Health, Safety and Environmental Management in Offshore and Petroleum Engineering
Prof. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

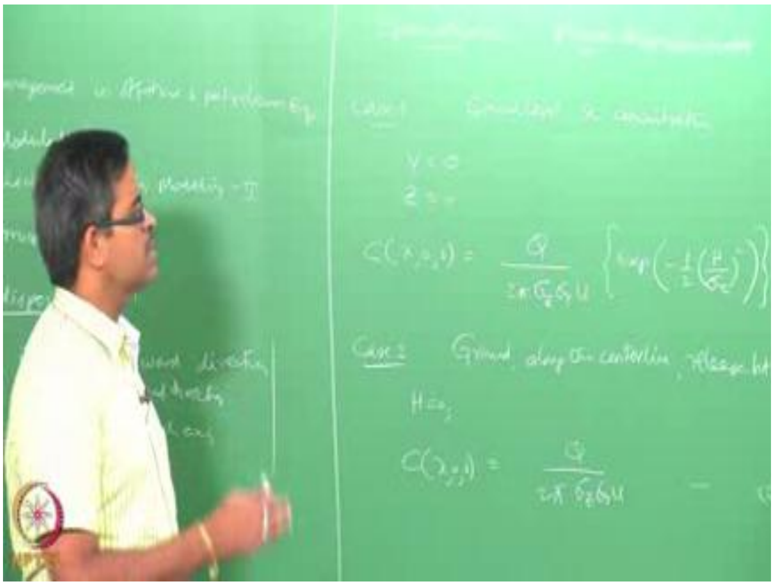
Module- 01
Lecture – 07
Pollution Modeling II

(Refer Slide Time: 00:15)

Friends, welcome to the 7th lecture on the online course title HSE Management in Offshore and Petroleum Engineering. We are talking about lectures in module one where we are focusing on environmental issues that arise exclusively from oil and gas industries exploration and production and processing.

In this lecture, we just title as pollution modeling two will continue to discuss atmospheric pollution. In the last lecture, we discussed about continues models which is a plume dispersion model. We have given you the equation to find the concentration of the plume dispersion which is happening in the side in terms of x, y, z coordinates where h is also involved x is an implicit function sigma x an implicit value in the function. Let us discuss some special cases about this so let us try to recollect x is in the direction or is in the windward direction, y is in the crosswind direction, and z is along the let say vertical axis.

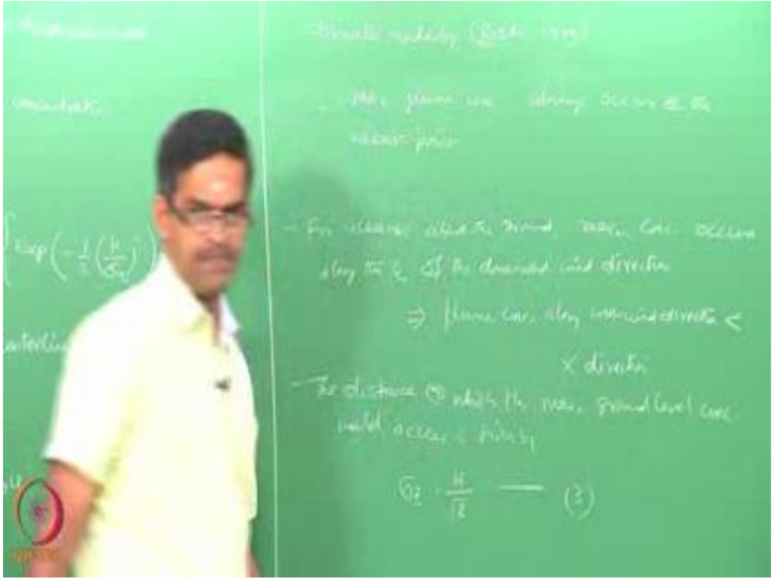
(Refer Slide Time: 02:08)



Let us discuss some special cases. The general equation is what is given to you in the last lecture let us substitute back some conditions in the general equation. There are special conditions for specific cases for plume dispersion models. Plume refers to continuous dispersion. Let us say case 1; the ground level central line concentration we want to find; so to determine the ground level central line concentration. The moment I say I am interested only in central line, so then I should substitute y as 0, because I am not looking at the cross wind direction at all the moment. I say ground level concentration, I should also say z as 0 then therefore my concentration will be now given as 0, 0, 0 Q by 2 pi sigma z and sigma y of U which is a wind velocity exponential of minus half H by sigma z square call equation number 1.

