Fundamentals of Environmental Pollution and Control
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Lecture No. # 33
The Point - Source Gaussian Plume Model

We were discussing about this mostly the dispersion of pollutants in the atmosphere and particularly today we will discuss about a very popular model which is used throughout the world and you know in very research establishments, many researches establishments where this the dispersion models of dust another things are generally carried out. So, we will see that you know in a, in this lecture today the, how this distribution or the dispersion model is worked out and what are its assumptions. As we know that you know any kind of, any kind of model should have to have some kind of assumptions. We will also greatly I mean in detail discuss about the assumptions that essentially are linked with a model, air pollution model similar to Gaussian plume distribution here. So, is we begin with you know the mostly you know there are few important thing that we would just begin to discuss with before we actually come to this model. The first and foremost important thing here is the relationship, the relationship between, the relationship between the height and velocity of air, the relationship between the height and the velocity of air.

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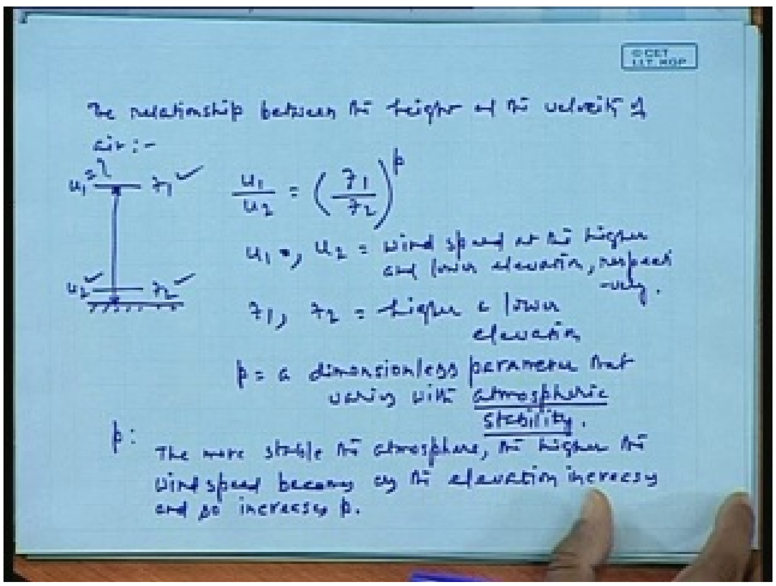

See, here this is what would be quite important for of all of us. See, you know if you are just trying to understand the situation, mostly all our velocity measurements, air velocity measurements are essentially at the ground level, are essentially at the ground level. Say you know at a, at a height almost, at most of the times at a height within 10 meters from the surface of the earth, from the surface of the earth. So, you know in such cases it is necessary to sometimes estimate what is the velocity at this height say at a particular height from the surface.

In such a case we can use this you know a power function which explains the, which is explained like this you know which is u 1, u 2 is equal to z 1 divided by z 2 whole to the power p. Now, here u 1 and u 2, u 1 is and u 1 is equal to u 1 and u 2, if you can write it like this together wind speed at higher and lower elevation respectively and this one is the z 1 and z 2 correspond to a similar height, higher and lower elevation, p a dimensionless parameter, a dimensionless parameter that varies with stability, that varies with atmospheric stability. So, here all you can see is say is a mostly in cases u 1 by u 2, so here it is say if it is just as for the convention as I have said u 1 and u 2 this one is this, this one is the z 1 and this one is z 2 either way if we know, if we know this p and we know u 1 and u 2 and also another parameter say z 2 in such cases we can find out if this is known to us, if this is known to us, this is known to us and this is known us we can find out what is this, so by using this power function okay.

