Fundamentals of Environmental Pollution and Control
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Lecture No. # 34
Ground Level Concentration

Right, so we begin this you know again you know the Gaussian plume distribution that we were discussing of say there are few interesting things to observe here you know what, what we essentially discuss about this Gaussian plume. See, you know if you see this plume here, just suppose you are taking a cross section of the plume at any point you are taking a cross section of the plume you see cross section of the plume along its line of travel.

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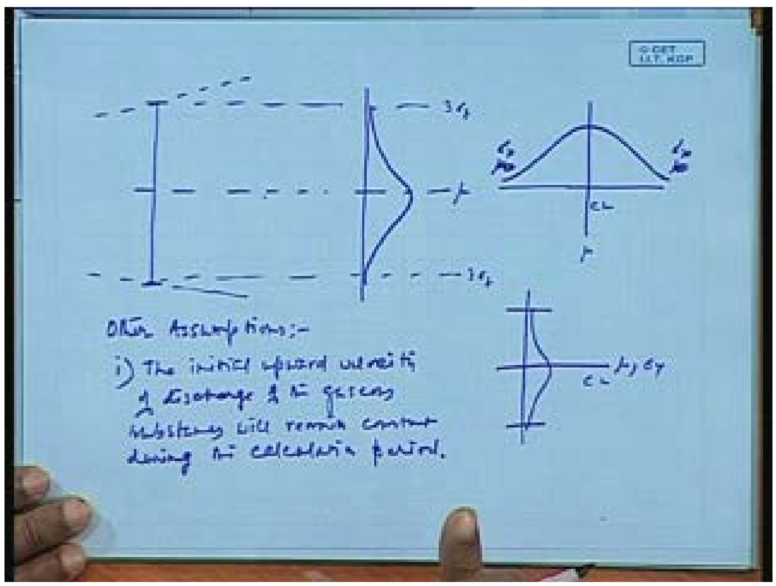

So, you know this is, this is travelling say the plume as we have, as we have already discussed about the plume taking a shape like this, plume taking a shape like this. Let me consider that you know we are taking an imaginary cross section inside this. What we observe here is, what is under this Gaussian plume distribution is one thing that it says is that you know across this, see here this particularly at this point if you just observe in this projection here if you just make a projection, here it would be this is the distribution is completely normal that means it would be having a, this having a mean and it would have a standard deviation and this is across the center line. So, this is say this is along the center line, this is along the center line, this is mu, this is, this you know this is 2 or say you know whatever say you just say 3 sigma, this is 3 sigma here is this is what is one, this is say across this is across see if it you can say this is sigma z, this is sigma z, this is one thing but there would be this is one part, there would be another along this, along this also, this would be following so a another normal distribution.

It would be always a normal distribution which is you know the center line, from the center line say this from the center line from the mu again on the center line concentration at that point of time this would be here this is again a sigma x sorry sigma x, you see this is sigma z we have written in the first place, this is sigma x and also along if you can just observe this also along the same also along, also along this, also along this you know the y direction also along the y direction it would also have a normal distribution which is again as you can see will have a mu, the mu as we know of and then this is sigma y. This is across the center line, this is about the center line, this so this is, this is where it is the center line is, the center line. So, this is so what its observe is across xyz direction it will follow a normal, the concentration of the gases would follow a normal distribution, would follow a normal distribution and this normal distribution having a particular, particular mean and mean and standard deviations, standard deviation across x direction, across x direction as sigma x, across y direction as sigma y and across z direction as sigma z. So, this is what is the major assumption of Gaussian plume distribution.

To observe you know when we are saying a plume and when we are saying a Gaussian plume, the essential difference is that in the Gaussian plume we consider that at x y z direction, the concentration of the pollutants, concentration of the gases or the pollutants are distributed. They are distributed in a normal distribution and each of these cases in x y z direction, it would be normally distributed. At any point, at any cross section or at any point if you take this, this would be a xyz in the xy z direction a normal distribution around a mean, around a mean and the mean would suddenly reside at the center line, mean would reside in the center line. So, here itself so this is the Gaussian plume the distribution that we generally discuss you know I think I have made the distinction between a plume and Gaussian plume. The Gaussian plum would be considered like this and this other assumptions are, other assumptions are, other assumptions, other assumptions are the rate of the initial upward velocity of discharge of the gaseous substances will remain constant during, during the calculation period, during the calculation period. initial upward velocity of discharge of the gases, gaseous substance will remain constant during the calculation period. Say, whatever calculation we are trying to do, I mean it can change but essentially with that with the mu and the sigma x, sigma y, sigma z also changes okay. This is number one, this is number one.

