Basic Environmental Engineering and Pollution Abatement
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Lecture 08
Transmission of Pollutants in Environment - 1

Hello everyone. Now, we will discuss on the topic Transmission of Pollutants in Environment. This is the Part 1 of this topic. In the last class we have seen that pollutants are generated in the environment through different sources. And it gets enter into the human body, other living organisms, etc. And for this it needs to be transmitted from the point of generation to the point where the living organisms are existing.

So, the transmission of pollution is very very important. If pollutant may be generated but it is not transmitted to the particular person or living organism, so then he or she or it will not be affected. So, the transmission is very important. And transmission can take place through air, through water or through soil.

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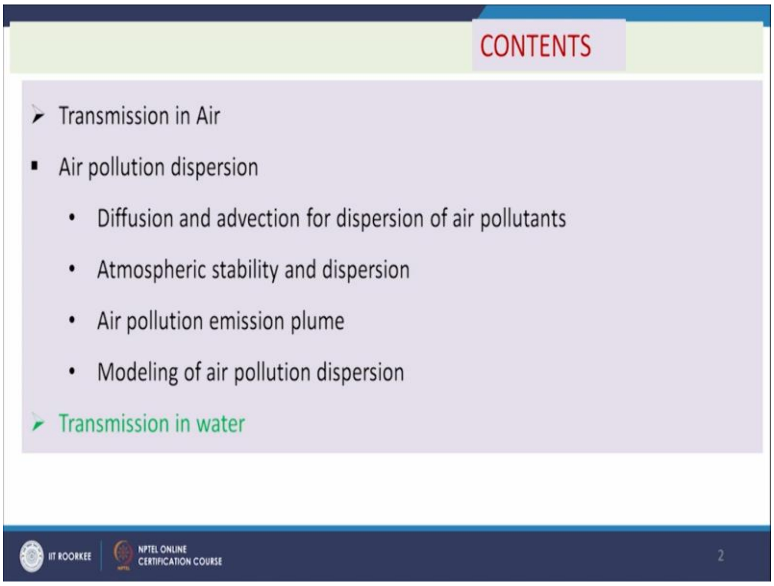

So, we will be discussing now, transmission in air and then air pollution dispersion. How the transmission is taking place? How the dispersion of the pollution taking place? How the pollution is moving from one place to others in the atmosphere. So, that part we will discuss. And then diffusion and advection for dispersion of air pollutants. We will see the major to mechanism for the dispersants that is one diffusion and another is your advection.

We will also see that this process is influenced by the stability of the environment. So, we will also discuss on the atmospheric stability and dispersion and air pollution emission plume.

So, when the air is polluted that means emission is coming entry into the atmosphere through a stack from a chimney shape, so, how this will be going downstream.

So, whether the plume will go up or whether it will come down. If it goes up then there is no risk if but if it comes down then it will be risky. So, people will be more affected. So, those things the different types of plumes we will discuss and modeling of air pollution dispersions we want to predict.

So, say here we have an industry and pollution is generated. So, after one kilometer or five kilometer what will be the concentration? So, pollutants in the atmosphere at certain height. So, that we can measure. And transmission of water that we will discuss in the next class. So, we have seen that dispersion of air pollutants can take place through diffusion and advection. What is diffusion?

Diffusion means pollutants are moving from one place to other place due to the difference in the concentration. So, concentration gradient is the driving force for this transfer and in case of advection we will see the flow of wind is helping the transfer of the pollutants from one place to other place. So, there are two major mechanism diffusion and advection.

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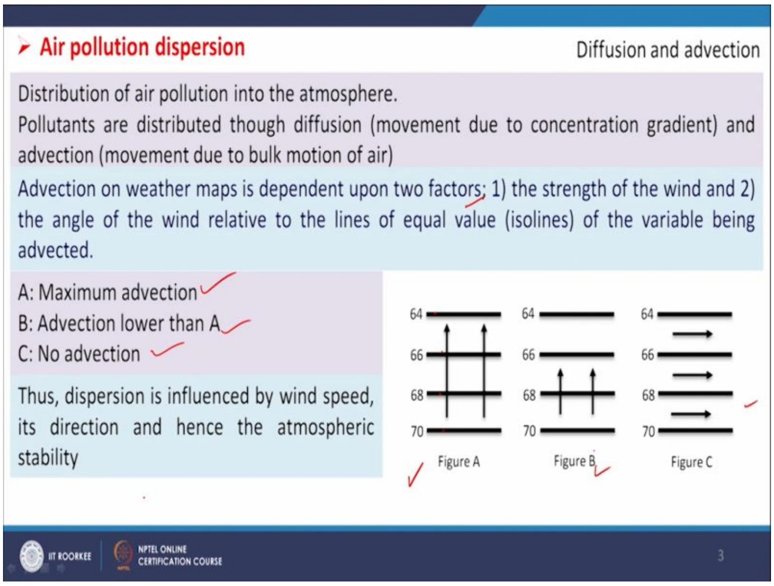

So, pollutants are distributed through diffusion. There is movement due to concentration gradient and advection movement due to bulk motion of air just we have discussed. Now, advection on weather maps is dependent upon two factors. That is the strength of the wind and the direction of the wind.

For example say we have here 68, 68, 68, 70, 66, 66. So, as we go up. So, our temperature of the atmosphere decreases. That is lapse rate. Now, say for a certain height, we are assuming that horizontally all points are having same temperature. If we go up, temperature will reduce. Like say here 70 here 68 here 66 here 64.

So, if wind blows this direction then what will happen? If wind blows this directions with same directions with lower speed, what will happen? If we wind blows like this direction, what will happen in case of advection? So, here maximum advections we can get. Because advections will help to upward movement, basically.