So, the value of this p as the dimensionless parameter I have discussed is essentially depends on another very important factor which we known as atmospheric stability, which is known as atmospheric stability. So, in such cases as you can see here so is say there is the value of p you can just understand this, this, the value p. So, p if we can start a discussion on p, the more, the more stable remember this, the more stable, the more stable the atmosphere, remember when we are saying the most stable the atmosphere we are not saying that they, there is absolutely lower velocity and there is no such situation as if not to explain, you should not convey a meaning whereby it states that the wind velocity is zero, it does not means stability as such that. Stability means you know there is less turbulence, there would be more of air velocity can be consistent, consistent air, velocity if we can consider that that is a stable atmosphere.

In an unstable atmosphere the velocity keeps changing, all the time the velocity keeps changing and as a result of this you know velocity, direction how does things essentially changes in an unstable atmosphere. So, in no way it should convey a meaning that you know the stable atmosphere means everything is stand still. So, the higher the most stable the atmosphere the higher, the higher, the higher the wind speed, the higher the wind speed becomes as the elevation, as the elevation increases and so, and so increases, so increases p and so increases p, so increases p, so, here also this is so increases p. So, the most stable the atmosphere the higher wind speed becomes at the, as the elevation increases and so increases p. So, we can just consider this p.

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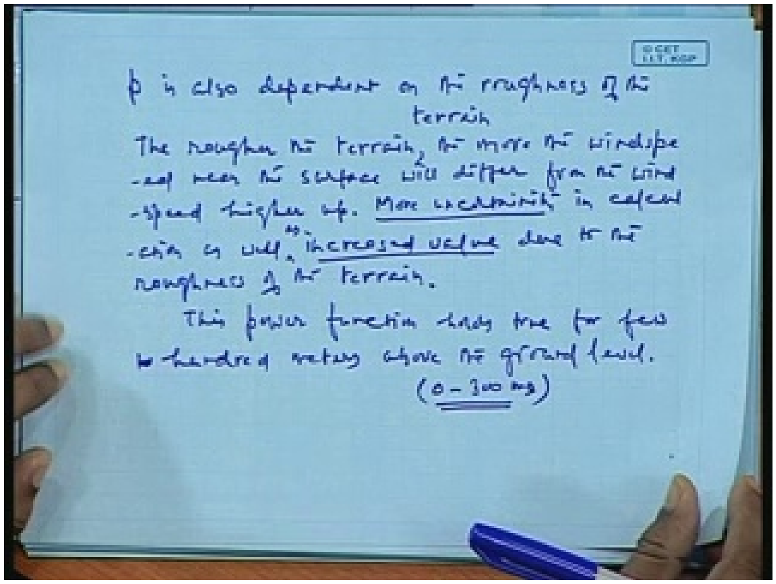

Also there is another effect, the p is also dependent on, p is also dependent on the roughness of the terrain, roughness of the terrain, the rougher the terrain. The rougher the terrain the more the wind speed, more the speed near the surface will differ, differ from the wind speed, wind speed higher up, higher up. So, you know it says this would, can see here just to explain this is the rougher the terrain the more the wind speed near the surface will differ from the wind speed higher up. So, there would be you know there is be greater amount of uncertainty, there would be more uncertainty in calculation as well as increased value due to the roughness of the terrain, roughness of the terrain right, due to the more uncertainty is in more uncertainty in calculation as well as, as well as, as well as increased value due to, due to, due to the roughness of the terrain, due to the roughness of the terrain.

So, you know is just you know trying to understand this, so we can estimate we can have an understanding of the characteristics of p depending on two aspects. One is the stability of the atmosphere and as well as the roughness of the terrain. We will see now how actually this value should be used you know the how this value should be formed. So, if it is you know if it is just to explain it here why I have come with this expression here this power function here is only to suggest one thing that you know in many cases in the calculation of the upper, the velocity at a height, velocity at a height say at few 100 meters, few 100 meters, about few 100 meters. If the velocity at the ground level is given we can estimate the velocity at a, at a higher level, at a higher level remember but this power law function thus this power function from this, this power function, power function holds true for few 100 meters above about the ground level, above the ground level. So, this is another important thing is that you know it can be wherever we are using this we must use this that you know between 0 to say about 300 meters, 300 meters. So, this 300 meters, this 300 meters is what is we should I mean more than that remember more than that this power law function does not hold good after say 300 meters, more or less after 300 meters. So, but at the same time as it is going up 300 meters the calculation of this p becomes increasingly difficult and also becomes increasingly difficult and more than that it should not be applicable, it should not applicable but this will suffice our purpose.