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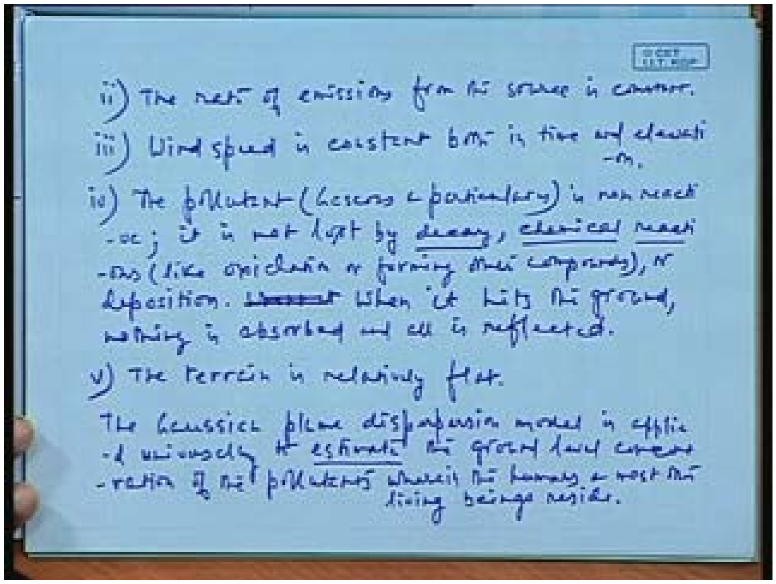

There is the number two is this, the number two is this you know the rate of emission, rate of emissions, emissions from the source, from the source is constant. Third: wind speed, wind speed is constant both in time, both in time and elevation. The pollutant, the pollutant gaseous and particulates is non-reactive, is non-reactive. So, it, it is to say it will not, it is not is not lost, it is not lost by decay say lost by decay something like you know a radioactive substances that you know they can decay during the discharge, during in the, during the suspension no chemical reaction lost by decay chemical reaction.

Chemical reaction that is you know they would not be oxidized or they would react with another substance to form a different compound. This will not happen, remember this. So, it is not lost by decay, chemical reactions, chemical reactions of any kind say you know which would lead to chemical reactions like, like oxidation, oxidation or forming other compounds right chemical reactions or, or deposition. It also assumes that when it sorry when it hits the ground, when it hits the ground nothing is absorbed all is reflected, so all is reflected and all is reflected, all is reflected. So, this is number 5 is you know is the, the terrain is flat, terrain is relatively flat. The Gaussian plume dispersion model, model is applied, applied universally, applied universally to estimate, to estimate, Gaussian plume dispersion model is applied universally to estimate the ground level concentration, ground level concentration, to estimate the ground level concentration of pollutants or air bound pollutants or air pollutants, ground level concentration of the pollutants wherein, wherein the humans and most other living beings reside.

Say, this is you know a, this is an universally applied model you know is essentially a, the good model to start with I mean you know say mostly even in, even in cases like you know in the most of this advanced websites if you make a search say something like USEPA that I have said, if you just observe you know they are still calculating. Most of the cases they are still calculating the ground level concentration depending on this model also. There are certain you know changes that have been made but some adoption has been made but mostly all the models of air dispersion models basically revolve around the Gaussian plume distribution okay. So, the

Gaussian plume dispersion model is applied universally to estimate the ground level concentration of the pollutants wherein the humans and most other living beings reside. So, if you are trying to measure say, say suppose if you have seen a power plant and if you are saying that it is discharging a pollutants like you know in the form of CO 2, SO 2 particulates, knocks and you want to estimate the ground level concentration say from 2 kilometers from the plant or say 5 kilometers from the plant or even say, say 500 meters from the plant, in such cases the most applicable model, most applicable model is Gaussian plume distribution model, most people use that without reservation in most cases.

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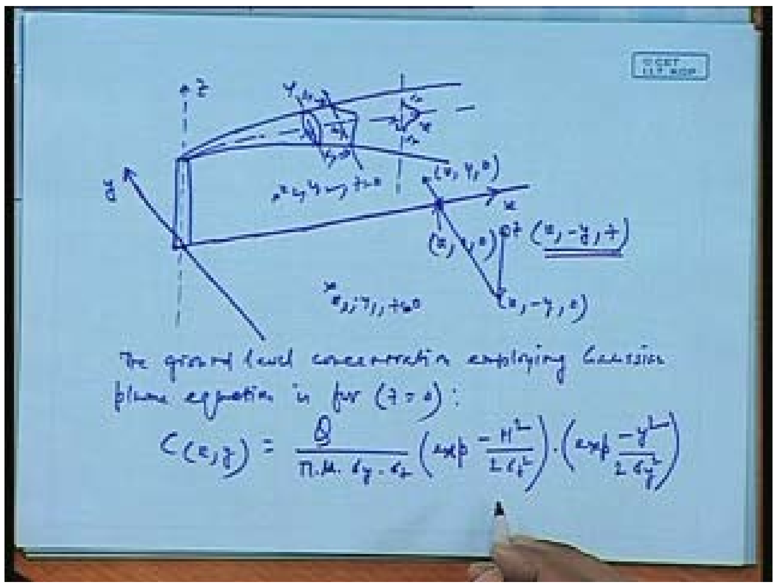