And then here it is lesser and in this case there will be no. Because this will be parallel flow. So, layers will not be mixed. No turbulence will be there. So, that this is the case. So, maximum advection in case of 'A' will get advections lower than 'A' in case of 'B' and 'C' will have no advections. Because wind speed.

So, it is clear that wind speed will influence and wind direction will influence the mixings of the different layers at the atmosphere across the height. So, that is the advection, which we are talking about. And then the dispersions is influenced by the wind speed its directions and hence the atmospheric stability. The stability is nothing but that resist the upward flow.

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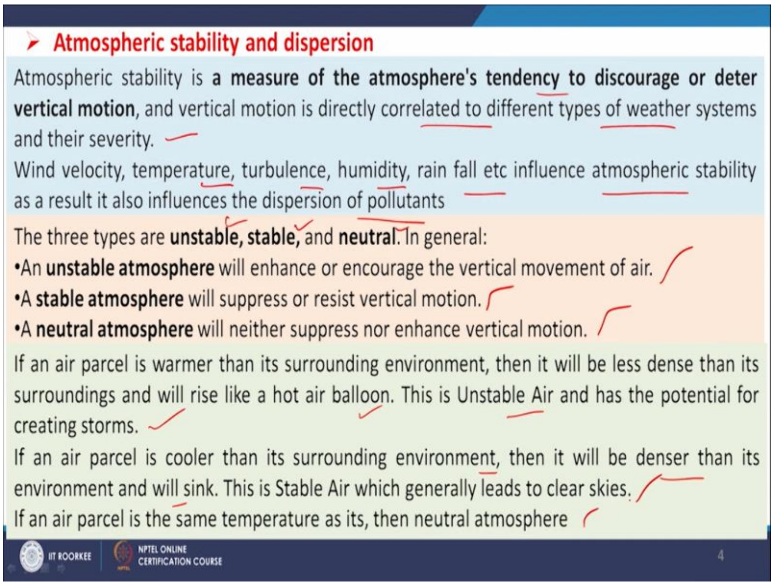

Now, atmospheric stability is a measure of the atmosphere tendency to discourage or deter vertical motion. And vertical motion is directly correlated to different types of weather systems and their severity. So, wind velocity, temperature, turbulence, humidity, rainfall, etc influence atmospheric stability. As a result it also influences the dispersion of pollutants.

Pollutants dispersion is also influenced by the stability conditions of the atmosphere. So, there are three types of stability conditions. Like say unstable, may be stable or maybe neutral. So, an unstable atmosphere will enhance or encourage the vertical movement of air. So, if vertical movement is encouraged means it is unstable a stable atmosphere will suppresses the vertical motion or it will resist the vertical motion and neutral atmosphere will neither suppress nor enhance vertical motion. So, these are three different atmospheric stability conditions, we can get.

Now, if we assume that air parcels is going up. So, inside its condition is different from the outside. It may be possible that inside is becoming less cooler with height but outside environment is becoming more cooler. So, that is lapse rate. If we go up temperature will decrease with the height. So, that is lapse rate.

So, when it is in when the absolute we consider for the actual environment that is the environmental lapse rate and if we consider under certain conditions that we have a parcel, it is going an air parcel, it is moving up and when it is moving it is not taking any heat or energy from outside.

So, adiabatic conditions, if it goes up in that condition, what is the lapse rate? If we can measure that is called adiabatic lapse rate. So, by comparing these two lapse rates, we can get, we can quantify that what is the conditions, the stability conditions that is unstable, stable or neutral.

So, now, if an air parcel is warmer than its surrounding environment then it will be less dense than its surrounding and will arise like a hot air balloon. This is unstable air and has the potential for creating storms. If an air parcel is cooler than its surrounding environment then it will be denser than its environment and will sink. Denser means less volume. So, outside will be, outside temperature higher, so that will be expanded and so the our parcel will be squeezed.

That is the case. And this is stable air, which generally leads to clear skies. And if an air parcel is the same temperature as it is then the neutral atmosphere we can get. So, if we have air parcel and outside environment both are having same lap rate, so then you will get the neutral condition.

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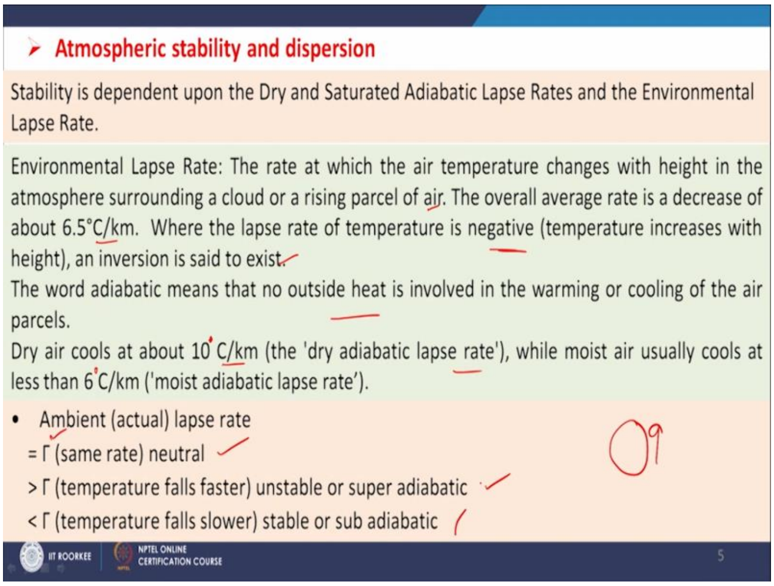

So, stability is dependent upon the dry and saturated adiabatic lapse rates and the environmental lapses. So, one is environmental lapse rates, another is your adiabatic lapse rates. So, adiabatical lapse rate means a balloon or the parcel which is going up. We are considering, it will not take any heat from the outside when it will goes up. That is adiabatic expansion or contraction whatever may take place, but it will be cut it will be happening in adiabatic condition. So, that is good.