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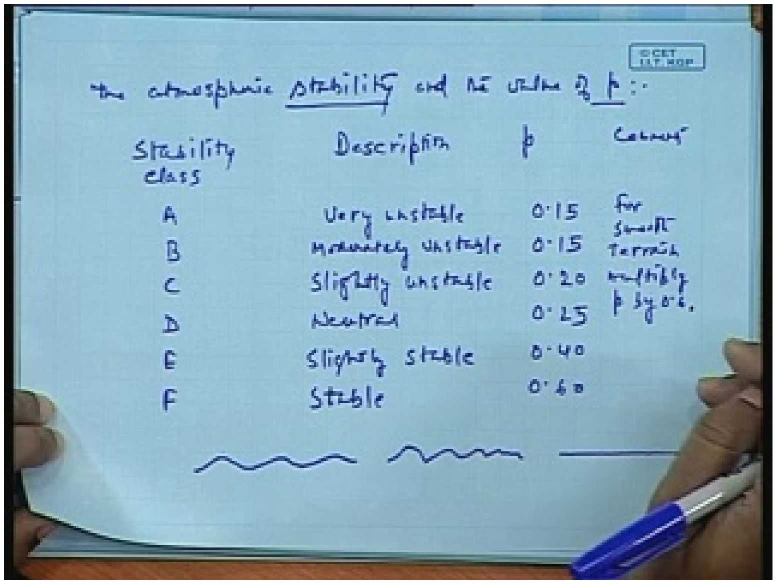

You will understand now this is the another important aspect is the atmospheric stability and the value of p atmospheric stability, atmospheric stability and the value of p. I will come back to this atmospheric stability so we will further you know in a generally in a more descriptive manner we will explain this, we'll understand this stability. This is what is you know stability class stability class. I will come back to this description, description and the p, p and comments and comments is ABCDEF this, this is a stability class. I will come back again as I have said to discuss about this ABCDEF which would means is very, very, very unstable, very unstable moderately unstable, moderately unstable. This can be physically understood as well I mean it's not neutral, slightly stable, slightly stable, stable, slightly stable and stable okay.

Here, what is the value of p is like this 0.15, 0.15, 0.2, 0.25, 0.40, 0.60 and the common should be in for smooth terrain, terrain, smooth terrain multiply p by 0.6. So, just to interestingly for smooth terrain multiply by 0.6. See, this is a reducing factor you can see this, this is a reducing factor for smooth terrain, so you know rough terrain. So, you know smooth terrain and rough terrain if you can, if you do not, if you have a confusion here a rough terrain would be like this or you know more like this is a rough terrain or there is a smooth terrain, is a relatively smooth surface area. So, if you have, if you are estimating the velocity at, at say at a surface like this and at a surface like this in at this two different surfaces the, the value of p would be higher here than the value of p on the smooth terrain and as you can see multiplying p by 0.6 is essentially a multiplying by a reducing factor, okay. So, 0.6 becomes a reducing factor that we would be we have come to know okay. Now, here you know just you know this is what you know from next we will try to understand you know on what basis this you know the, the dispersion of this you know the dispersion of the pollutant takes place.