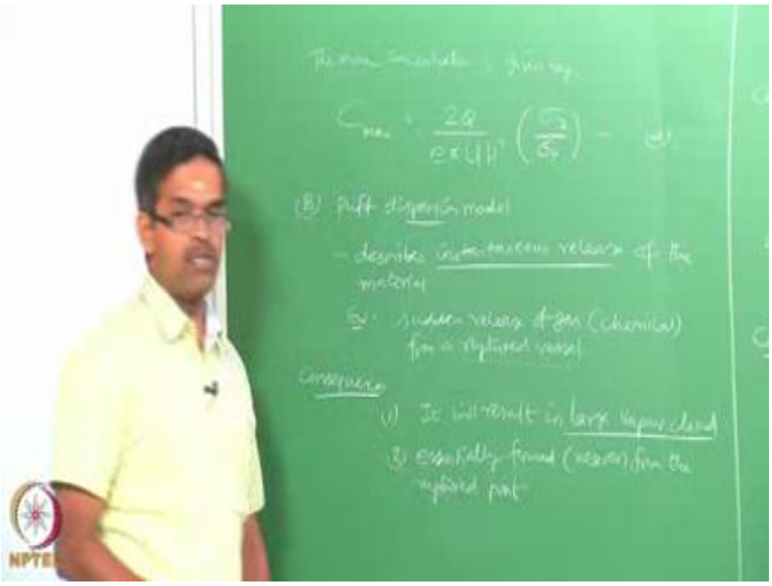
The next case - case 2 where I want the concentration at the ground along the centerline, and in this case, we are interested at H is also equal to 0, the release height is practically at the ground level itself. In that case, c x, 0, 0 for the plume dispersion model will be simply given by Q by 2 pi sigma z sigma y of u which I call as equation number 2. In both these expressions, you can notice that x is implicitly present within the dispersion coefficients.

(Refer Slide Time: 05:02)



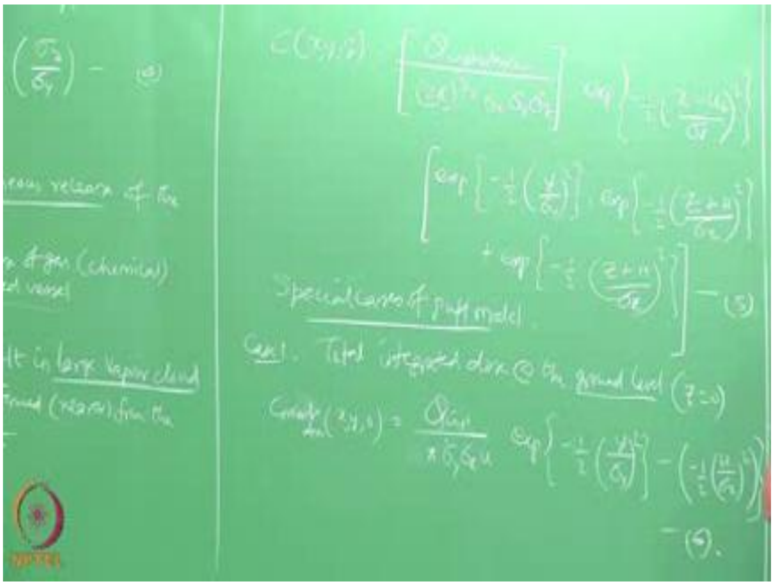
It is very important observation made by Brode in 1959. What is that observation he says that the maximum plume concentration always occurs at the release point probably this is one of the basis on which these equations that derived. Interestingly, for releases above the ground the maximum concentration occurs along the centerline of the downwind direction, so this implies a simple statement saying the plume concentration along the crosswind will be always will be lesser than that along the x-direction where we all know that x direction is the downwind direction consider in the study. Now, the distance at which the ground level concentration would occur is given by sigma z is H by root, Equation number 3.

(Refer Slide Time: 07:33)



And the maximum concentrations is given by C max which is 2 Q by e pi U H square sigma z by sigma y and call this as equation number 4. This about the discussion what we had a special cases for the plume dispersion model. Let us discuss puff dispersion model which in intermittent release model. The puff dispersion model describes instantaneous release of the material. You can give an example of this sudden release of a chemical from a ruptured vessel can be a classical example. What could be the consequences of such kind of instantaneous releases which occur essentially because of these kind of accidents, because ruptured vessel is sort of an accident let us say. The consequences could be it will result in a large vapor cloud, which is essentially formed nearer or I should say from the rupture point, which essentially originates from the ruptured point.