So, having said this, having said this you know we will like to explain this you know make a relatively what we have said here is if you just observe this you know let, let us make another drawing here I mean as you can see as I have already explained is a this, this case as you can see here say if you are just trying to observe it like this. I have already said this but you know let me pictorially represent this, this is I have already discussed I have already told you about all these but let me just give you a further on this. This is the z direction, this is the z direction that I have already said, this one is the x direction and this one is as you know is y, y okay. So, and if this, this you know if the dispersion is taking place, if the dispersion is taking place like this, as per our explanation, as per the explanation that I have already made, as per the explanation that I have already made if it is following a center line, if it is following a center line, this center line across the center line this is the plume, this is the instantaneous plume, this side would be this is the plume okay.

If it is the plume, if you can just observe you know here so this is what you know is just to explain you say this is around y, this is about y direction, this is about say this is about x yeah, this is y around, y direction it would as I have already explained along y it will also have along the center line this is mu, this is mu, this would be sigma x here, sigma x on both side this is plus minus sigma x as you know. This is where it is you know here it is also you can see the mu here is the, the at this point a value of mu, mu 1 or mu 2 you can see this mu this keep at mu 2, this one is mu 1 and this mu 1 you can find out here, this would be having sigma y, sigma y on both sides you know that is what this is a mu 1, okay.

All I say is this there is nothing much to a explain other than what I have already said that you know in the plume itself, in the plume itself along xyz direction, along xyz direction there would be at you know different points, at different points the mu would be different at the center line itself. The mu would be mu 1, mu 2, mu 3, mu 4 like this but mu 1 mu 2 mu 3 whatever the center line values their dispersion along the value along the x direction, y direction and z direction would be dictated by the dispersion coefficients that is you know we would know of as the mostly the standard deviation that we know of is basically sigma x, sigma y, sigma z along xyz directions. Is that clear? So, this is what you know this is just begin pictorially explained here at you can see this you know I think you know it does not need an explanation here that you know this one is the point here at this point here is (x, 0, 0) at this point and this one is as you can see this one is x, minus y, 0. This is, this being the positive direction, this is what is the x, x, y, 0 and this one is as you can further say from this top here this is of you can see the height along this, this z direction if it is in the z direction, so, you can find is x, minus y, z.

So, this is the, so if you are just trying to find out so this is how this direction would be emphasized. So, if you are just trying to observe say the concentration at this point xyz, xyz direction, xyz direction then we can see you know the ground level concentration considering z to be 0, considering the ground level concentration, the ground level concentration, concentration, the ground level concentration employing, employing Gaussian plume expression equation or expression is for, is for z equal to 0, remember this z equal to 0. what I mean to say is at this you know it between you know x and y here has x 1, y 1, y 1 say this is x 1, minus y 1 or x 2, x 2, y 2 here but this is don't have any or x 1, y 1 and z 0 z equal to 0 sorry z equal to 0, x 1, x 2, y 2, z is equal to 0. So, concentration at this point all these ground level concentration only on the ground level concentration that is if you are just putting, if you are just keeping this page, this page showing x y in the plane, this is an x y plane.

If it is an xy plane what we are trying this is the smokestack, we are only observing the ground level concentration, we are not observing at any point, at any height xyz. We are just interested about the ground level concentration because what I said is most of the humans and other living beings reside in that particular zone only. So, here as such as you can see this is the Gaussian plume distribution can be, the concentration at x and y, the concentration at x and y can be written as Q divided by pi u the velocity u remember this is u, this is not mu or anything like that this is u and sigma y, sigma z, these are the sigma z, this is the typical normal distribution, normal distribution standard deviation or we would call them here the, call them here this dispersion coefficients, dispersion coefficients, exponential minus H square divide by 2 sigma z square into exponential, exponential minus y square 2 sigma y square.

Let me repeat it again this is Q, this is the quantity that would be discharged, this is pi is as you know 22 by 7. This is u is the velocity at that ground level is velocity at, velocity at the average sorry, sorry at the stake level, at the stack height level I will, I will come back to that sigma y and sigma z, this is like this sigma y and sigma z then exponential H this 2 sigma z square this is y minus y square divided by 2 sigma y square okay. Having gone from there, having known this, having known this let me explain this parameters in more detailed here.

