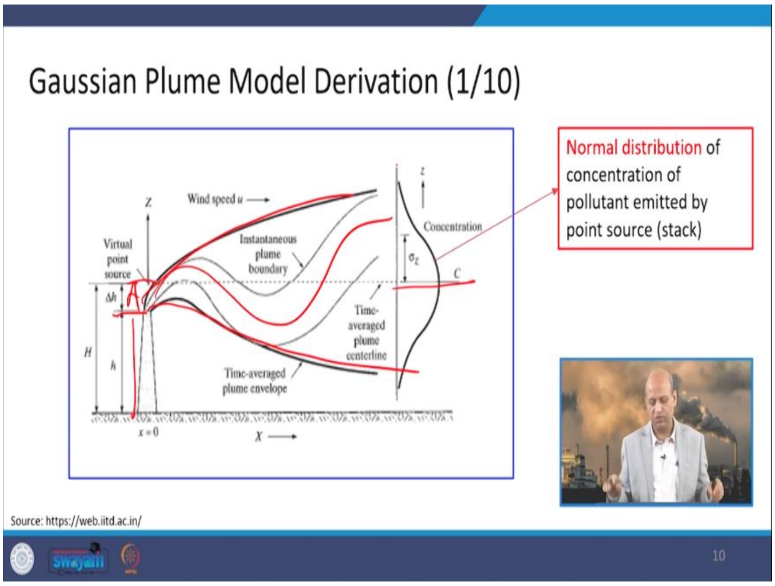

So, here as I said, this is the this physically stack height, this is the plume rise Δh and the total of these two is effective stack height, here this plume is going like that maybe unstable atmosphere, but we assume that this is following this kind of funnel or conical shape, and their normal distribution because at the central line, it is maximum. Then as you go away this dispersion occurs and normal distribution occurs a statistically, that is there.

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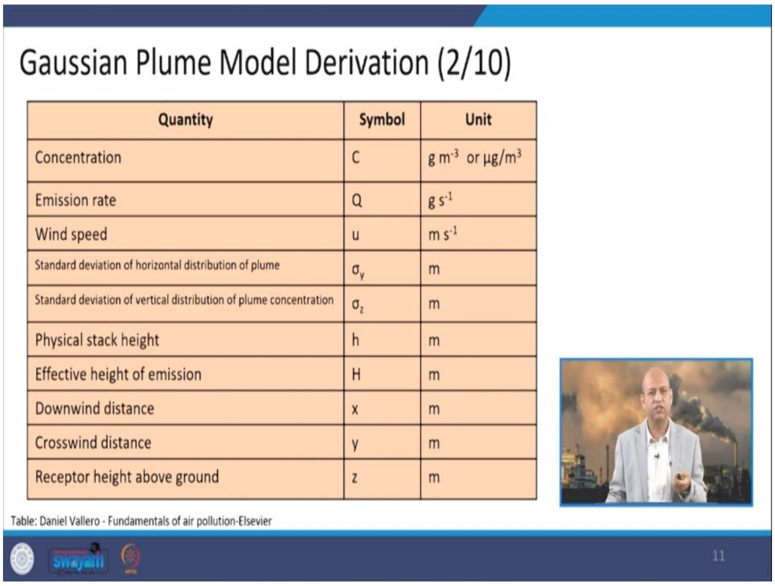

Now, if we want to derive the equation the basic equation of Gaussian plume dispersion model then there are certain nomenclatures we follow. For example, concentration we represent it, see, although in different books you will find different nomenclature does not mind. The concept is same; there is concentration of the pollutant which can be represented as microgram per cubic meter or gram per cubic meter, means mass per unit of volume.

Then emission rate which is coming out of the stack or point source that is the Q which is like a mass per unit of time, gram per second, kilogram per hour, whatever unit you are taking. Then the wind speed like u, average wind speed that we are taking at the stack height. Normally the wind speed is measured at ground level. Ground level means 10 meter above the ground. Then we convert that wind speed at the stack height.

So, there is equation for that we will see later on and that average wind speed we include in the model that is meter per second right. Then there are σ_y and σ_z, which are dispersion coefficient. Horizontal dispersion coefficient σ_y for the plume and vertical dispersion coefficient σ_z. These are in meter. Then physical stack height as I have shown and effective stack height, physical stack height plus Δh that is the plume rise.

Then the crosswind distance that is the Y and this receptor height above the ground that is Z. So, X Y Z, that kind of coordinate system is there. X is the distance in the downwind direction, right.

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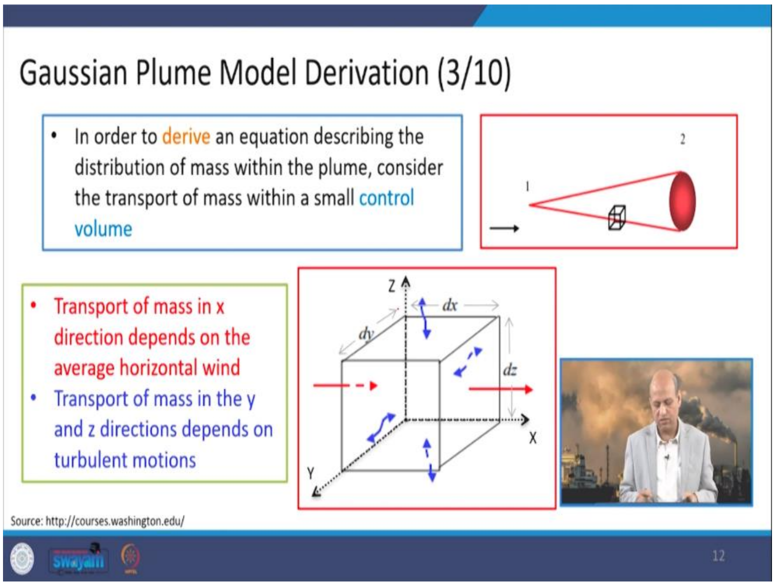

Now, we will see like, we want to derive the Gaussian Plume model. So, there are certain things. For example, you have to assume certain, this box of very small size like dx dy and dz. dx is in the direction of wind velocity X direction, Z is vertical direction; Y is crosswind direction, right. So, this box can be assumed in that sense. dx, that parcel or that kind of dx, dy and dz.

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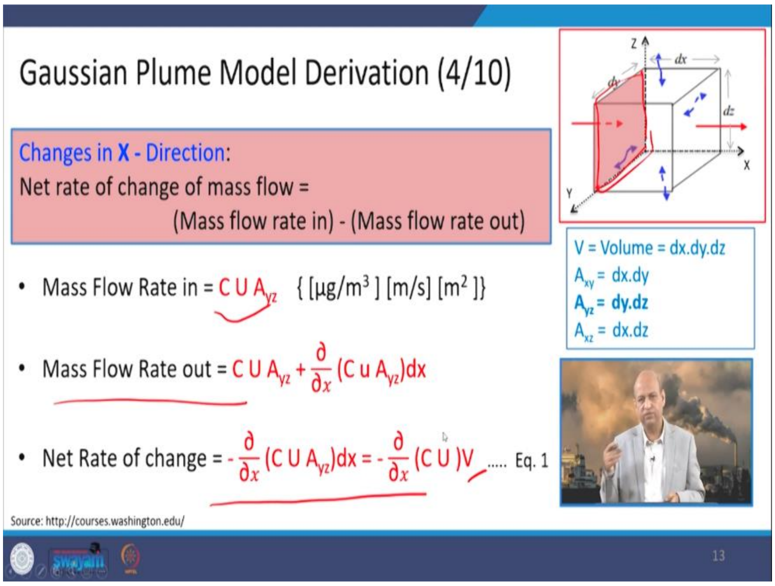

Now, if you see like mass flow rate, so, mass flow rate is nothing but concentration multiplied by the u that wind velocity and then the area. So, area into wind velocity u, that will give certain value and then if we multiply with dx that distance, so, this area into the short distance will be the volume.

So, that is why this mass flow rate C U A_{yz}. A_{yz} is this one, this one A_{yz} A_y A_z. So, this is the A yz surface area, vertical to the wind flowing direction. And then mass flow rate out, this is the mass flow rate in, C U A_z, mass flow rate out C U A_{yz} plus δY δX of CUA_{yz} into dx, means if some direction dx is there, so, how much change is there. So, that mass flow out rate is calculated like this. Then the net rate of the change.

- Mass Flow Rate in = $C\ U\ A_{yz}$ { [µg/m^3] [m/s] [m^2]}
- Mass Flow Rate out = $C\ U\ A_{yz} + \frac{\partial}{\partial x}(C\ u\ A_{yz})dx$
- Net Rate of change = $- \frac{\partial}{\partial x}(C\ U\ A_{yz})dx = - \frac{\partial}{\partial x}(C\ U\ )V$

So, you can convert it into like this. Multiply by dx, so, dx and A_{yz} will be V and this will be δY δX and C U, minus means the change of that reduction of the concentration.