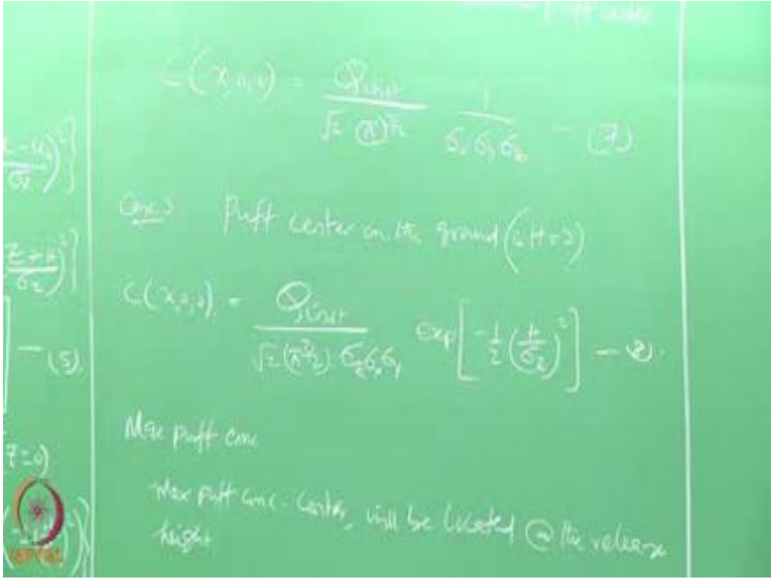
(Refer Slide Time: 10:30)



Now, I want to estimate the average concentration of this kind of release average concentration of puff release is given by C x, y, z, where the terms x, y, z directions remains same as that of the plume model. Which is given by Q instantaneous 2 pi to the power 3 by 2 sigma x sigma y sigma z multiplied by exponential of minus half of x minus u t by sigma x square multiplied by exponential of minus half of y by sigma y square multiplied by exponential of minus half z plus H by sigma z the whole square plus exponential of minus half of z plus H by sigma z the whole square, which I put a bracket here and a bracket here. This becomes an entire product with these two terms call equation number 5, where the terms have the same meaning as we explain in the plume model.

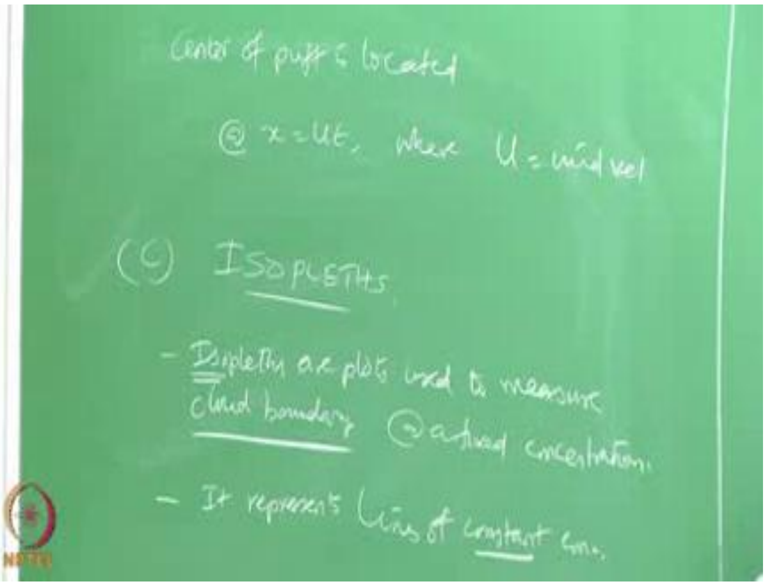
Let us now consider some special cases of puff model, let say case 1. We wanted to find out the total integrated dose at the ground level, which is given by dose. So, in this case, you will easily see z will be 0, because I am locking at the ground level. So, dose x, y, 0, we can say concentration as well of the dose is given by Q instantaneous by pi sigma y and sigma z of u exponential minus half y by sigma y square minus of minus half H by sigma z square equation number 6.

(Refer Slide Time: 14:39)



The next case could be concentration on the ground below the puff center, which can be given by I am also not looking at the cross wind value which can be Q instantaneous root 2 pi 3 by 2 1 by sigma x sigma y and sigma z, no this is sigma y square call equation number 7. The next case could be the puff center on the ground the moment I say this I should say H is 0, which can be given by is Q instantaneous by root 2 pi 3 by 2 sigma z sigma x sigma y exponential minus half H by sigma z – 8. The maximum puff concentration is a very important item which is to be also computed. The maximum puff center is located at the release height itself, concentration center will be located at the release height.