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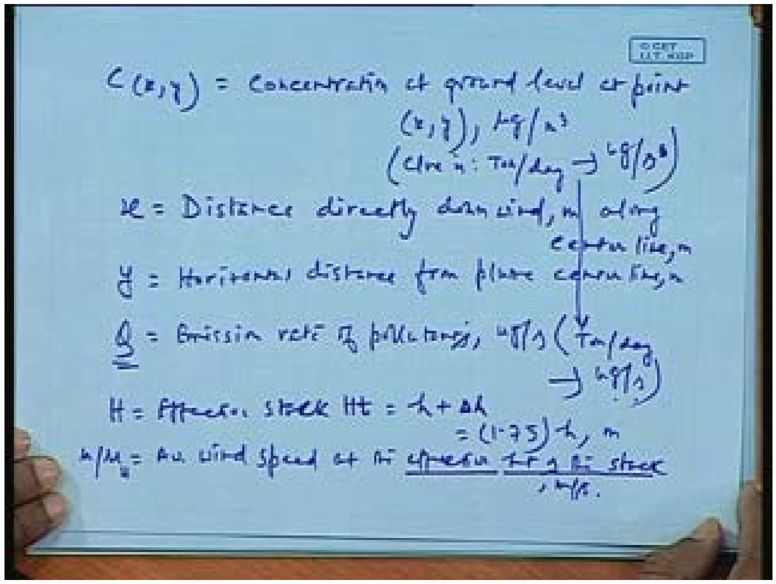

Say, this one is C(x, y), C(x, y) is equal to the concentration, concentration at ground level, concentration at ground level at point, at point x y. remember, this microgram per meter cube the clue is here clue is if, if the value is given in terms of say tons per day say ton, ton per day you have to convert it to microgram per meter cube. Remember, this don't ever confuse this. See, the mostly the power plant, the discharges would be in terms of tons per day. A power plant, usual power plants essentially emits to the tune of 20 to 50 tons of say tons of sulphur dioxide, right a tons of particulates. So, you know in such cases we have to change it to microgram per meter cube. Remember, this don't ever confuse this. X, x is equal to the distance, distance directly downwind, directly downwind, this is m, distance directly downwind, directly downwind, this is y downwind along center line you can write this along center line, this is important.

The line of x should be set on the center line itself say this is y is the horizontal distance, horizontal distance from plume center line, horizontal that is from the line of x, the line from x in meter. This is all in meter, remember this. This is of great importance, this is a meter. I will tell you why this is of great importance because you know most of this sigma x value, sigma, sigma z and sigma y value should be given in terms of meters. Q is, Q is emission rate, emission rate of pollutants, emission rate of pollutants, here emission rate of pollutants. More than what I say this microgram per second say this is something I am, I am I made a mistake here, clue is second here you can see just make a correction tons per day can be only be converted into microgram per second, it's microgram per meter cube I am sorry.

This is emission rate of the pollutants essentially this one would be, this particular thing would be required here. This is, this would be given in tons per day and you have to convert it into microgram per second. Just you know this one is superfluous, this is not much of importance because this one is important where this value, this value would be essentially be changed by this, all these parameters, okay. So, here this is ton per day if it is given a power plant emitting pollutants at tones per day, it has to be changed into microgram per second, microgram per second.

H as I have said, H is the effective stack height, effective stack height which I have already said as h plus del h, h plus del h. So, you have already known, so if it is nothing else is given you can find it as 1.75 of h, 1.75 of h. This del h becomes almost close to 0.75 h. So, h is this, u is average wind speed, average wind speed at effective height of the stack, this is in meter per second, this is in meter per second. See, here one important thing here is that effective height of the stack, remember this is not, this is see you will be mostly be given the ground level velocity at the stack.

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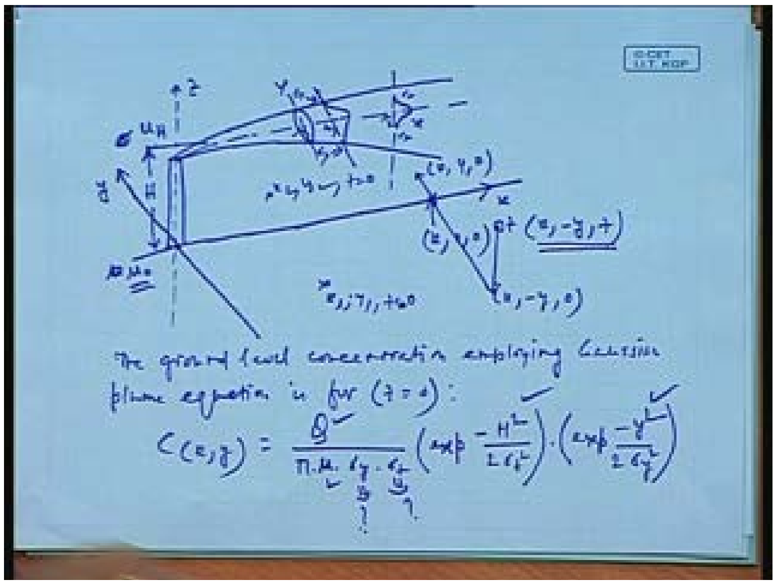

See, here as I have said if you remember in this, if you just begin here, this one is this is the ground level value would be given say u 0 would be given. You have to find out say that the center line, at the center line where it is say sigma h say here it is this, this is what is H, capital H you have to find out the, this value at H, at the point H remember this, this would be we have given to you in most cases because this is where you can measure it we have to estimate that at that stack height uH. So, this is, this is uH, uH you can write it like this uH, u or uH, u or uH as you can write this u or uH average wind speed at the effective height of the stack in meter per second. This height is, effective stack height is essentially in meters. So, in some cases the stake height is given in feet, we have to convert it into meter, we have to convert it into meters for calculation purposes.