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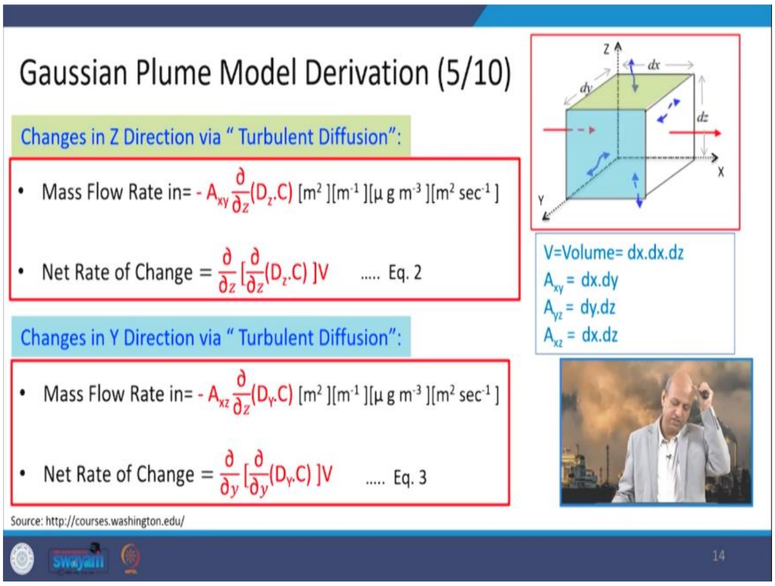

Mass flow rate and similarly in Z direction and Y direction is calculated and the similar equations are brought.

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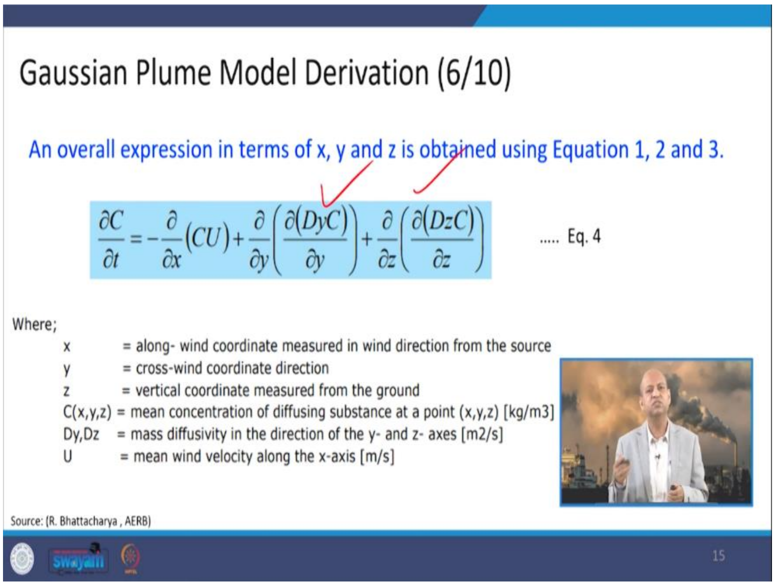

Then we do the summation of those. So, the concentration that overall expression of the concentration variation with respect to the time δC by δt is like δ by δX into C U minus terminology plus these dy and dz, these are the mass diffusivity coefficients, which are in the Y direction and Z direction, they are taken into account along with this concentration. So, the summation of these three components give us the concentration with respect to time.

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(CU) + \frac{\partial}{\partial y}\left(\frac{\partial (D_y C)}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{\partial (D_z C)}{\partial z}\right)$$

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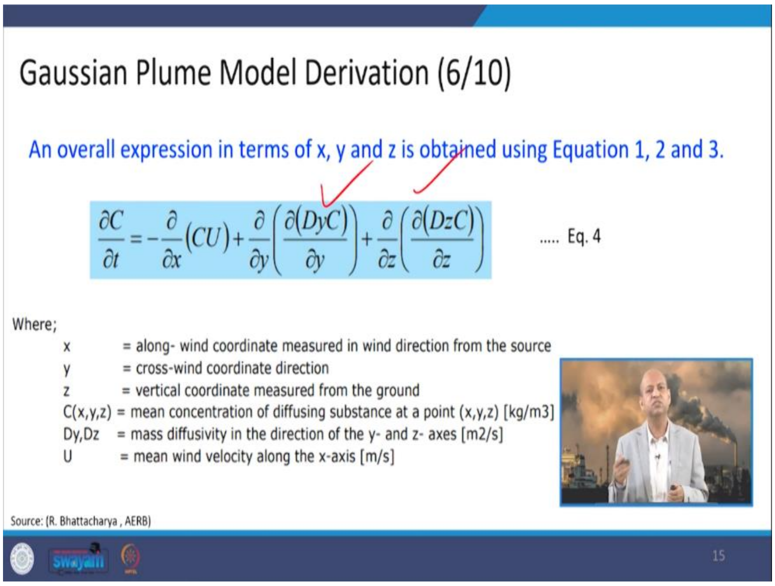

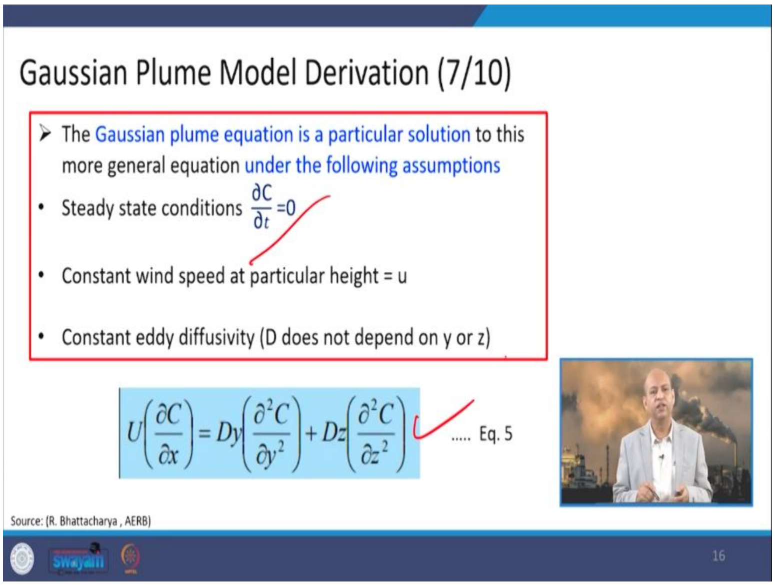

Now, you see further you can have this steady state condition that means with respect to the time concentration is not changing, change rate is zero. So, this when we put then that particular equation give this kind of relationship.

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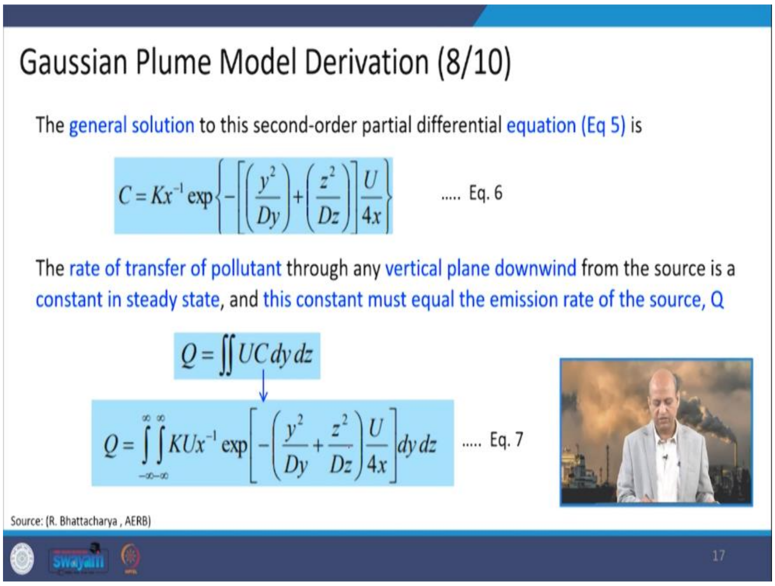

And then next we can further solve it like second order partial differential equation. So, you can have this expression ultimately Q equals this summation or integration of KUx to the power minus 1 exponents of Y square upon Dy plus Z square Dz, those kinds of expression.

$$C = Kx^{-1}\exp\left\{-\left[\left(\frac{y^2}{D_y}\right)+\left(\frac{z^2}{D_z}\right)\frac{U}{4x}\right]\right\}$$