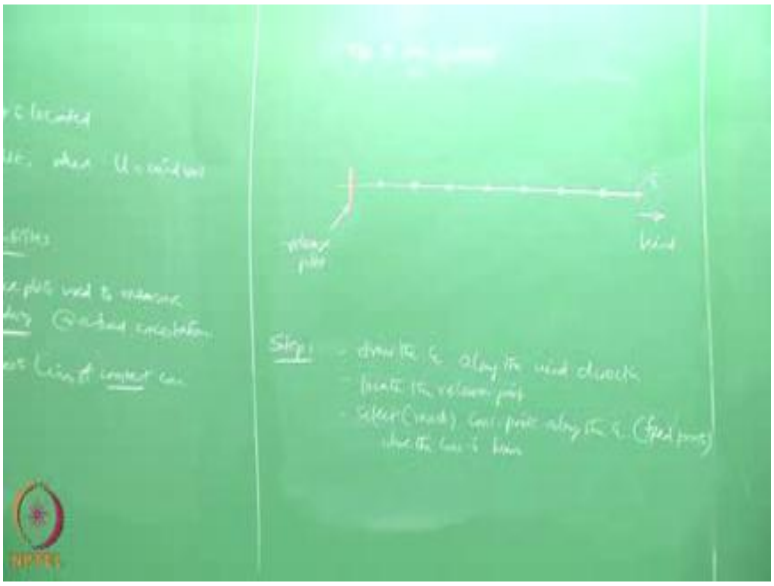
(Refer Slide Time: 17:44)



And the center of puff is located at x is equal to u t, where u is the wind velocity it can be easily understood that the maximum concentration will always occur directly below the puff center. The next interesting discussion on the atmospheric pollution modeling and dispersion modeling is isopleths.

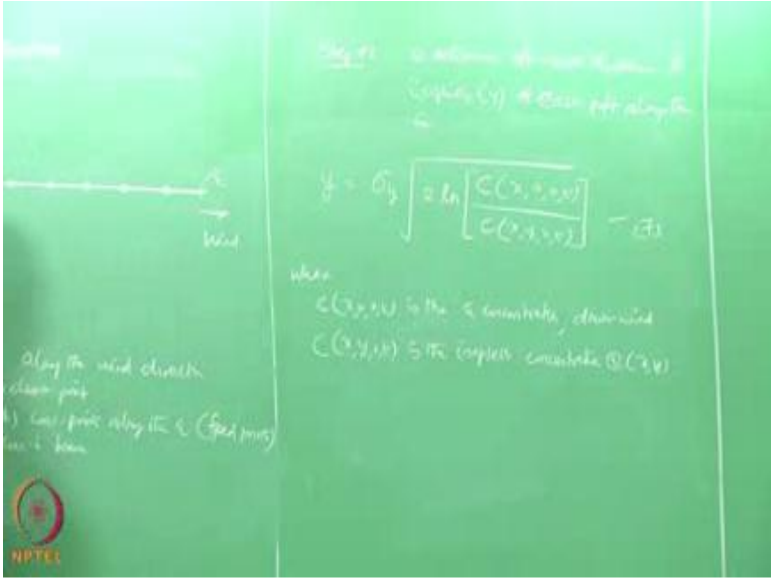
What are isopleths? Isopleths actually are representative values which are used to measure the cloud boundary at a fixed concentration. Isopleths are plots used to measure the cloud boundary that is what is the extension of the cloud at a fixed concentration. So, if you know the concentration one can always estimate what did the spread of this particular dispersion so cloud boundary. So, basically the term ISO stands for a meaning that it represents lines of constant concentration that is why the term ISO has come. There are different steps, which are followed to find out or to draw or to plot an ISOPLETHS graphically. We will see the figure now.

(Refer Slide Time: 19:52)



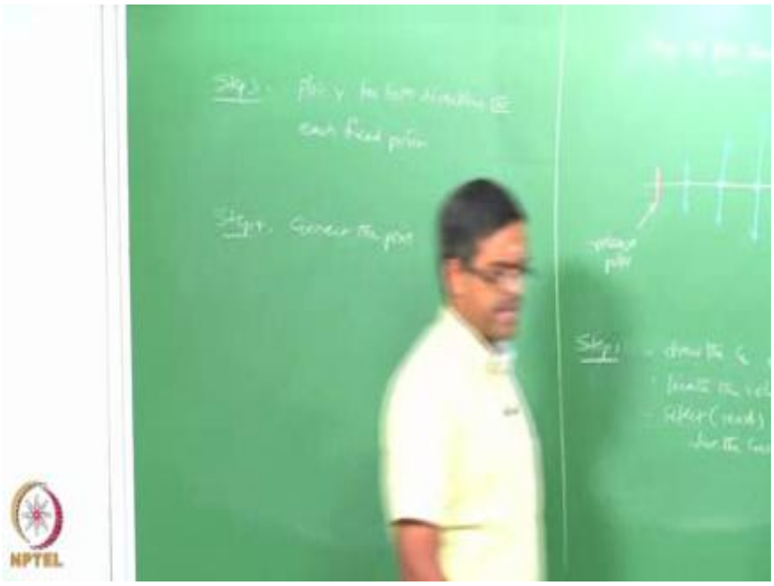
Let us say step number one. So I now looking for steps to plot isopleths. Let say this is my windward direction so that is my windward direction. Let say this is my release point; once it is released, and this is of course, a center line along the windward direction, so center line means the cross wind dimensions or relatively zero. So, let us mark certain points along the centerline. So, the first step is draw the center line along the wind direction. Locate the release point select or mark concentration points along the centerline, which are called fixed points. These points what has been selected along a centerline or fixed points where the concentration is known to me is known rather I can compute that.