Now, if it is that the air may be dry or may be wet. So, under depending upon the dry and wet conditions will be getting dry and saturated adiabatic lapse rates. So, environmental lapse rates, the rate at which air temperature changes with height in the atmosphere, surrounding a cloud or rising parcel of air.

So, the overall average rate is decrease of about 6.5 ^{o}C/km, where the lapse rate of temperature is negative. As you know that we go up, the temperature reduces. That is your negative lapse rate. And inversion is said to exist where the lapse rate of temperature is negative, that is temperature increases with height. And inversion is said to exist.

The word adiabatic means that no outside heat is involved in the warming or cooling of the air parcels, just we have discussed. And dry air-cools at about 10 ^{o}C/km. The dry adiabatic lapse rates it is while moisture usually cools at less than 6 ^{o}C/km that is moist adiabatic lapse rate. So, these two adiabatic lapse rates that we have.

Now, ambient lapse rate is equal to adiabatic lapse rate. So, then that is dry adiabatic lapse rate, then it is neutral. If ambient lapse rate is greater than that is dry adiabatic lapse rate or temperature falls faster in that case though unstable or super adiabatic and if the ambient lapse rate is less than the dry adiabetic lapse rate, so it is stable or sub adiabatic condition. So, these are the different conditions we can quantify the environmental stability condition.

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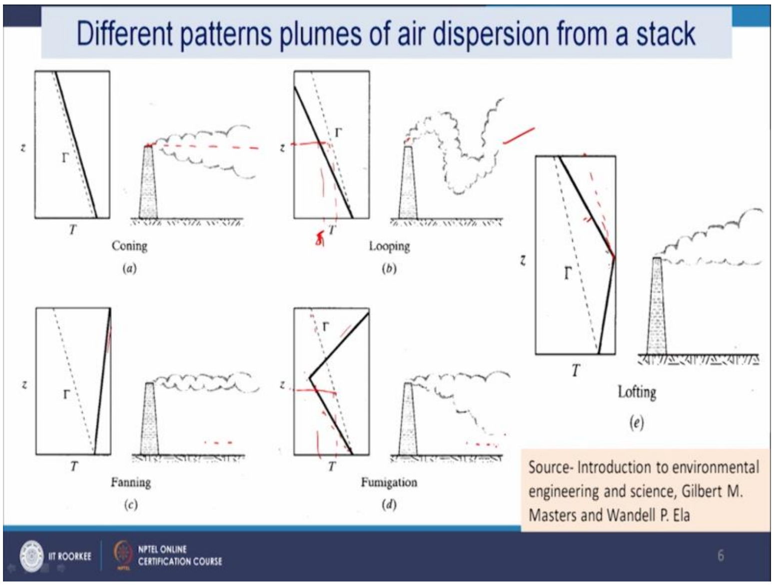

And because of these different stability conditions when the gas comes out from a stack, they will they are dispersed in different fashions. Like say we can get somewhere coning. So, this is coning we can get looping. We can get fanning. We can get fumigation. We can get lofting. So, what is happening in case of coning?

So, here this dotted line is our dry adiabatic lapse rate and solid line is your environmental lapse rate. So, what is happening in this case? Both are parallel having same that means the environmental lapse rate is equal to dry adiabatic lapse rate, same. So, there will be neutral environment. So, when a pollution is emitting from this stack, so, it will not go up nor go down. So, it will be uniformly distributed both way.

If you take the center of it, so it is uniformly distributed. So, this is a coning type of plume. We get this type of situation when the neutral environment is there, neutral atmosphere is there. But here we see, this is dotted is our adiabatic lapse rate and this is our natural environmental lapse rate. So, this if we consider some points here certain height. So, 0 to this height.

So, for this, we are changing this temperature here and for this case, we are getting this temperature. So, ∂T by ∂s for same z, we are getting more ∂T in case of actual lapse rate. So, actual lapse rate we are getting more ∂T. So, ∂T/∂t that is lapse rate is more. So, when environmental lapse rate or atmospheric lapse rate is more than the adiabatic lapse rate then we get this system is unstable.

And if it is unstable then what will happen? The pollution which is emitting here that will goes up. And when it is goes up and again there will be some chance and coming down also because the there will be some turbulence and then this type of looping plume we will get. Other way say another example, if we see here, so here, we are getting inversion, that is with height increase the temperature is on increasing not decreasing.

So, inversion is there. So, in case of inversions, so, we can get the fanning. The pollutions will not be able to come down, where the people are here. So, the pollutants are not coming here. So, these people are relatively safe. Now, another is your lofting. So, lofting here the first part. From this part is your inversion and second part is this one. So, here what is this if you make a parallel line here? So, you are getting the rate of this is more than this one.

So, even unstable is there. So, first part is your, this first part is your inversions the from bottom to certain height, it is inversion and then above that it is your unstable. So, in that case with there will be less chance of the pollutants to come into the environment. So,. this is called lofting. And another type of plume can be available because of this type of environmental condition.

So, in this case you see this, if we take this point, so, 0 to z, same z, these are having ∂T. So, this is unstable and then we are getting this one is your again inversion. So, unstable inversion. So, this will give us the fumigation. So, these are the different types of plumes we get and we see that fumigation is one of the most dangerous plume types when people will be mostly affected by the pollutants being emitted in the stack.