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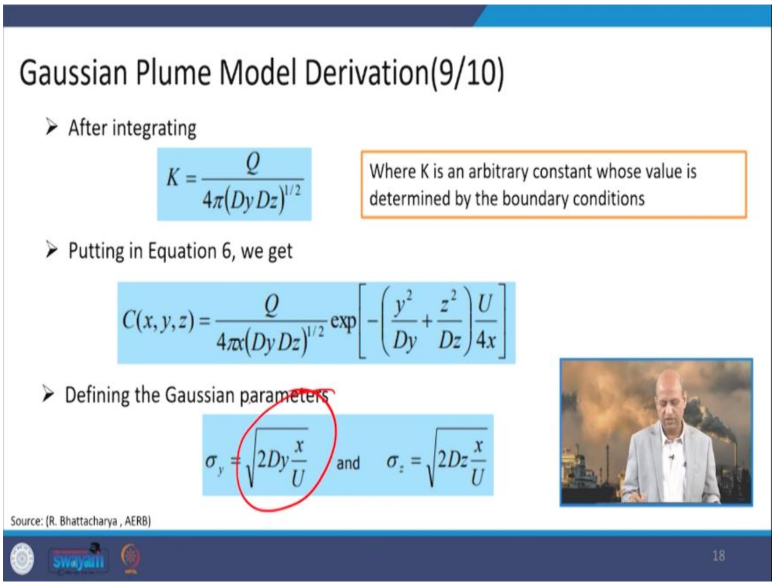

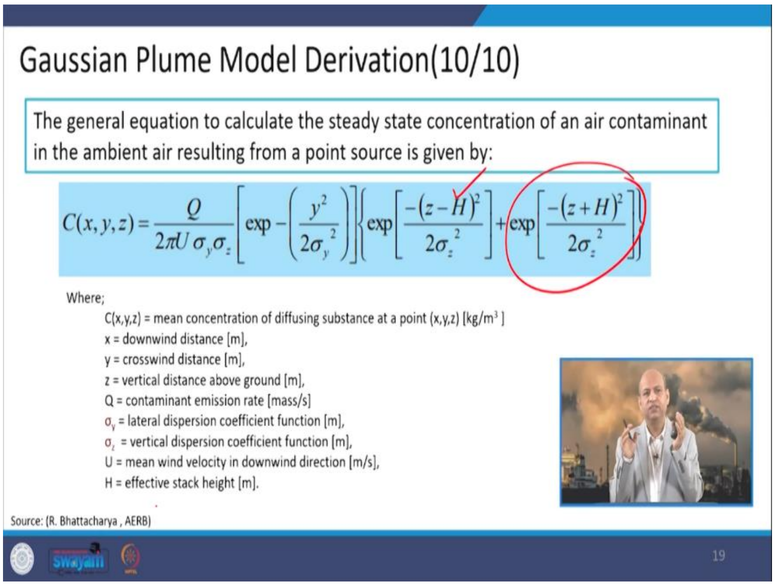

Ultimately, we get this relationship where σy is this terminology. So, the final equation of the Gaussian dispersion model is in this form, where Q is this emission rate divided by 2π into U. U is the average wind velocity at the stack height, effective stack height. σy, σz, those components which are related to diffusivity coefficient X Y U is terminology is there. So, σy and σz, they also incorporate these values x.

Sometimes, when looking at this equation people get confused that we are calculating concentration at the X distance and there is no X in this equation, but X is there which is included in σy and σz that we have to remember. Now, this H is effective stack height. This terminology because of reflection. We assume that whatever concentration of the pollutant went to the ground, it has come back to that point.

$$C(x,y,z) = \frac{Q}{2\pi U \sigma_y \sigma_z}\left[\exp -\left(\frac{y^2}{2\,\sigma_y^2}\right)\right]\left\{\exp\left[\frac{-(z-H)^2}{2\,\sigma_z^2}\right] + \exp\left[\frac{-(z+H)^2}{2\,\sigma_z^2}\right]\right\}$$

So, summation is there and then this is the crosswind and this is the vertical wind, you can have this equation. So, this is the final equation of the Gaussian plume model dispersion. C(x, y, z) means concentration at the coordinate X, Y, Z, in the downward direction X distance, Y means from the centerline, Y away, Z is in the like hanging at certain point above the ground level.

So, these nomenclatures are there for every terminology or you can see. So, there are some simplified cases in the sense because this was the total overall C(x, y, z) at the X Y Z coordinate.

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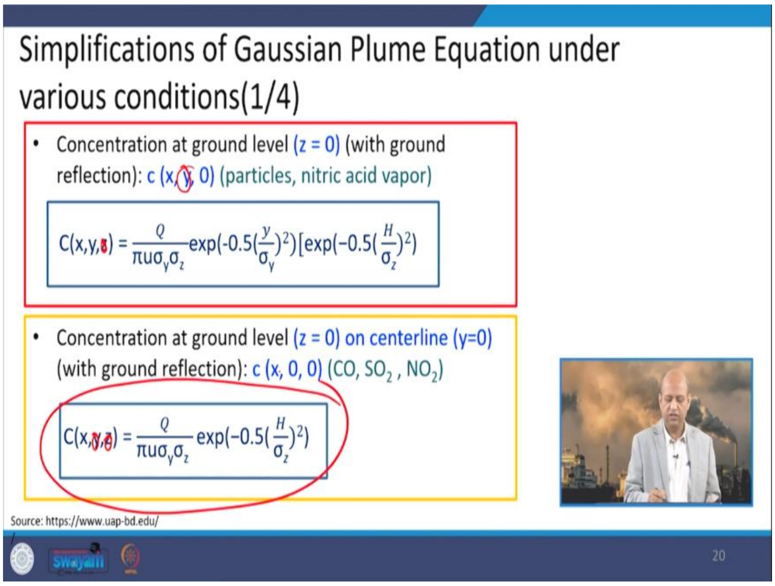

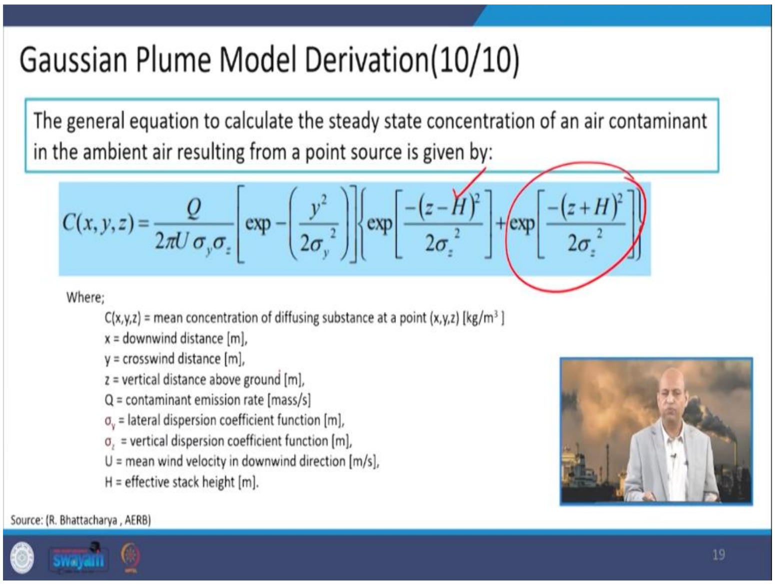

Now, there are some special cases, for example, we want to calculate concentration at the ground level. So, ground level means Z = 0, height coordinate is not there, Z = 0. And with ground level reflection that reflection is here. So we can have this simplified version. So, C(x, y, z), basically, this Z = 0. So Z terminology has been removed here. So we can call it C(x, y, 0).

$$C(x,y,z) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left(-0.5\left(\frac{y}{\sigma y}\right)^2\right)\left[exp(-0.5\left(\frac{H}{\sigma z}\right)^2\right]$$

Similarly, concentration at ground level on the central line, Y = 0, here Y term is there. Here Y is also the 0, Y = 0, Z = 0. So, in that case C(x, 0, 0). So, this form will be, it is derived from the original form. You can put those values and you will get these values.

$$C(x,y,z) = \frac{Q}{\pi u \sigma_y \sigma_z}\left[exp(-0.5\left(\frac{H}{\sigma z}\right)^2\right]$$

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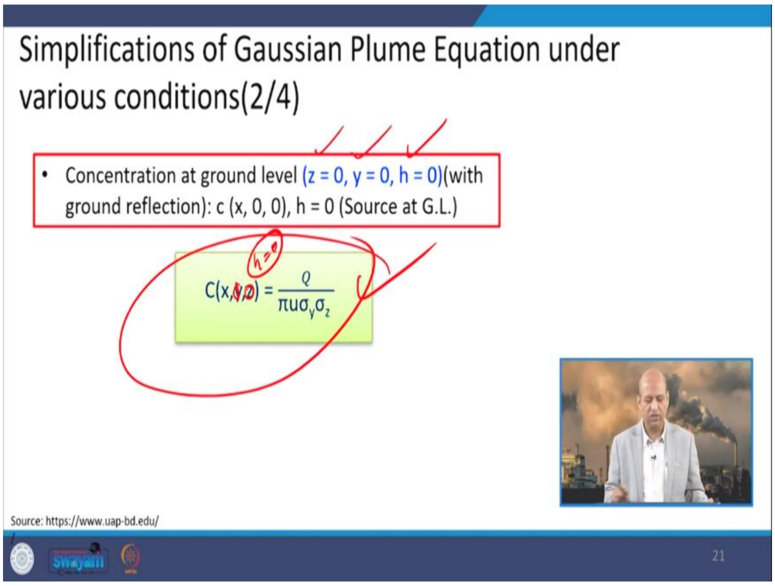

Similarly, if we go for like even stack height is 0 means like some heap of the leaves is built. So, how this person will occur? What would be the concentration at certain distance? So, in that case Z = 0, Y = 0 and H = 0. Stack is not there. At the ground level only something you are burning and emission is occurring. So, in that case, this becomes very simple. So, C (x, 0, 0) and H = 0. In that case this kind of relationship we use.

$$C(x,y,z) = \frac{Q}{\pi u \sigma_y \sigma_z}$$

There are other special relationships also, I am not taking into account, but for the sake of this introductory lecture of Gaussian plume dispersion model, this much is enough for you to understand.