(Refer Slide Time: 22:28)



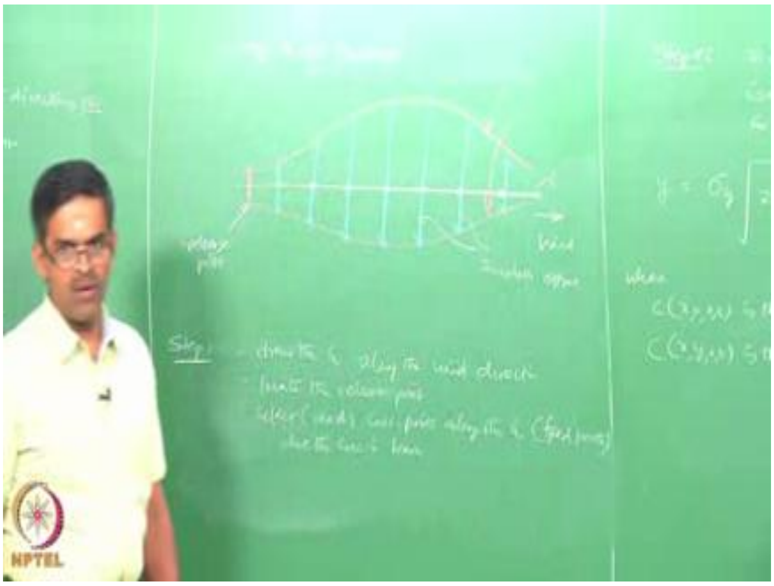
In step number 2, I want to find the off center the distances to isopleths which are nothing but y y values at each point along the centerline. So, we know there are many points we have along the centerline may be x 1, x 2, x 3, x 4 and so on, at each point where the concentration is known to me, I am interested to estimate the off center distance depending upon the concentration along the windward direction at fixed chosen points along the centerline. So, how do you get that? So, y can be given by a simple equation here which depends on sigma y and square root of twice of natural logarithm of c x 0 0 at any time t divided by c x y 0 at any time t equation number 7. So, in this case where c x 0 0 t is the downwind ground centerline concentration, whereas c x y 0 is the isopleth concentration at point x comma y where x is chosen by u at fixed points along the centerline.

(Refer Slide Time: 25:04)



Step number 3 plot y for both directions at each fixed points.

(Refer Slide Time: 25:31)



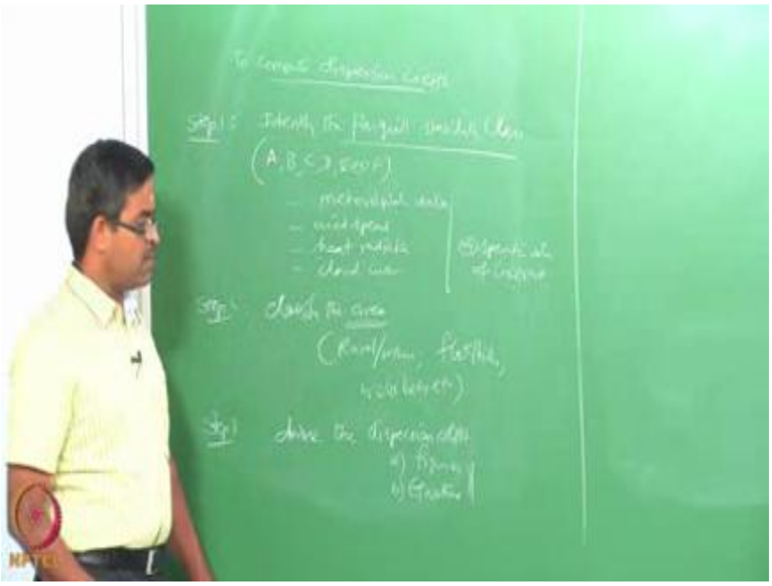
Let us try to do it here. So, now, we can call them as isopleths. These are nothing but isopleth offset which you computed from the equation 7, knowing the concentration c x 0 0 t and c x y 0 t from the equations which you have described in the earlier slides. Now step number 4, connect the points. So, let us connect them. Now, this spot we call as isopleths. So, one can easily draw the isopleths by using this four steps where an equation is involved one can easily compute that.