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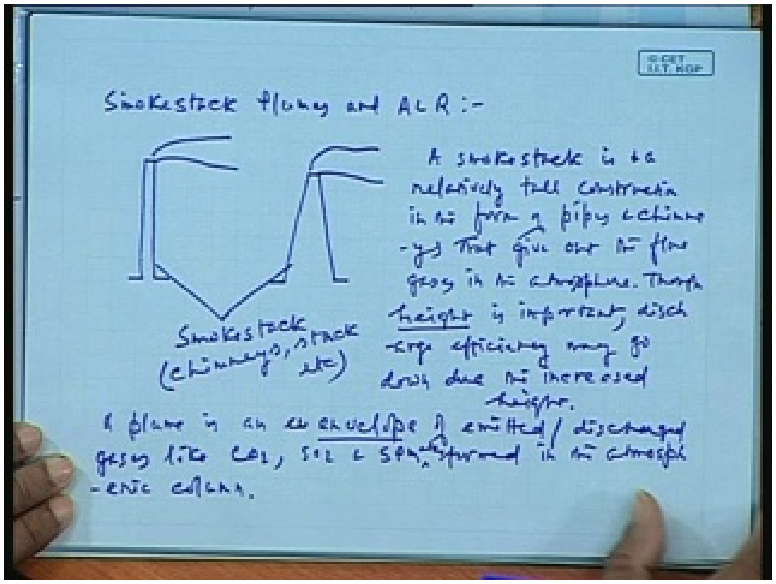

We will see now we will particularly take this case you now all these dispersion models, this is in the mostly all this you know we will consider this as smoke smokestack, smokestack plumes and adiabatic lapse rate ALR, smokestack plumes and ALR. See, this ALR I have already said this is adiabatic lapse rate. What we have, what we are trying to do now is this you know we will try to see how this smokestacks plumes you know what is a smokestack. See, you know you have seen you know in a power plant in a small, small, small plants you know small foundry shops you have found that you know you would observe that you know there are, there are smokestacks through which the smoke comes out. This is essentially if we are just not interested about the details at the bottom you can see this you know you have observed the plumes coming out like this, this there are, there are, these are called smokestacks.

This is where you know through which the, thus the, the plume generally comes out say they come out of different shapes, this is come out for different shape you know so these are, these are the smokestacks, so this is a smokestack. So, they have other names also you know sometimes they would be knowing as chimneys then say in the, in the power, in the power plant you know that there would be known as chimneys then they would be simply known as stack okay, they would be simply known as stack etc. So, there are, there may be few number of you know the nomenclature about this smokestacks to for all, for all practical purposes a smokestack is a relatively, relatively tall construction in the form of, in the form of pipes and chimneys that give out flue gases in the, in the atmosphere though height is important discharge efficiency may go down, discharge efficiency may go down right though height is important discharge efficiency may go down due to, due to the increased height, increased height. Though height is important discharge efficiency may go down due to increased height.

So, height is important we will explain you know why height is important, why height is, this is called a smokestack and this adiabatic, this is a called a smokestack and will now observe how you know, you know different kind of smokestacks how this, this the plume characteristics changes, plumes characteristic changes. A plume, is a plume, a plume is, a plume is an envelope,

envelope of emitted or discharged gases like CO 2, SO 2 and SPM formed in the atmospheric column. A plume is an envelope of emitted or discharged gases like CO 2, SO 2 and SPM etc, you can think of something else as well etc formed in the atmospheric column, formed in the, a plume is an envelope of emitted or discharge emitted slash discharged gases like CO 2, SO 2 and SPM etc formed in the atmospheric column. This will, we will come back to this word envelope, we come back to this word envelope I mean in the course of the lecture. So, here as we, as we further go on to this, as we further go on to this, as I have said this is the relationship that we generally observe.