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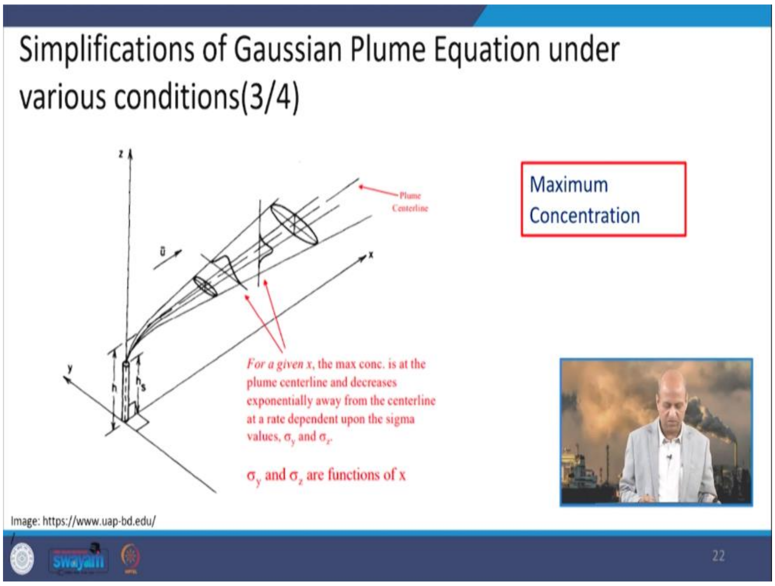

Then now, if we look at this maximum concentration, where will be the maximum concentration? One concept says that at the central line maximum concentration will be there, but how far away? At what distance maybe the maximum concentration?

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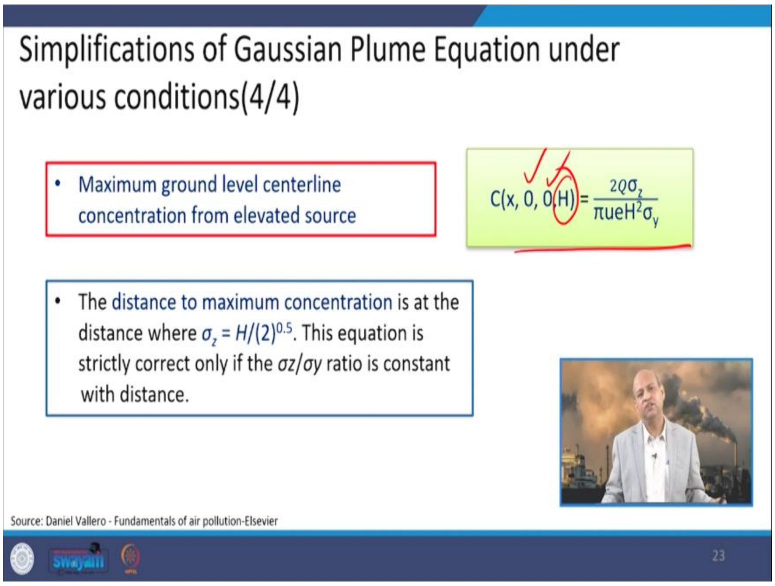

For that, we go for these kind of relationships, there are some empirical relationships which have been derived, this is X component is there, effective stack height and at the ground level at the centerline, so, Y = 0 and Z = 0. This is the relationship you can have. The maximum ground level concentration from elevated source is given by this formula.

$$C(x, 0, 0,H) = \frac{2Q\sigma_z}{\pi u e H^2 \sigma_y}$$

$\sigma_z = H/(2)^{0.5}$

And the distance to maximum concentration is at the distance where σ_z equals H divided by 2 the power 0.5. So, this equation is strictly correct only if the σ_z divided by σ_y ratio is constant with the distance. So, those kinds of limitations are there, within those limitations with these within those terms and conditions, we can calculate certain concentration values.

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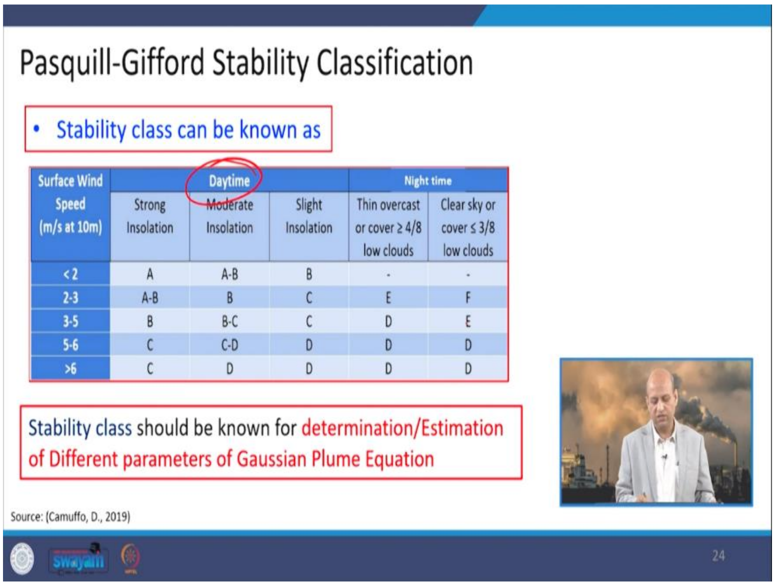

Now, we see like Pasquill-Gifford stability classification, which we have earlier also seen. So, this is the surface wind meter per second at 10 meter, that is the ground level, less than 2, 2 to 3, 3 to 5, those kinds of. A strong insolation, so, daytime insolation related dependencies there.

Strong insolation means lot of sunshine is there, moderate insolation may be there, slight insolation may be there. And the nighttime, it depends upon the cloud cover. So, how much part of the sky is covered by the cloud. Accordingly this A B C D E that stability classification, which we discussed accordingly these classifications exist.

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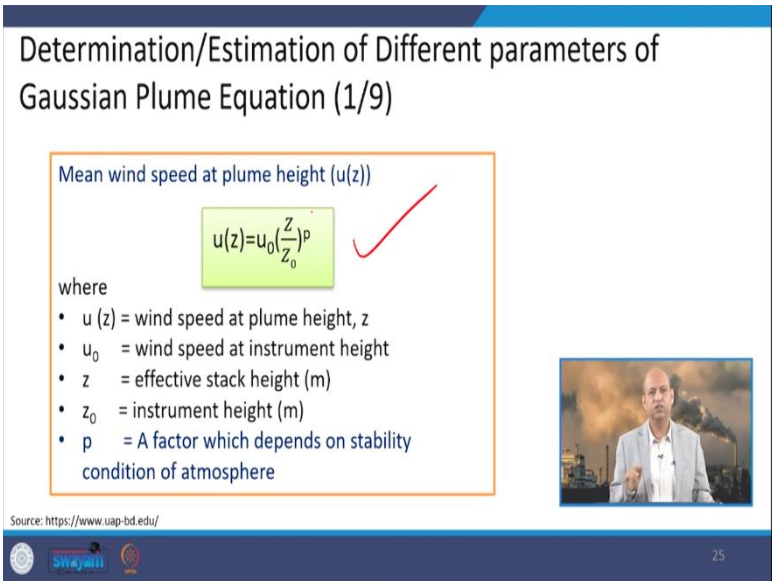

They will influence, basically, this wind velocity, because when we want to calculate wind at different heights, we use this particular formula, where p is this constant value effector with dependence upon the stability conditions of the atmosphere. So, u = 0 is at the Z = 0 height and u (Z) is at the Z height and this component (Z/Z_0) power of p. So, this equation has to be used. And where this p is derived?