(Refer Slide Time: 27:58)

Now, in this it is important that I have to estimate the dispersion coefficients to really understand the release scenarios using plume and puff models. So, plume is a continuous release whereas puff is an instantaneous release of a gas or a cloud vapor. How they are getting dispersed in the atmosphere, how they are modeled to account for atmospheric pollution is what we are trying to capture.

So, I would like to now estimate the dispersion coefficients, they are very important, they are required to model the release scenario both for plume and puff model is very well explained by Wiltox 2001. Wiltox said that the dispersion coefficients depend on the stability class and the downwind distance. These are the two factors on which the dispersion coefficients will depend on. Stability class, we already know it can be also derived from Pascal stability class, which accounts for the humidity, relative temperature, rain, fog, etcetera everything. And of course, the downwind distance is the point of interest along the x-direction where the wind velocity is considered to be in the prerogative direction.

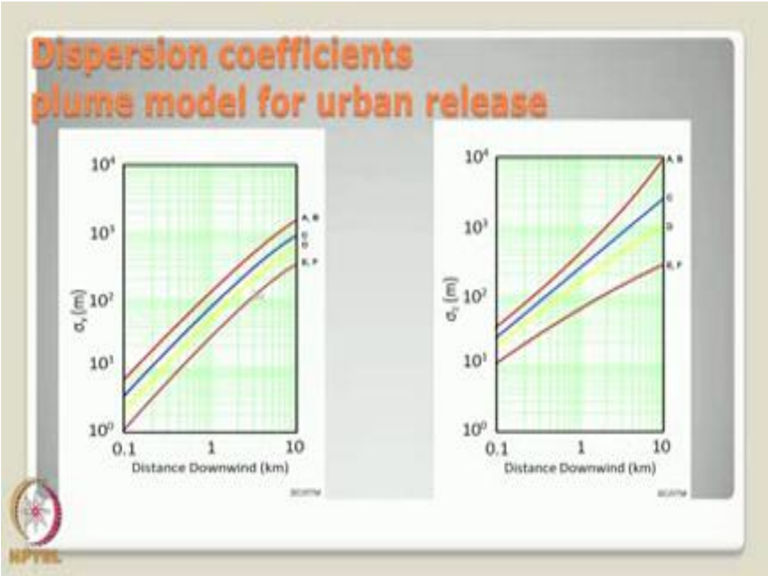
(Refer Slide Time: 29:47)



Let us now look at the steps to compute the dispersion coefficients. Step number 1, as it depends on the stability class, you have got a first identify the Pasquill stability class applicable to a specific location so identify the Pasquill stability class which essentially an alphabetic character named as A, B, C, D, E or F. This of course, depends on obtain from metallurgical data, it also depends on wind speed, it also depends on heat radiation, it also depends upon cloud cover which is also a path of relative humidity at a specific site. So, identify the stability class. Once you identify, then classify the area the classifications could be is it rural or urban, because a wind velocity a wind speed is dependent on various parameters which we already discussed in the previous lectures. Is it flat or hilly is it having any water body etcetera, so classify the area.

So, then one can find the dispersion coefficients by two ways. One can find them graphically from the figures, which I am going to show you now or one can also calculate the dispersion coefficients from the empirical relationship or equations which I will show you subsequently. So, step number 3, derive the dispersion coefficients either from the figures, which I am going to show you or using the equations which I am going to give you. Remember they all depend on any respective downward distance because as I just now showed you the dispersion coefficient depends on two parameters. One is the stability class which you are identified; the second is the downward distance x along the wind prerogative direction. So, for every distance of your choice you have to compute the dispersion coefficient which is case specific, site specific and distance specific from the release source.