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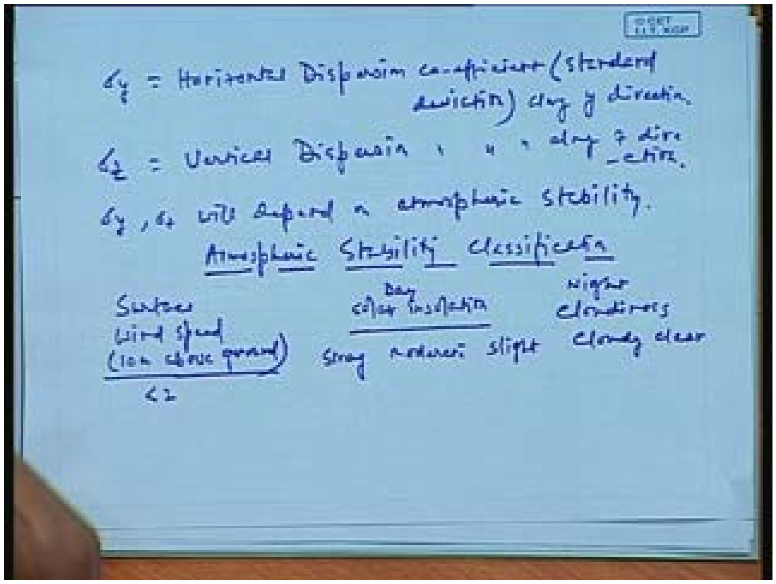

And sigma y, sigma y is the horizontal coefficient, horizontal coefficient that is standard deviation that I have already said, standard deviation along y direction and sigma z as you know this vertical dispersion, dispersion coefficient, vertical dispersion coefficient and also the standard deviation along, along z direction, along z direction okay, along z direction. So, what we can observe now is along this z direction. Well, there are few important things is you can see here in this as we have already or we consider this expression here, considering the expression here is this, this one is given to you, this one is known, this one would be known, this one would be known, these two are relatively unknown we will find out about them. This is, this is what is question mark here and this one as you can see this one also H and y will be also be given, H and y would be also be mostly known right but we have to find out sigma y and sigma z.

How we can find out sigma y and sigma z? There are you know standard, you know standard say mostly we use this tables for but you know just let me explain this. See, they are would be, this sigma y, sigma y and sigma z will depend on atmospheric stability, atmospheric stability will depend on atmospheric stability and this would be derived from this atmospheric stability classification. So, we would discuss this depend on this atmospheric stability classification. We will find you know most of this textbooks on air pollution, most of the standard books, textbooks of air pollution you will find this atmospheric stability classification given which is let me tell you about the features of this surface, surface wind speed, surface wind speed, this is surface wind speed is 10 meter, 10 meter above ground, this is 10 meter above ground. Say, this one is we know as day solar insulation, solar insulation and this is night cloudiness, night, this is would be generally strong, strong this is moderate and slight and this is cloudy and clear, cloudy and clear, cloudy and clear.

So, you know if you just make this distinctions here see this, this is less than velocity 2, less than velocity 2 day solar insulation, solar day, solar insulation say you know is a solar insulation is, this solar insulation is particularly this strong one. The strong one is here it says the strong one is like this okay let me, let me explain this day solar insulation. What it says I will, I will again come back to this. Let me explain what is day solar insulation, this day solar insulation is say particular time of the day, particular time of the day, when you say at a particular point say where we are measuring this we are going to measure about the, about the zone where we are going to measure the, the dispersion.