$$u(z) = u_0\left(\frac{Z}{Z0}\right)^p$$

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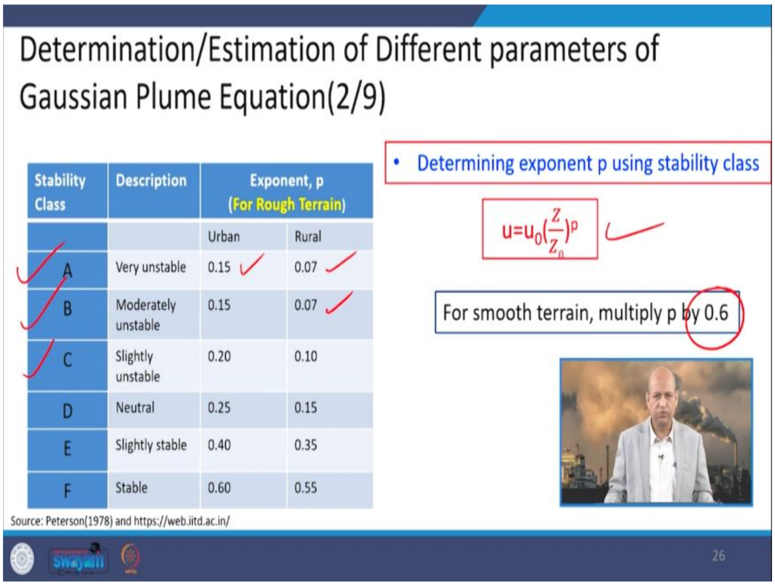

From this particular table, which is as we said dependent upon the stability classification, very unstable then urban and rural areas and this is the rough terrain related values. 0.15, 0.07, 0.15, 0.07, like that. And, if you want to calculate this value for a smooth terrain, this is for rough terrain, so, then you have to multiply it by 0.6. Whatever value is coming then we can multiply it by 0.6. So, if there is a smooth terrain then this equation gives the value but 0.6 factor multiplication must be there.

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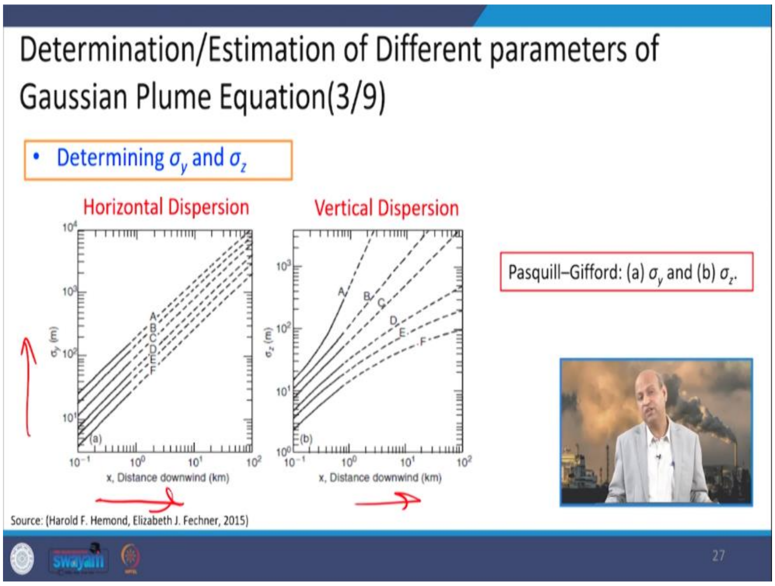

Now, like σ_y σ_z, how to determine? A rill or also we see these kinds of curves which have been developed by these researchers, this can be used. A B C D E F, these are related to a stability classification. Then σ_y value is there. This X distance downwind distance is there in kilometer. This is in meter.

Similarly, and the σ_z value you can see in meter in this direction, X direction, distance in kilometer. And A B C D are there. So, whatever distance of the horizontal, where you want to calculate concentration, you go to that point, you go up and up to that classification of the stability and go horizontally to read the value of σ_y or σ_z. So, that dispersion coefficient values we can get from these charts. There are certain empirical relationships also which we have already seen, again we will see.

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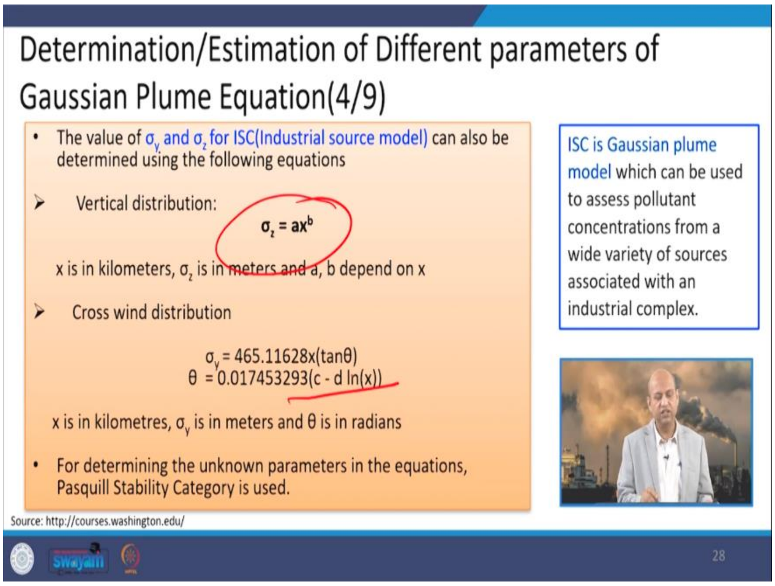

These kind of σ_z equals ax^b. a into X to the power b. Those values a and b are to be taken from other table. Similarly σ_y is like 465.11628 tan theta and this theta is by this, where c and d again some constant value, right.

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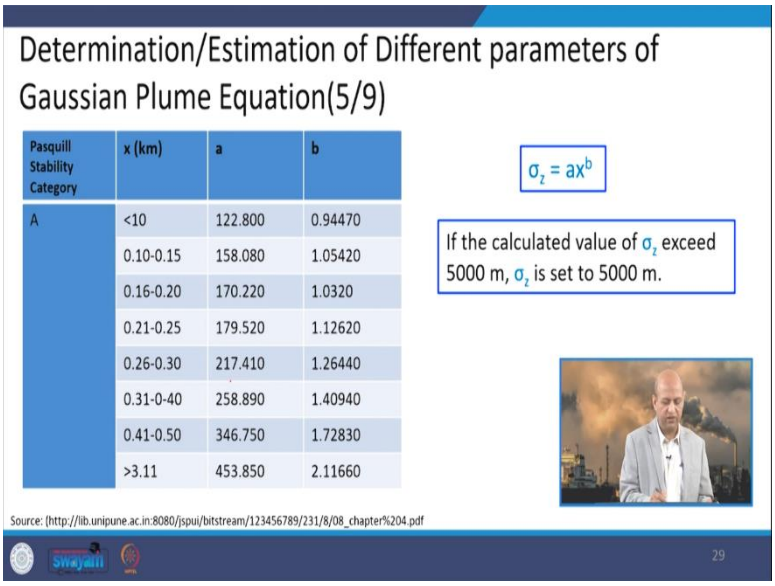

Pasquill Stability Category	x (km)	a	b
A	<10	122.800	0.94470
	0.10-0.15	158.080	1.05420
	0.16-0.20	170.220	1.0320
	0.21-0.25	179.520	1.12620
	0.26-0.30	217.410	1.26440
	0.31-0-40	258.890	1.40940
	0.41-0.50	346.750	1.72830
	>3.11	453.850	2.11660

So, these are the a b depending upon the X direction. And this also depend upon the stability classification. For a it will be different.

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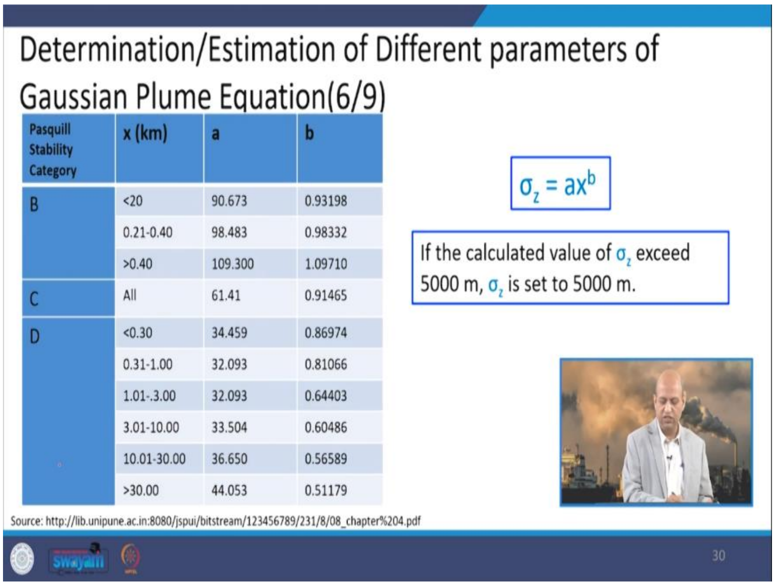

And for B C D, it will be different. And it is given one condition that the calculated value in case the σ_z exceed the 5000 meter then σ_z is set to 5000, which do not take more than 5000 meter that is the maximum value we have to take.