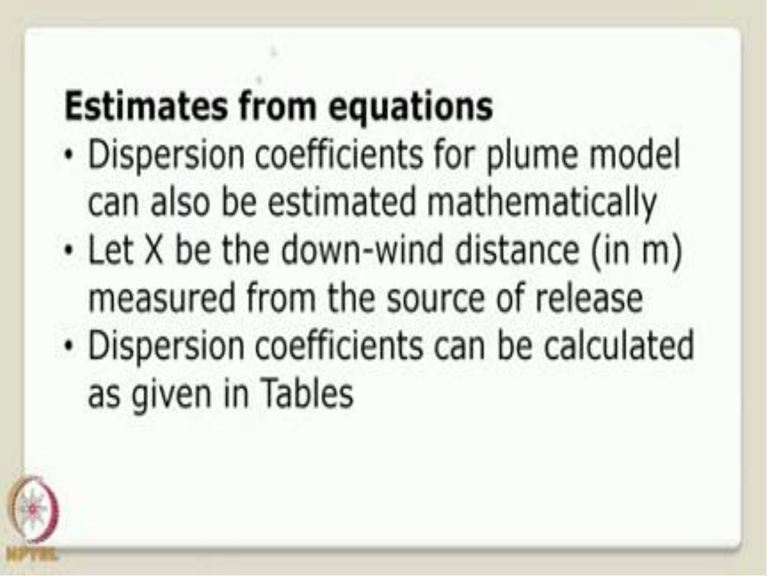
(Refer Slide Time: 33:33)



I may request you to look at the screen now. The screen shows dispersion coefficients for the plume model for a rural release. There are two figures shown in the screen. The left one is enabling you to complete sigma y values the right one enables you to compute sigma z values which are required for estimating the coefficients. The horizontal axis indicates the downward distance along the windward direction in kilometers; and different colors having given as a legend for different pasquills stability class varying from A to F as you can see from the figure. So, for a specific distance which you are identified for a specific pasquills stability class let us say in this case A can always find possibly what is the sigma y value and correspondingly what is the sigma z value for rural release for a plume model.

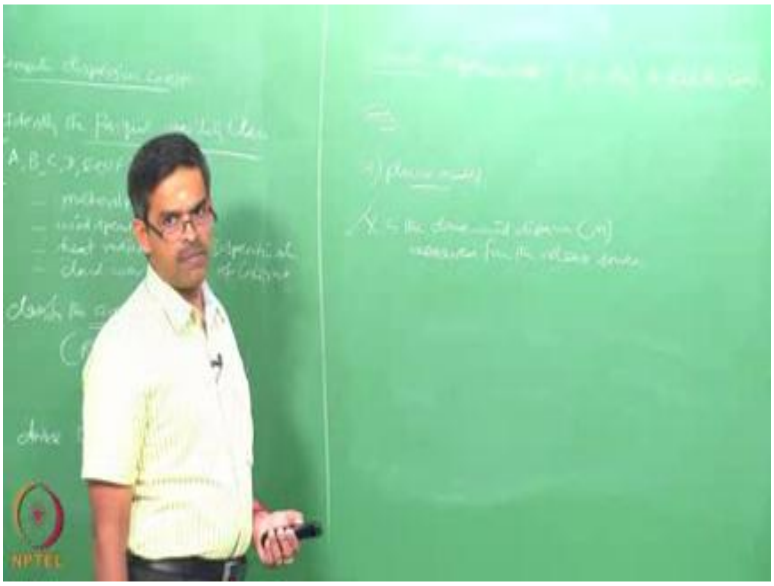
Similarly, look at the screen now you have figure illustrating dispersion coefficients for the plume model for urban release. So, again it shows pasquill stability class varying from A to F, similarly A to F for sigma z value and sigma y value as similar to that of the rural release, which you saw in the previous slide. So, one can easily for a known downward distance in kilometer for a known pasquills stability class given as a legend here one can easily find the sigma y value and sigma z value which are required to compute the dispersion coefficients.

(Refer Slide Time: 35:47)



Similarly, the dispersion coefficients for puff model are also given to you on the screen in the similar understanding. Once the dispersion coefficients for either the plume model or the puff model are estimated then one can easily find out the concentration at any fixed point along the downward distance, what is interesting for us.

(Refer Slide Time: 36:17)



One can also estimate the dispersion coefficients from the equations, estimating a dispersion coefficient that is sigma x, sigma y and sigma z sigma y and sigma z which are used to find the concentration. Let us now estimate them using equations earlier we discussed estimating them for the graphical method. So, if you talk about plume model, please understand x is the downward distance downwind distance, which you have to fix in meters measured from the release source. Once you know this value which is the only variable even the graphical method also this is the only variable of course, the other variable was the pasquills stability class which you are identifying I can also use dispersion coefficients from this equations.