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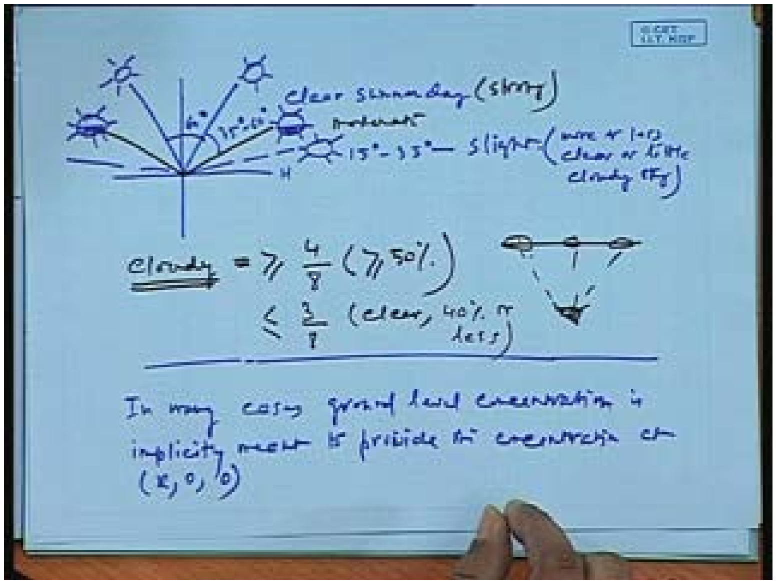

Here, if you see this, this is where is the, if at this point here if the sun, if the sun is 60% above the horizon. So, you know this, this is the horizon, this is the horizon if it is 60% say about this, so here if the sun is between these two zones see is 30, 30, 60 see this 60 degree here, 60 degree here. This is when the sun is here, when the sun is here on a clear sky, on a clear summer day, on a clear summer day, clear, clear summer day and you are calculating the dispersion at that point of time. So, this one would be known as day solar insulation has to be strong. When this is you know when this is between 35 degrees to 30, 60 degree say between this position here.

When it is clear summer day, on a clear summer day okay you have the sun like this, sun is half cost say you know the is, the sun is not fully exposed, sun is not fully exposed say the sun is exposed only this much, this much is dark say due to cloudiness, due to cloudiness this part is dark, few clouds, few clouds there and as if the sun is not completely exposed, we would know as, this one as moderate. This is a moderate, clear summer day this is strong, this would be you know summer day you know summer day with this, this one is, with this one the sun at say 35 to 60 degree. This one is known as the broken clouds, this one is known as moderate, moderate and if it is, if it is this, if it is between say between this, it has to be between 35 and 60 degrees, 60 degrees is the moderate. If it is below than this, if it is again if it is below than this, if it is below than this the sun is here say during the evening time, during the evening time or the early morning time, during the evening time or the early morning time clear summer day cloudy or see is between 15 degrees to 35 degrees and with somewhat cloudy, somewhat cloudy so this one would be known as slight okay. Say, more or less this is more or less clear or little cloudy sky, this one is known as this one would be is a moderate, strong moderate slight and this is cloudiness, night cloudiness cloudy, cloudy and clear that this cloudy would means that this, this is, this is between 4 to 8 say of the 8, of the total 8, if 4 out of 8% that is about cloudy is total portion is about more than, if it is more than equal to 50% we would call them as cloudy. This is of the 8, 8 portions of the sky if 4 portions are covered say something like this say if it is if you just try to see the sky like this and if you observe the clouds are like this and if this clouds by your own estimation, by your own estimation you know by your own estimation here by your own estimation here if it is, if this is if this covering 4 parts, if these are covering the 4 parts of the 8 parts that I can think of then this would be known as cloudy. Otherwise in case of anything less than, if it is generally less than 3 by 8 it would be known as clear. So, 3 by 8 as you can very well make this calculation to be somewhere or about say is a 40% or less okay. So, this is how we are defining. Under such a situation at a particular wind speed, at a particular wind speed, at these wind speed that we are talking about, of these wind speed that we are talking about 2 to 3, 2 to 3 say 3 to 5 this is in meter per second remember, 3 to 5, 5 to 6 and say more than 6, more than 6.

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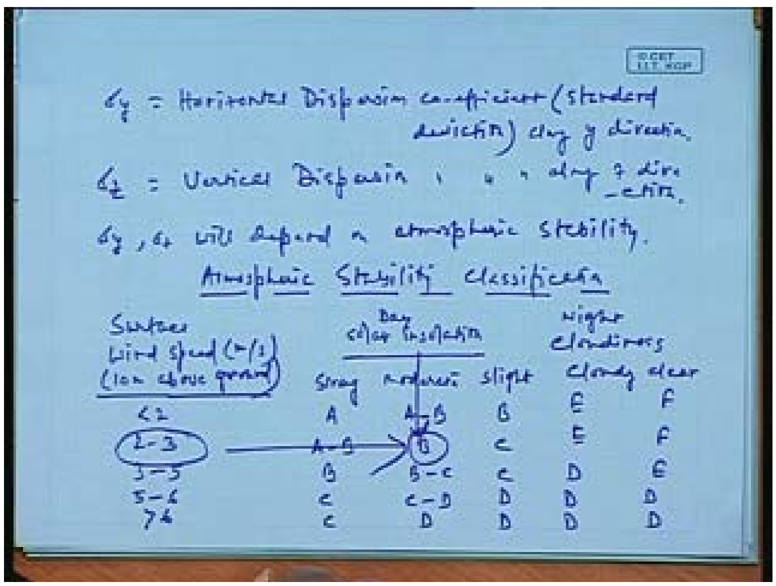