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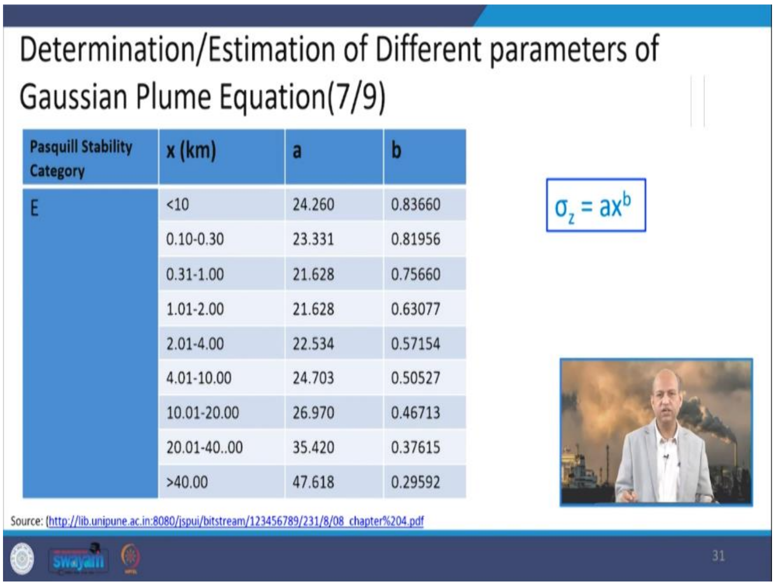

Similarly, we can calculate the σ_z that was for E that was for B C D.

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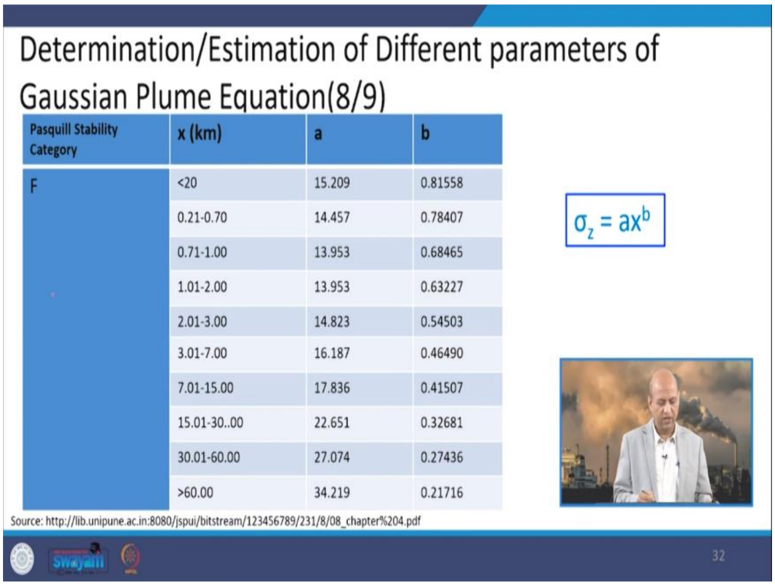

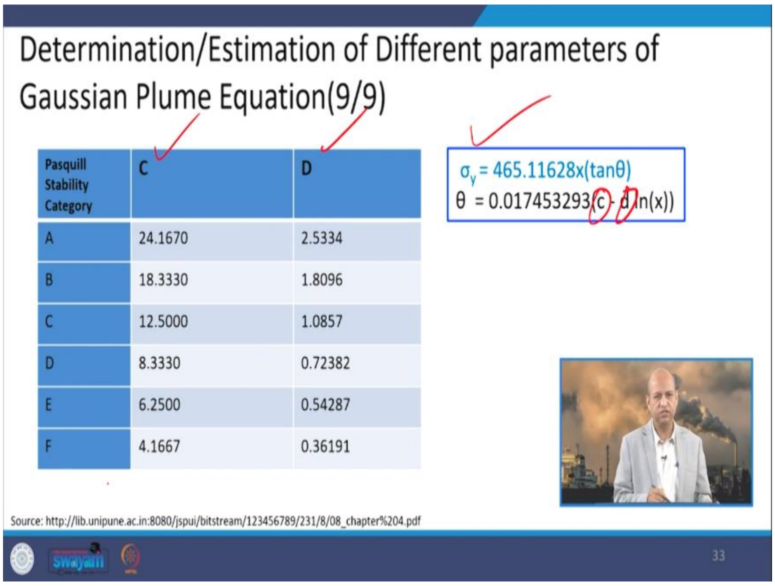

And next is for F, right. Then σ_y calculation can be taken from this empirical relationship. Again, the C and D values are there, here, we use in this particular relationship. So, you take c and d value from this A B C D E F dependent on the classification of the atmospheric stability.

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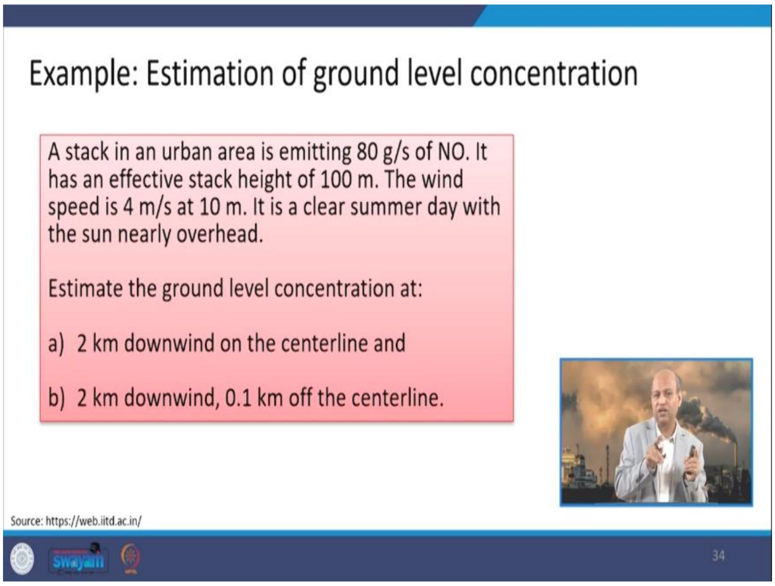

Now, if you want to give some example, how to estimate the ground level concentration. So, this is one very small example you can try like a stack in an urban area is emitting 80 gram per second of nitric oxide. It has an effective stack height of 100 meter. So, the effective stack height is given.

So, you do not need to calculate plume rise, otherwise plume rise value needed to calculate effective stack height if physical height is given, but directly effective stack height is given, so, we do not need to calculate it. Then the wind speed is 4 meter at 10 meter. So, that means, we have to calculate wind speed at the 100 meter by using that power relationship of the P.

It is clear summer day. Clear summer day means very hot day. So, solar insolation is very high. So, from that table we can see, what is the stability classification and sun is nearly overhead. So, it is known and very hot day you can. Then you have to estimate the ground level concentration at 2 kilometer downwind on the central line means Y = 0 and Z = 0. And second point 2 kilometer downwind, but 0.1 kilometer of the centerline means Y value is given 0.1 kilometer. So, for that σ_y value we will need.

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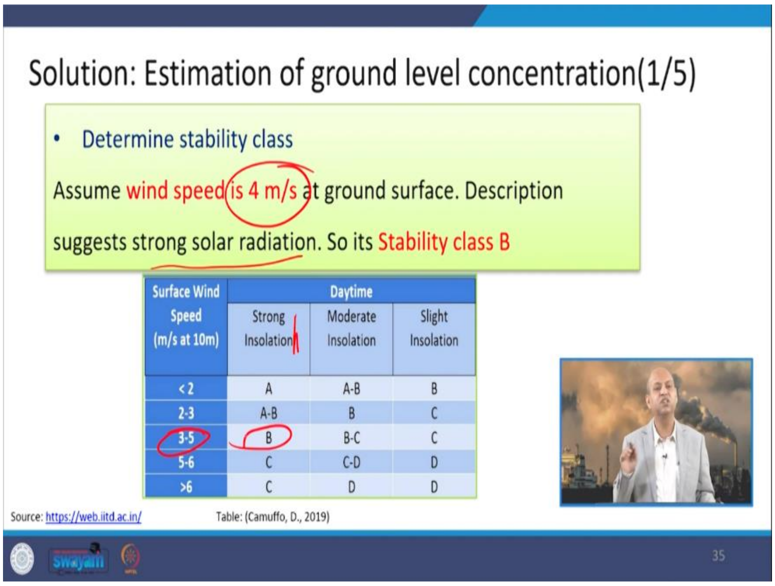

Now you can determine the stability class. So, for 4 meter per second in this table, 4 meter per second will be in this 3 to 5 and the strong solar radiation. So, strong solar radiation is this particular column. So, here this one. So, B is the stability class.