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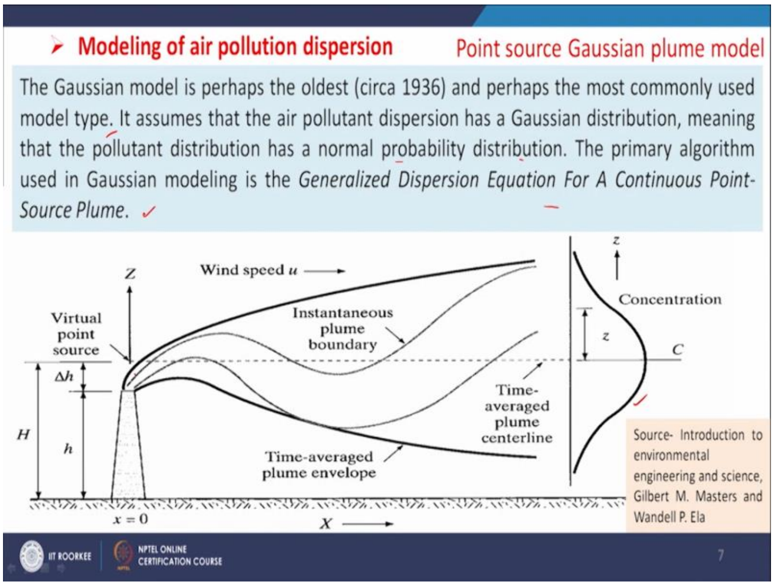

Now, we will see how to model this dispersion process. So, point source Gaussian Plume Model is mostly used. There are many approaches. People have tried to develop some model to predict the concentration of pollutants after certain distance, downstream of the wind and from the location of the emission.

So, people try to develop different models. So, one is your point source Gaussian plume model is very very important which is mostly used. And the Gaussian model is perhaps the oldest and perhaps the most commonly used model type. It assumes that the air pollutant dispersants has a Gaussian distribution. That means this is the center point. So, it will be dispersed like this. So, maximum concentration will be having then it will be decreasing like this. So, this is the maximum concentration and it will decrease both side.

So, it assumes that the air pollutant dispersions has Gaussian distribution meaning that the pollutant distribution has a normal probability distribution like this. And the primary algorithm used in Gaussian modeling is the generalized dispersion equation for a continuous point source plume. So, this is a continuous point source plume. So, how this will be distributed at different positions?

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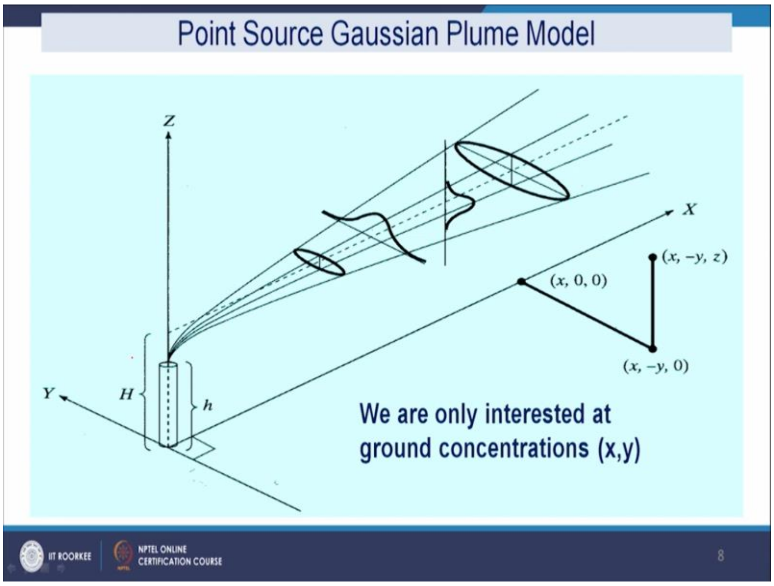

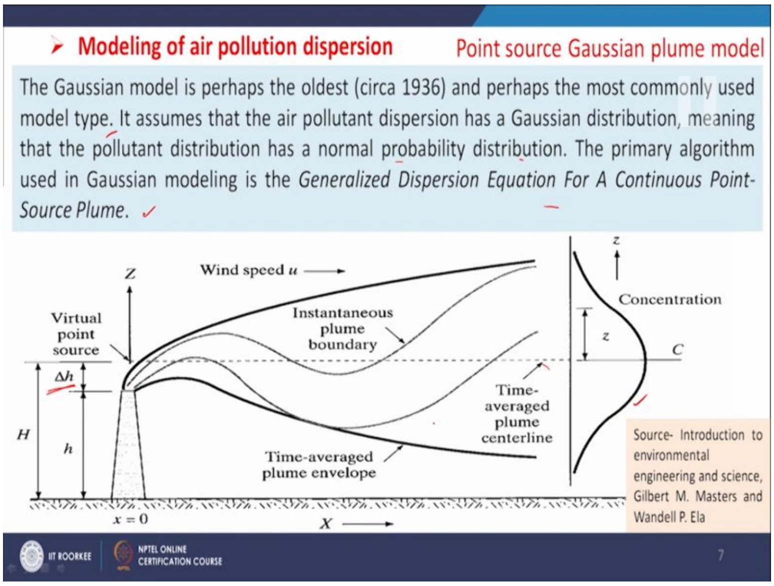

This can be derived on the basis of this model. This is the height height of the chimney and here plume is generated. So, this is plume height Δh. So, Δh is the plume height and h is the stack height, physical height. So, this h plus Δh that is capital H, this is the actual working height of the emission. This is a virtual point source and this is the center point of it. And then instantaneous plume boundary it is told. And this is wind speed. And this is time averaged plume centerline and this is time averaged plume envelope.