If you observe this at a particular say at a strong day insulation, we find the condition to be A. We find the condition to be A to B that is what I am I was talking about this atmospheric classification which I said I will bring out later again. So, this one is C, this one is C. This is A minus B, A to B sorry A not A minus B, A to B, B, B to C this is C to D and D and this one is B B C C D D then this one is E F E F D E D D D D, it’s okay all right. So, you can see this you know this is what is if you remember earlier I said about this the power coefficient that in the first class itself when I discussed in the, today in the first class we said about this power equation that is about this wind velocity at different heights that here the P that I used the P is basically classified in terms of A B C D and like this C D E and F. So, whenever we are discussing that P you know we have to find out in this manner about this is actually what it means by A B C D what we have, we have tried to explain.

So, in any case just for your case or example, so when the wind speed is like 2 to 3 and we have this moderate insulation, solar insulation that I have discussed already so you have find that the condition prevailing is B. Is it okay? So, this one A B C D E F that is how we can find out.

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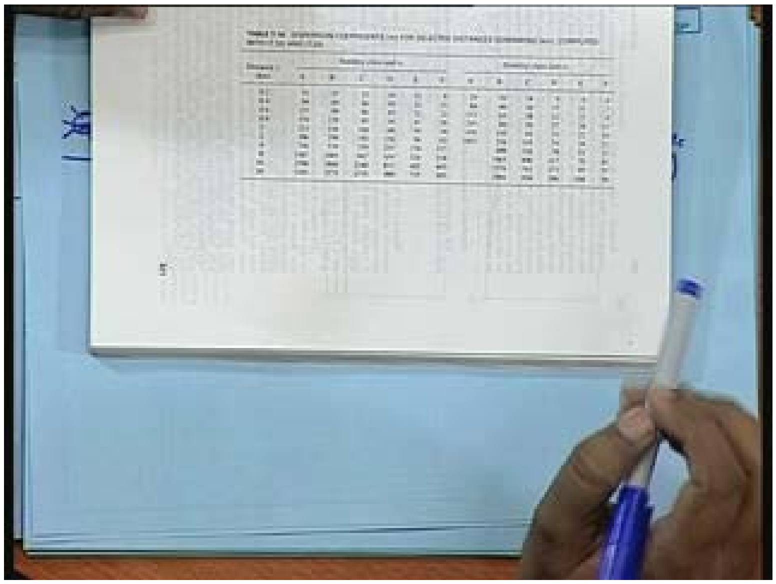

So, in any textbooks say from this if you are knowing that you know if you are knowing from this just to explain you a little bit on this you know here you can see this you can read this, you can read this just, just try to you know this would be you know we will find this values very easily any case. If sigma y and sigma z are not given okay you can make use of this table, we can make use of this table to find out the value. Suppose you have found out that atmospheric stability class is A and you are going to measure the distance say the, from the, from the stack to a particular position say at 1 kilometer, the A the sigma y that it you should have is 2 1 3, sigma y that you can see here is 2 1 3. Isn't it? This is 1 kilometer, 1000 meters from the stack, from the meter from the stack and at say at a stability class A, the stability class A we have defined clear sky and less than 2 kilometer of velocity of wind.

Clear sky more than say more than say the sun at a horizon sun at 60 degree from the horizon and so you can find out at that point of time, at that point of time the stability class as stability class as A and if it is A at 1 kilometer away, at 1 kilometer away from the stack, the stability the sigma y is 2 1 3. Similarly, sigma z would be, sigma z would be 450, so sigma z would be 450. Here, anything more than this, anything 4 4 8 16 20, the value of 9 1 9 5 3 has to be repeated. So, what it basically observes here is one is essentially the Gaussian plume distribution restrict itself to explain the situation within say 2 kilometers away from the stack. One should not actually try to use Gaussian plume distribution say more than 2 kilometers from the stack, right from the position of the stack. So, sigma y and sigma z can be found out and by which you can ultimately estimate the concentration, the ground level concentration at of the pollutant from the emanating from the, from the stack, okay.

Another important thing that is you know I would like to explain, tell you here in many cases, in many cases whereas so in many cases we observe that you know in many cases we observe that you know here we have said y but in many cases the ground level concentration the, in many cases, in many cases ground level concentration, ground level concentration, ground level is implicitly meant to provide a concentration at x 0 0, x 0 0 it is on the center line. It is just on the center line and it is not y is equal to 0, z is equal to 0. So, the center line concentration if you have going to find out you can very well understand that you know is the, in most of this, this Gaussian plume equation that I have said, the one term reduces because the exponential minus y square divided by 2 sigma y square that is given there we will observe that y, if y is put as 0 that that particular expression reduces to 1, reduces to 1. So, we can also find out the value of the ground level concentration like this. There is just you know a little bit of explanation required about how we find these values.