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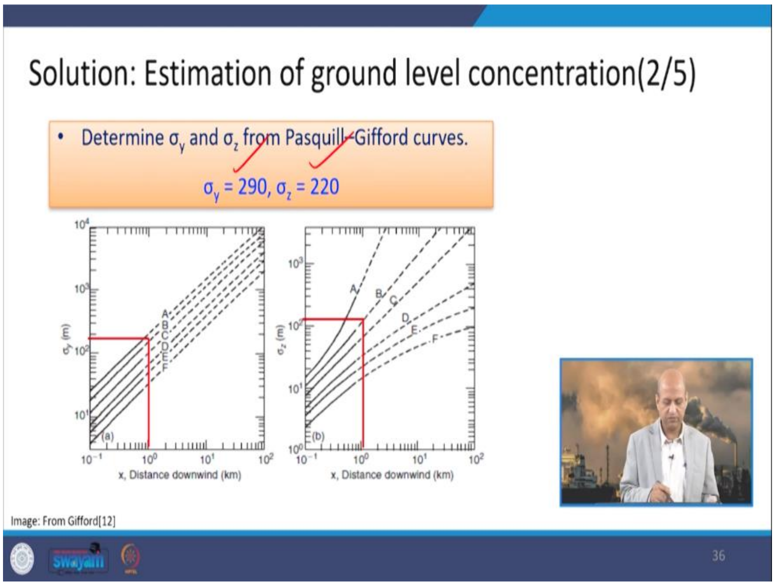

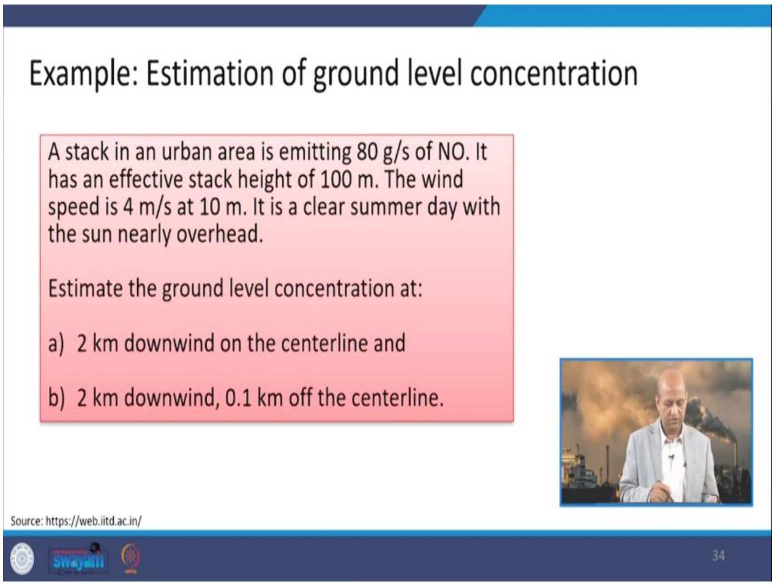

So, this will determine those σ_y, σ_z values, if you use the empirical relationship, otherwise, directly you can calculate from these charts, right. So, σ_y 290 σ_z is 220, with this point and 2 kilometer is given. Basically, you can have this 2 kilometer away.

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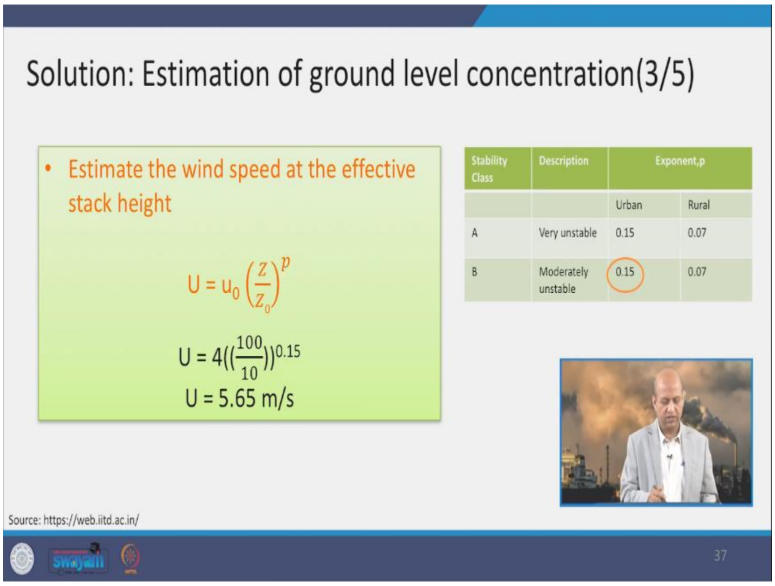

Well next, this is the u the wind velocity at the 100 meter that is the effective stack height, because 10 meter height wind velocity is given. So, we can use this 100, that is effective stack height z. Z_0 is 10. 0.15 why? Because, this is 0.15 for B. This 0.15 for the B and urban area it is urban area, so, 0.15 we have taken.

$$U = u_0 \left(\frac{Z}{Z0}\right)^p$$

$$U = 4 \left(\frac{100}{10}\right)^{0.15}$$

U = 5.65 m/s

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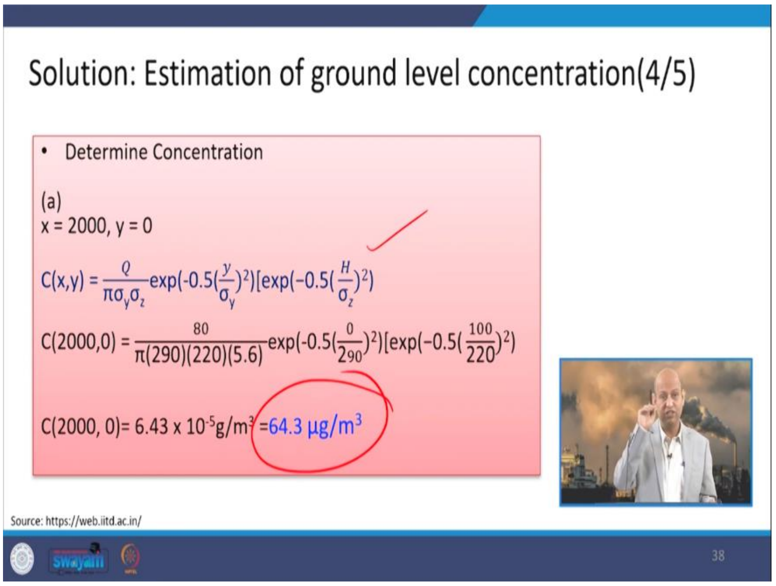

Well, now, we determine this concentration by putting those values. So, Q value is given 80 gram per second. And the Y value is 0 because at the central line, we are having H effective stack height is given. So, ultimately 64.3 micrograms per cubic meter concentration is obtained at that 2000 meter that is 2 kilometer.

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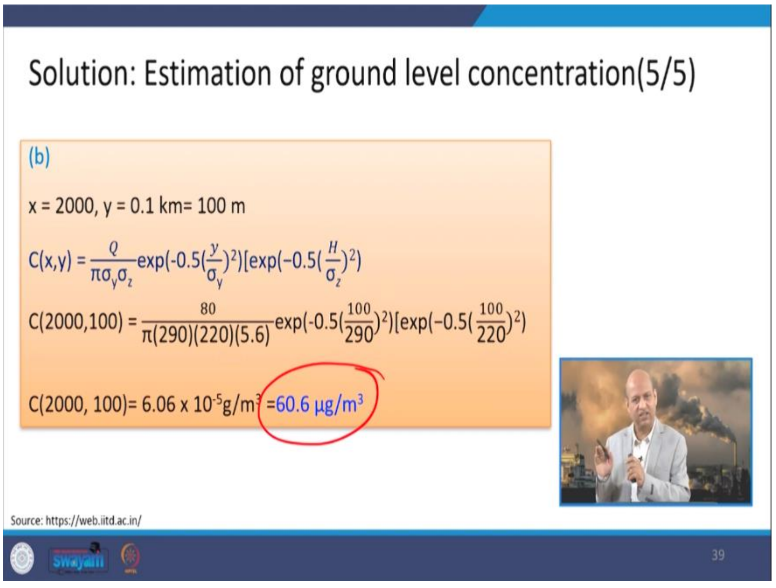

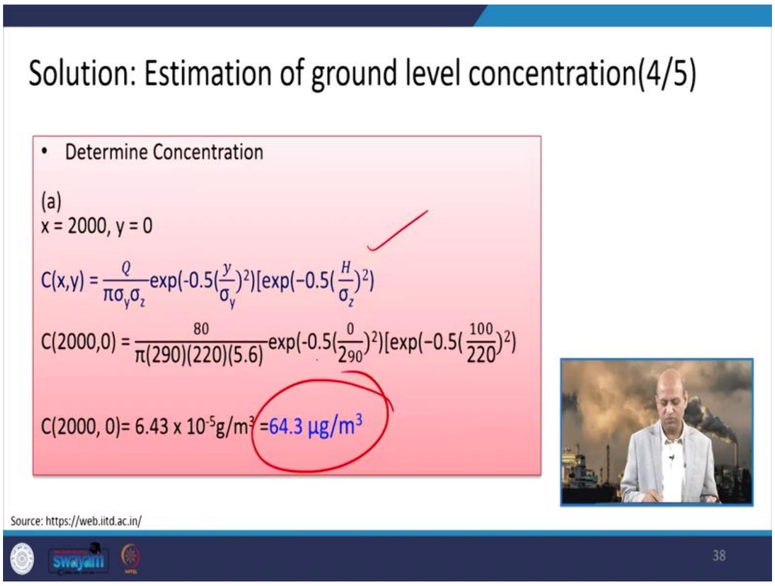

And when we go away from the centerline, 0.1 kilometer, 100 meter away from the centerline, then the estimated concentration is 60.6. So, you can see, it was 64 and now it is 60. That means the concentration is decreasing when we go away from the central line. So, very simple to understand that particular concept, that as we go away from the centerline concentration decreases.