So, this is the different parts to describe this Gaussian plume model like this. It can have x, y and z direction nearly interested at ground concentrations. As we are interested only, you know, people are here at the ground. So, if this is the point may be here, maybe here, may be here, anywhere position, the people may be available. So, at that position x, y will change and z, we are not concentrated because pollutants has to be available at the ground to make it impact on the human health. So, model structure and assumptions, some assumptions are there for this.

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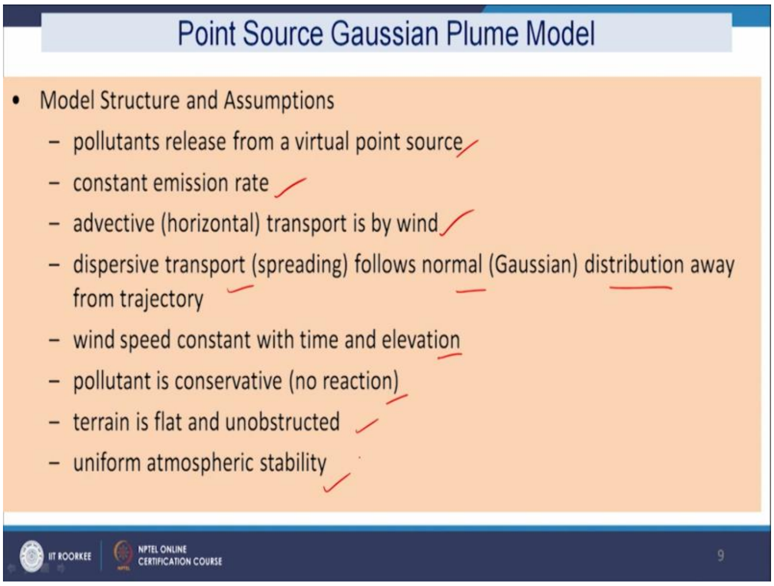

That is pollutants release from a virtual point; source pollution is released from a virtual point source. It is a point source. So, that it is easy to identify and then it is a constant emission rate. Rate of emission is not changing with time. And advective transport is by wind. Wind is responsible for the advection.

And dispersive transport that is spreading follows normal that is Gaussian distributions away from the trajectory. And wind speed constant with time and elevation. Pollutant is conservative, non-reactive. Say, it is not the fact that now the pollutant is present but after sometime it will be converted to other form, not like this.

We are assuming that pollutants are conservative in nature. And train is flat and unobstructed and uniform atmospheric stability. It is also assumed that atmospheric stability is not changing from certain place to place. So, that is way these are the major assumptions on the basis of which the expressions has been developed.

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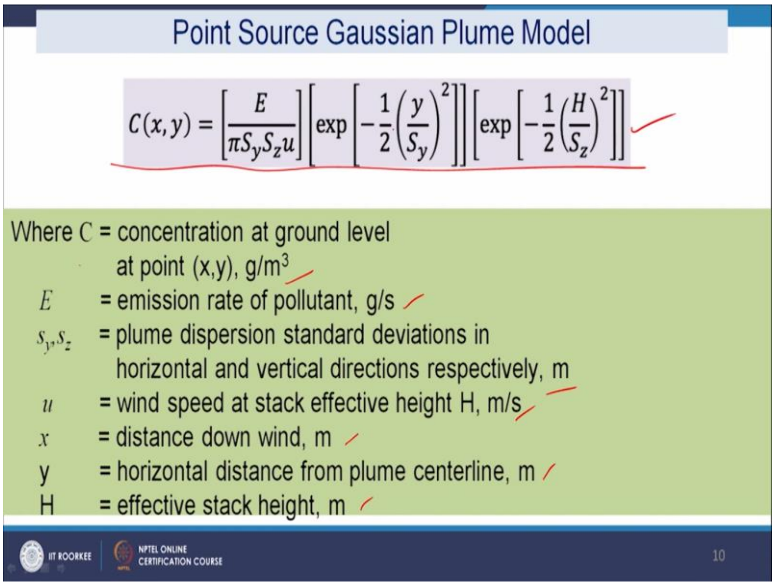

And the expression is like this.

$$C(x,y) = \left[\frac{E}{\pi S_y S_z u}\right]\left[\exp\left[-\frac{1}{2}\left(\frac{y}{S_y}\right)^2\right]\right]\left[\exp\left[-\frac{1}{2}\left(\frac{H}{S_z}\right)^2\right]\right]$$

So, this is the expression. And in this expression C is the concentration at ground level at point x, y and then E is the emission rate of pollutant gram/second unit.

And Sy Sz plume dispersion standard deviations in horizontal and vertical directions respectively in meter. And u, wind speed at stack effective height H that is m/second, And x is distance downwind in meter. y horizontal distance from plume centerline in meter. And H is effective stack height in meter. So, these are empirical relationship. So, we need to take the formula in the same unit only. And how to find out the effective stack height that capital H? H= h +ΔH we have seen in the previous slide.