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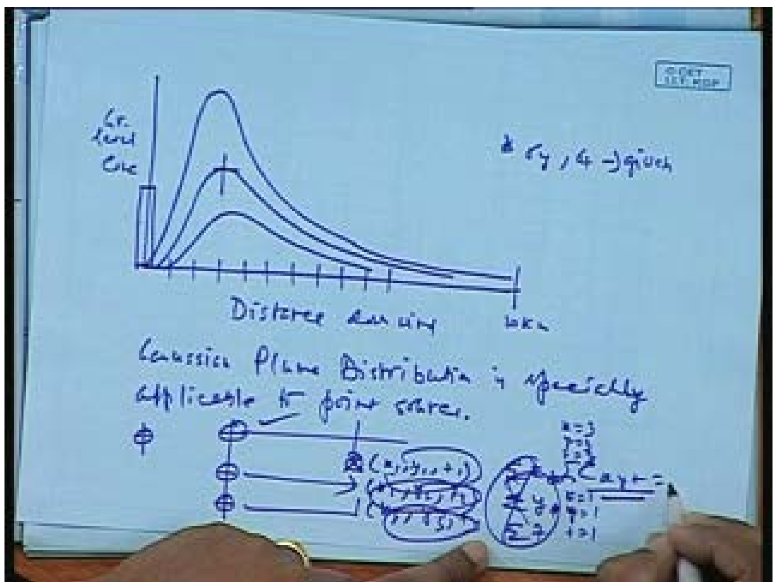

If you just observe now say this concentration values, ground level concentration values how this ground level concentration values vary from using Gaussian plume distribution model. This concentration, concentration say 1 kilometer, 1 kilometer, 2 kilometer, 3 kilometer like this distance downwind 4 5 6 7 8 9, this you know is up to say up to about say 20 kilometers, up to about say 20 kilometers. If you just observe these values see by using this ground as Gaussian plume distribution model mostly the plots look like this. What we have found is this is ground level, ground level concentration, ground level concentration, ground level concentration and we have found out the distance, distance downwind with you know sigma y, sigma y and sigma z given, given.

So, sigma y and sigma z that is atmospheric stability class is identified and sigma y and sigma z are given, in such cases what is the concentration forms like this. So, what is to be explained here is just to explain here is this that suppose take this curve, almost these curves are similar looking. What you observe is they are picking and then finally going down okay. So, this is what we observe here is ground level concentration here is that as I have said you know initially, initially at this suppose this is where, this is where the stack is, this is where the suppose for this curve, this is where the stack is okay, this is where the stack is. What happens is initially due to buoyancy this the particularly this the concentration, concentration would be at this point away from and with the velocity at this point the concentration would be somewhat less but this concentration certain distance away from the stack would essentially pick and then it will continuously go down which is expected because larger the distance, the concentration would essentially would be reduced. So, this is what is just to say you know particularly the typical characteristics that we can observe due to using this Gaussian plume distribution model.

This model perfectly suits for most of this atmospheric concentration calculation and which is also another important thing is say you know some cases if these are all point source you know the Gaussian plume distribution is applicable remember this write this Gaussian plume, plume distribution is specially applicable to point source as we have said you know in the case of a stack, this is a point source. It is say it is coming out from a point, this coming out from a point but this can, this Gaussian plume model also can be used for finding out this the line sources, the line sources where it is this would be, the points are on the line. These are essentially point estimation but considering that points are in a line we can consider, we can find out the concentration in the line sources also. What we do in that case? We just find out the xyz coordinates remain the, we manipulate the xyz coordinates to identify a particular point and from different sources the concentration, the likely concentration that should exist there and the contribution of different sources would be calculated.

So, here say if this is, this is the plume model, so here it is if you are just trying to find out the value here the concentration value here say at this point, at this point here so you are only what, what manipulation you are going do is this one is x 1, y 1, z 1 for this curve. This would be x 2, z 2, y 2, z 2 for this curve, this point and this one would be say x 3, y 3, z 3. What we essentially do is sigma x 1, sigma y 1, sigma, sigma x, sigma y, sigma z to find out the concentration at this point. So, all these concentration values, if all these cut this all, if all these concentration values are C is the summation of C xyz. So, here x is equal to 1, y is equal to 1 to z is equal to 1 to x, x is equal to 3, y is equal to 3, z is equal to 3 can be computed. So, we can find out the concentration at this point due to the contribution of the line sources. So, point sources can be converted or can be used as line sources. So, Gaussian plume distribution is essentially worked out for all these kind of problems and which is quite applicable and preferably used, okay. We complete this today’s lecture in this, okay.