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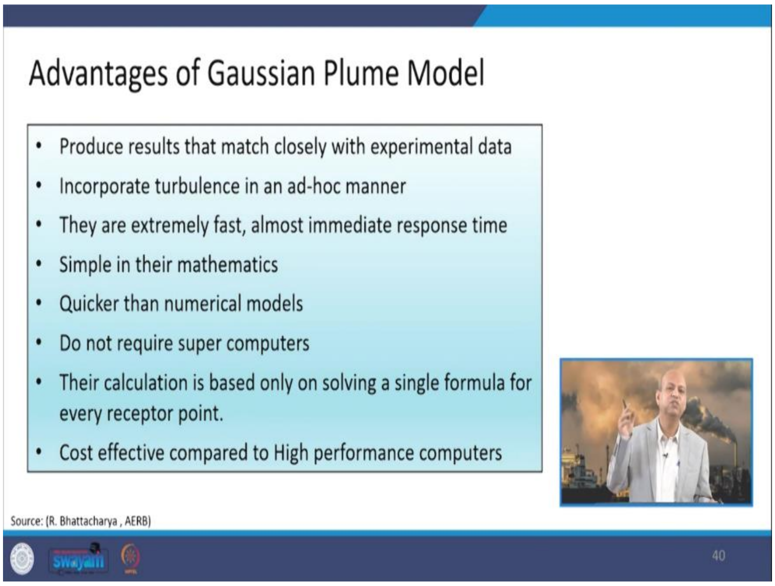

Now, we see these advantages of Gaussian plume model are many, like it gives the quickest results and very closely to whatever we are observing, although, there are so much uncertainty that even 50 percent deviation, we do not mind, in corporate turbulence in ad hoc manner. It is not very precise or something like that. And they are extremely fast almost immediate response time. So very quick to calculate simple in their mathematics which we have seen.

Quicker than numerical models. Numerical models are quite complex. It requires computational time, much more than this Gaussian dispersion model. It does not require supercomputer because simple calculations can be done by a simple desktop computer, even on your laptop. Their calculation is based on solving a single formula as we have seen, at the receptor point. And the cost effective compared to high performance computers, the very simple thing.

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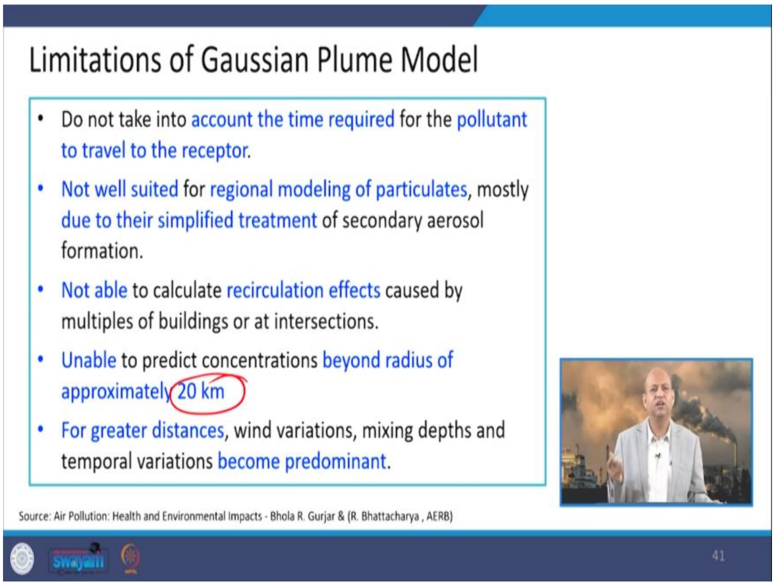

Then there are certain limitations because it does not take into account the time required for pollutant to travel to the receptor. So, that is the limitation. But, again as for rough estimation it is fine. It is not suited for regional modeling, because the distance for which we can use it, limited like 20 kilometer or so, beyond that results are not much reliable.

And then there are like we are assuming non-reactive that means, the secondary aerosols, etc. we cannot take into account of this particular, in this particular model based calculations. So, for larger distances, this is not much applicable and for reactive pollutants or for secondary pollutants, if you want to estimate, then it is not going to help us.

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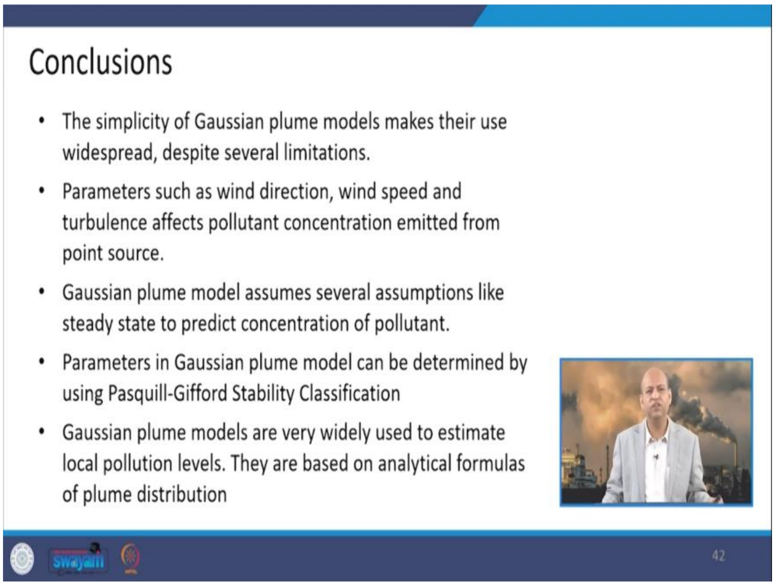

Anyway, so, this was the introduction for the Gaussian dispersion model for point source. Otherwise, line source modeling is also there, area source modeling is also there. We will discuss them later on. So, in conclusion, we can say that this the simplicity of the Gaussian model makes it very popular and widespread use is there, despite, there are certain several limitations, but still atmospheric scientist or environmental engineers are very fond of using these for policy related calculations or simple estimations.

Then the parameters, for example, wind direction, wind speed, turbulence, they affect the pollutant concentration emitted from the point source. So, they are included in this. Then Gaussian plume model assumes several assumptions which we have discussed like a steady state condition of the concentration of the pollutant, uniform kind of concentration.

Then there are certain stability classifications which we have used accordingly we have used the p value for determining the wind speed at certain heights. And this model is very popular because it gives very quick results and analytical formula are very simple to understand and use. So, this is all for today for Gaussian dispersion model or Gaussian plume model from the point source.

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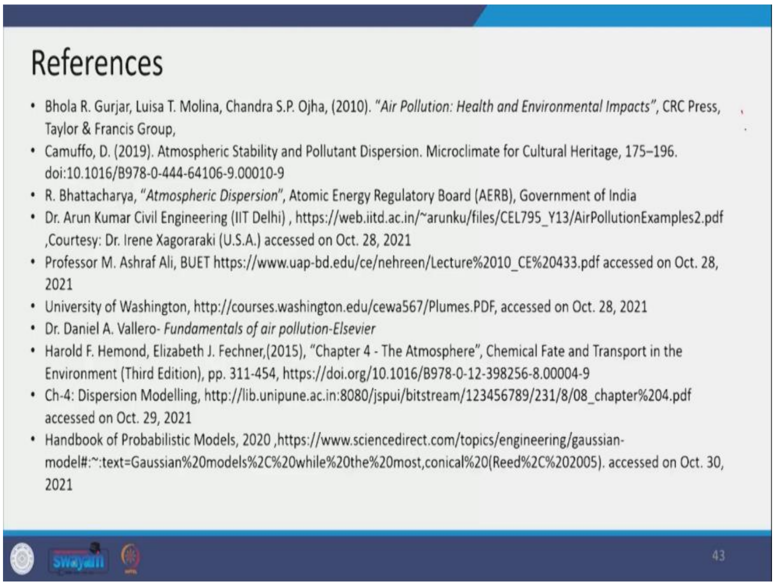

These are the references for additional information. Thank you for your kind attention. See you in the next lecture. Thanks again.