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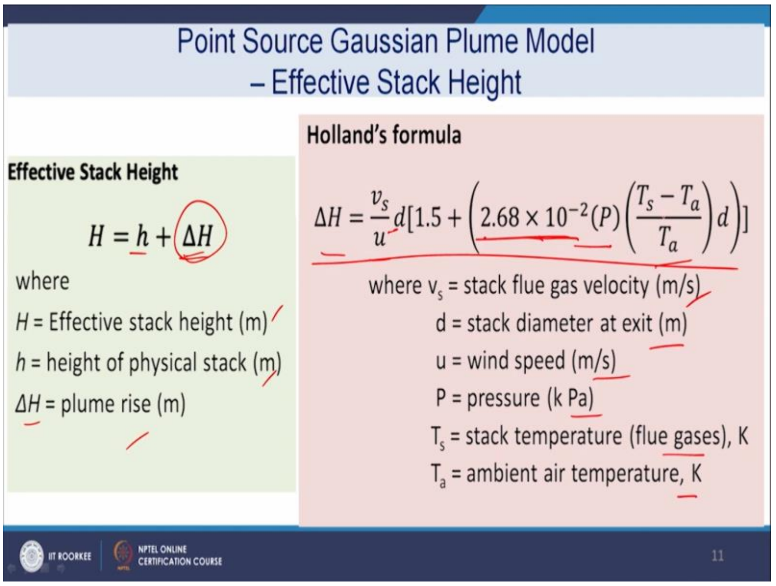

So, here H is the effective stack height and h is the height of the physical stack and ΔH is the plume rise. Holland's formula. How we can determine this ΔH then? ΔH that is plume rise, how we can measure?

$$\Delta H = \frac{v_s}{u} d[1.5 + \left(2.68 \times 10^{-2}(P)\left(\frac{T_s - T_a}{T_a}\right) d\right)]$$

So, this is the expression. In this expression, ΔH is nothing but the effective plume rise in meter. And v_s is the stack flue gas velocity meter/second. And d is the stack diameter at exit, the stack diameter in meter. u is the wind speed at the stack height. And then p is the pressure kilo pascal, if kilo Pascal then 10^{-2}, this constant will be there. And Ts is stack temperature flue gases that is your in K. And Ta is the ambient air temperature at K. So, stack temperature and air temperature, ambient air temperature Ts and Ta, respectively. So, these are the expressions to calculate the ΔH value.

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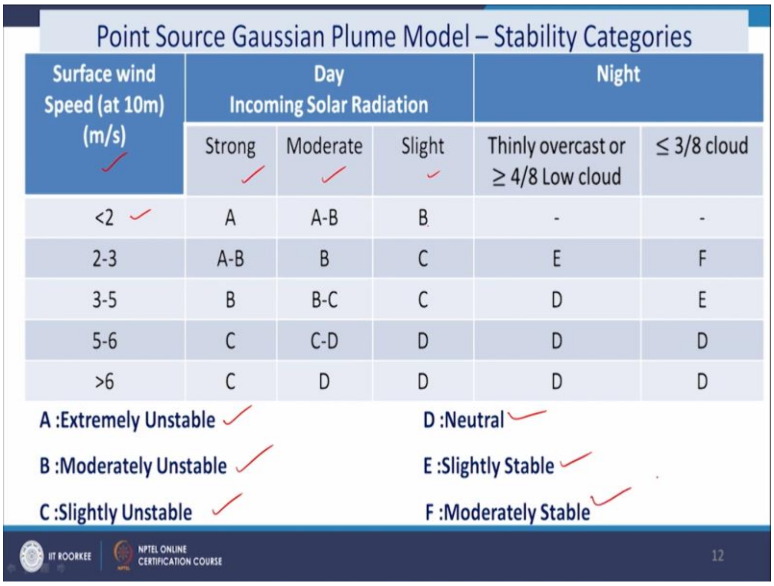

Surface wind Speed (at 10m) (m/s)	Day Incoming Solar Radiation			Night	
	Strong	Moderate	Slight	Thinly overcast or ≥ 4/8 Low cloud	≤ 3/8 cloud
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Now, the stability conditions may be of different and different type of stability we can get. And we have seen that the people have worked and on this area and the information is available. So, if surface wind speed at 10 meter height is less than 2 m/s and then it day time or night time the people consider.

If day coming day time with strong sunlight or moderate radiations and then slight radiation, so then different types of stability condition. Similarly, for night also, it may be covered, it may be partially covered with cloud, so, in that case different stability conditions are obtained.

Say depending upon the wind speed at 10 m height in meter/second and day and night condition, whether the sun is very, sun shining is very strong or it is cloudy, so all those things are considered and different stability condition ‘A’ to ‘F’ has been defined. So, ‘A’ is extremely unstable ‘B’ is moderately unstable, ‘C’ slightly unstable, ‘D’ neutral, ‘E’ is slightly stable and ‘F’ moderately stable. So, these different conditions are defined.

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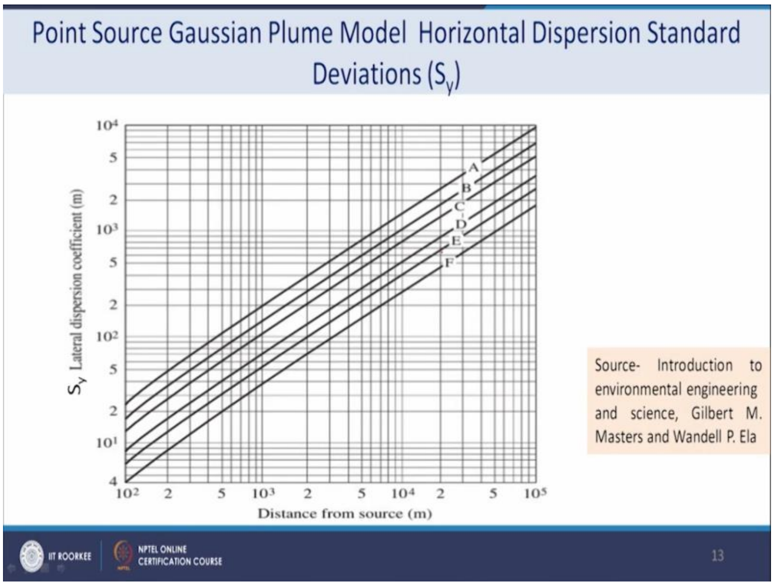

And out of these different stability conditions, we can get the value of Sy and Sz, which are available in literature as the many people have worked on it and these have been accepted for applications. So, these are some distance from source if we measure, if we know the stability condition for that particular case, we will get the value of Sy.