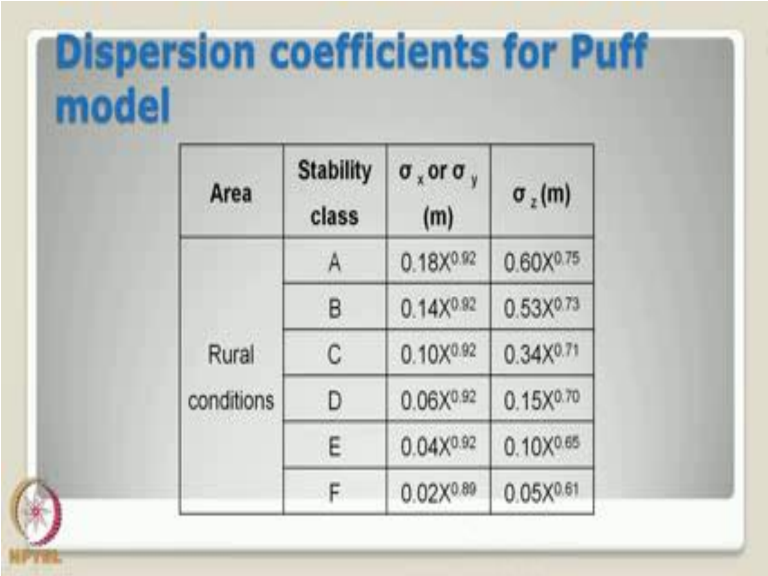
(Refer Slide Time: 37:40)

Calculation of dispersion coefficients (Plume model)

Area	Stability class	σ_y (m)	σ_z (m)
Rural conditions	A	$0.22X(1+0.0001X)^{-0.5}$	$0.20X$
	B	$0.16X(1+0.0001X)^{-0.5}$	$0.12X$
	C	$0.11X(1+0.0001X)^{-0.5}$	$0.08X(1+0.0002X)^{-0.5}$
	D	$0.08X(1+0.0001X)^{-0.5}$	$0.06X(1+0.0015X)^{-0.5}$
	E	$0.06X(1+0.0001X)^{-0.5}$	$0.03X(1+0.0003X)^{-1.0}$
	F	$0.04X(1+0.0001X)^{-0.5}$	$0.016X(1+0.0003X)^{-1.0}$
Urban conditions	A-B	$0.32X(1+0.0004X)^{-0.5}$	$0.24X(1+0.0001X)^{-0.5}$
	C	$0.22X(1+0.0004X)^{-0.5}$	$0.20X$
	D	$0.16X(1+0.0004X)^{-0.5}$	$0.14X(1+0.0003X)^{-0.5}$
	E-F	$0.11X(1+0.0004X)^{-0.5}$	$0.08X(1+0.0001X)^{-0.5}$

Please look at the table now which is showing the dispersion coefficients or plume model for two different conditions rural and urban which you classified. For different stability class A to F and A to F in both categories, you get dispersion coefficients sigma y and sigma z which has equations given where in this equation the only variable what you see here is the capital X, where capital X is the down wind direction or the distance, which you have to substitute in meters in this equation. So, for a plume model you can either find out the dispersion coefficients from the graphical method or from the table or equations given to you in the slide.

(Refer Slide Time: 38:42)



Dispersion coefficients for Puff model

Area	Stability class	σ_x or σ_y (m)	σ_z (m)
Rural conditions	A	$0.18X^{0.92}$	$0.60X^{0.75}$
	B	$0.14X^{0.92}$	$0.53X^{0.73}$
	C	$0.10X^{0.92}$	$0.34X^{0.71}$
	D	$0.06X^{0.92}$	$0.15X^{0.70}$
	E	$0.04X^{0.92}$	$0.10X^{0.65}$
	F	$0.02X^{0.89}$	$0.05X^{0.61}$

Similarly, if you look at the screen, now you will now find the dispersion coefficients equations for the puff model for the rural conditions for different stability class varying from A to F as a pasquills stability class. And it can be either sigma y or sigma x because puff depends upon the concentration point below the release point on the ground and of course, sigma z. The only variable in these equations for every stability class for a rural condition is X, where X is the downwind distance substituted in meters.

Ladies and gentlemen, in this lecture, we are able to explain you the dispersion coefficient and the concentration of the plume and puff releases which are instantaneous and continuous models which uses different kind of plots and equations to compute the concentration of the release material. We have also discussed the importance and explanation of isopleths, how are they plotted, and how are they useful in estimating atmospheric pollution from any release source, which happens as an output source, which comes out from a process industry.

In our whole discussion, we are focusing the process industry to be or considering the process industry to be a petroleum refinery which actually works on crude oil to get a commercial outlet of the product from the crude oil. Do you have any doubts, please post them to NPTEL website on a periodic discussion forum, and let us have or share the information what are we learned.

Thank you very much.