Similarly, we can get the value of Sz, if we know the different stability conditions from this graph. So, these graphs are already developed by many researchs and those are available for us now, for our application. And wind speed, I told you that at stack height wind speed and somewhere we defined ‘u’ in the table that at 10 m height. So, we have to convert it to at stack height.

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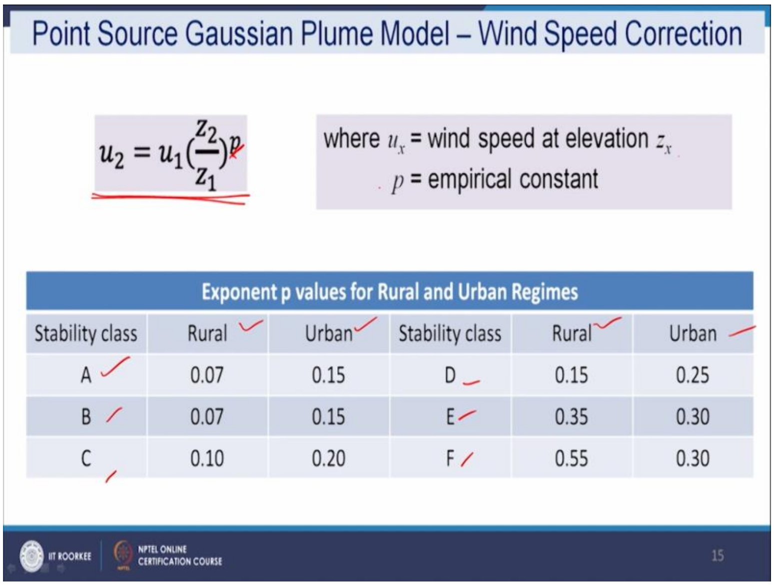

$$u_2 = u_1(\frac{z_2}{z_1})^p$$

So, this is the expression which is used to calculate the wind speed at stack height, at 10 m height, we know, but at stack height, that will be determined by this formula. And in this case, p value will depend on the stability conditions. If you see here, if we have stability class A, B, C, D, E, F and it may be rural area, it may be urban area.

So, depending upon this area, so, these values are defined. People have worked and on the basis of experience these p values have been recommended for computation or for prediction. That is wind speed correction. And here where ux, that is u_1, u_2 we have shown. So, u_x in general term, wind speed at elevation z_x and p is the empirical constant. This p will be used to determine the value of u_2.

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Example

Q. A stack in an urban area is emitting 80 g/s of NO. It has an effective stack height of 100 m. The wind speed is 4 m/s at 10 m. It is a clear summer day with the sun nearly overhead. Estimate the ground level concentration at

a) 2 km downwind on the centerline

b) and b) 2 km downwind, 0.1 km off the centerline.

Solution

Step 1: Determine stability class

Wind speed is 4 m/s at ground surface

It is a clear summer day with the sun nearly overhead

Key to stability categories

Surface wind Speed (at 10m) (m/s)	Day Incoming Solar Radiation			Night	
	Strong	Moderate	Slight	Thinly overcast or ≥ 4/8 Low cloud	≤ 3/8 cloud
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Description suggests strong solar radiation. Stability class B

Step 2. Estimate the wind speed at the effective stack height

Note: effective stack height given – no need to calculate using Holland's formula

Exponent p values for Rural and Urban Regimes

Stability class	Rural	Urban	Stability class	Rural	Urban
A	0.07	0.15	D	0.15	0.25
B	0.07	0.15	E	0.35	0.30
C	0.10	0.20	F	0.55	0.30

$$u_2 = u_1\left(\frac{z_2}{z_1}\right)^p = 4\left(\frac{100}{10}\right)^{0.15} = 5.65\ m/s$$

Now, for example. So, a stack in an urban area is emitting 80 g/s of NO. It has an effective stack height of 100 m; the wind speed is 4 m/s at 10 m. It is clear summer day with the sun nearly overhead. Estimate the ground level concentration at 2 km downwind on the centerline and 2 km downwind, 0.1 km of the centerline. So, x and y value is given in the case 2, and in the case, no value is given.

So, what we will do? What will be the first step? So, we have to determine the stability class. So, how can we determine the stability class? For the determination of the stability class, I have shown you some table. So, here the speed at 10 m height is important. So, in our case 4 m/s at 10 m height, it is given.

So, we will be considering that the wind speed is 4 m/s at ground surface. It is a clear summer day with sun nearly overhead. That means strong sunshine daytime and strong sunshine. So, if we see this table. So, here we will get 4 m/s that means 3 to 5, this one. We have strong radiation, solar radiation because middle of the day and clear day.

So, this will be of B type of stability. And if it is B type of stability then what will be our job? Our job will be to find out the value of p. So, p we have another table, we have discussed. So, in this case we are having B. So, B will be having this p equal to 0.15. So, in this case, if we put this value to get the value of wind speed at our stack height then

$$u_2 = u_1\left(\frac{z_2}{z_1}\right)^p$$

When u_1 is 4 and z_2 is your how much, it is given 100 m effective stack height is given. So, we do not need to calculate the effective stack height. It is already given physical stack height plus plume rise. So, that is given 100 m. So, that formula we do not need to know to determine the value of del H and then to make, it add it with h to get H equal to small h plus del h, that is not needed.

$$u_2 = u_1\left(\frac{z_2}{z_1}\right)^p = 4\left(\frac{100}{10}\right)^{0.15} = 5.65 \text{ m/s}$$

So, this is the wind speed.

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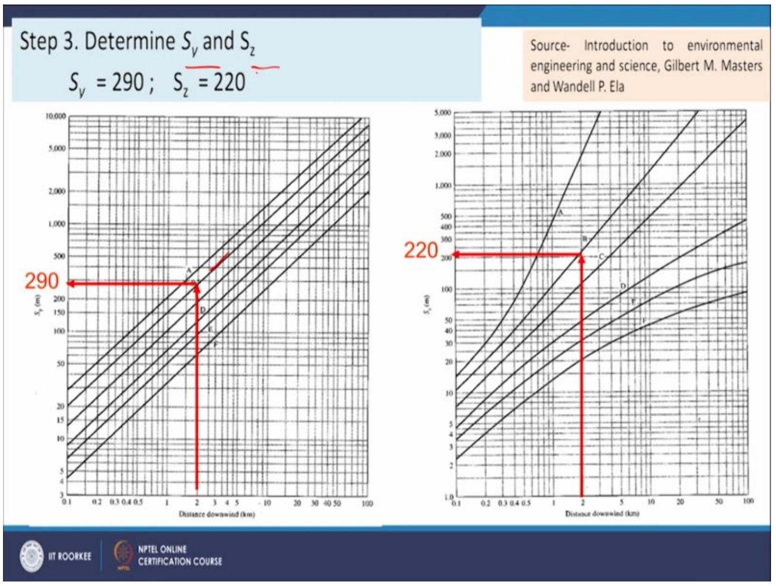

So, now, we will put it into the formula. But before that we need the Sy and Sz values. So, Sy and Sz values, we will be calculating it from the graphs available. So, in our case, what is the case we have? The B type of stability. So, this is our B type of stability graph at this distance downwind.

So, downwind, what is the distance that we have to see. It is given that distance is equal to 2 km downwind. So, 2 km in the case of 1, And in the second case 2 km downwind 0.1 km off the centerline. So, will be using this formula to find out for 2 km.

So, this is our Sy because this is down in distance 2 km and Sy values are becoming here this point so, 290 we are getting. So, similarly, Sz for this A case, we are having 2 km; we will go here for B type of stability. We are getting 220. So, Sy and Sz values we are getting by that way Sy 290, Sz 220.

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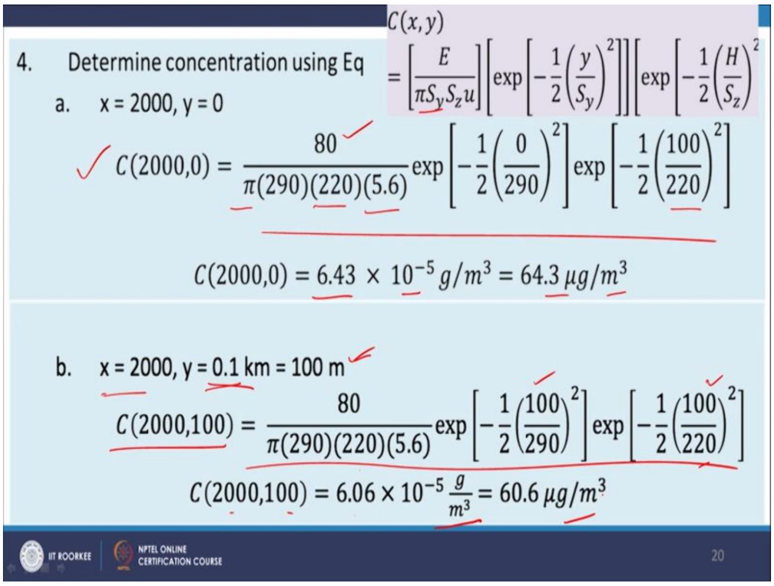

Then we will put this, the values.

$$C(x,y) = \left[\frac{E}{\pi S_y S_z u}\right]\left[\exp\left[-\frac{1}{2}\left(\frac{y}{S_y}\right)^2\right]\right]\left[\exp\left[-\frac{1}{2}\left(\frac{H}{S_z}\right)^2\right]\right]$$

So, in this case E is 80 g/s. It is mentioned and then π value we know and 290 Sy, 220 Sz, we have calculated. 5.6 u, we have calculated and then y value is 0 in this case because it is only 2 km downwind in the centerline.

$$C(2000,0) = \frac{80}{\pi(290)(220)(5.6)}\exp\left[-\frac{1}{2}\left(\frac{0}{290}\right)^2\right]\exp\left[-\frac{1}{2}\left(\frac{100}{220}\right)^2\right]$$

$$C(2000,0) = 6.43 \times 10^{-5}\, g/m^3 = 64.3\, \mu g/m^3$$

So, this is the concentration which will be available at 2 km downwind. And in the second case, we have to find out for 2 km downwind and 0.1 of the centerline. So, we have

x = 2000, y = 0.1 km = 100 m

$$C(2000,100) = \frac{80}{\pi(290)(220)(5.6)}\exp\left[-\frac{1}{2}\left(\frac{100}{290}\right)^2\right]\exp\left[-\frac{1}{2}\left(\frac{100}{220}\right)^2\right]$$

$$C(2000,100) = 6.06 \times 10^{-5}\frac{g}{m^3} = 60.6\, \mu g/m^3$$

So, now, we are able to determine the concentration at these two locations. So, up to this in this class, thank you very much for your presence.