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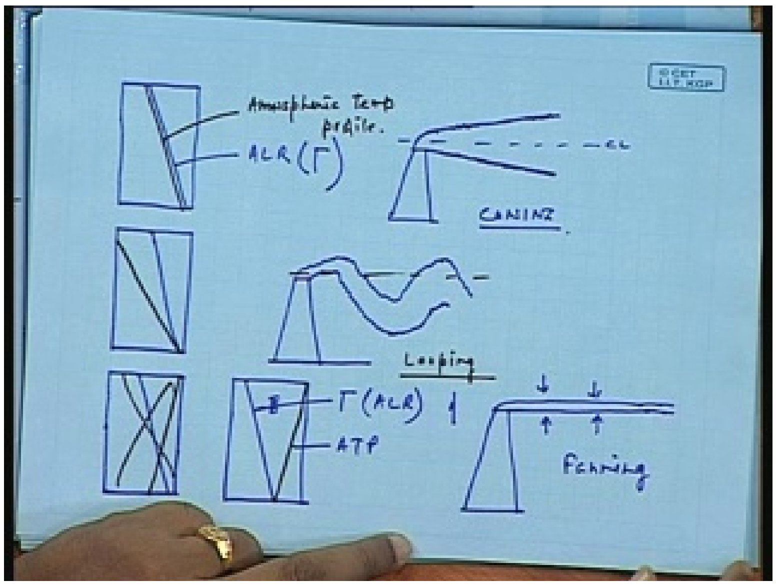

See here, the plot that I make here is something like this you know where you can see this okay, here what we there are two plots as we can see this we would make two plots say this is what is adiabatic lapse rate. This is consider this to be say this consider this to be adiabatic lapse rate, this is would be this is, this is the adiabatic lapse rate curve ALR, also you know in many books you will find this refereed as this with a sign like this ALR which would means that adiabatic lapse rate. So, what it’s is simple I mean if you have not understand, stood it as here this is where is the surface temperature. So, surface temperature as I have said 10 degree centigrade per kilometer or say 1 degree centigrade per 100 meter it will keep on reducing.

So, if you just plot 2 or 3 through points on this, from this the surface temperature and then try to plot it at reducing the value at 100, 100 meters and then 100 meters and the, reducing the temperature by 1 degree, so you find the plot. So, if it is say 25 degree centigrade here and another point would be at say 24 degree centigrade at 100 meter. Isn’t it? So, this is, this is say this would provide you, this would provide you the, this adiabatic lapse rate. This, this adiabatic lapse rate if you just consider this you know with this adiabatic lapse rate, if you just try to find out this the value of the value here just like this you know there if it is the atmospheric temperature profile, this is atmospheric temperature which is actually available at the atmospheric say this is the atmospheric temperature profile, this is atmospheric temperature profile which is almost closely resembling to this adiabatic lapse rate in a situation like this. This is adiabatic lapse rate which is an ideal condition. This is the atmospheric condition okay, this is called atmospheric, atmospheric temperature profile, atmospheric temperature profile.

If this is so, if this is so we can find this, this the plume model that we can observe here the plume would show a characteristic like this. The plume would show irrespective of the height of stack, irrespective of the height of the stack it would show a characteristic of the plume would be like this. It would be, it would be like this you know forming a, forming a clearly distributed pattern, clearly distributed pattern of you see this one would be, there would be some changes in this. So, but this would be according to this one is along the centre line, it would be, it would be symmetrically distributed along a central line, this is central line okay. This is the along distributed along the simple line, this is, this particularly would remain in an a situation like this this is known as coning, this is known as coning atmospheric temperature profile you know is connected with this ALR and atmospheric temperature profile when they are like this in a particular time of the day or you know particular season, when ALR and ALR and say atmospheric temperature profile are quite similar or quite close to each other in such cases we will find a, the plume which would be discharge from the smokestack would have an identical distribution on both sides of the central line, okay. So, this is what is the called the coning.

In some other cases we can think of in cases like this, we can think of a situation like this where we would find this as this here that you know we would if we just try to plot the same thing, the adiabatic lapse rate does not change. Remember, this adiabatic lapse rate remains same, this one remains same but if we just observe that you know this one is being changed to, this one is being changed this atmospheric temperature profile changing like this atmospheric temperature profile changing like this, we will find this the, the pollution the particularly the, the smokestack dispersion of the plume, dispersion of the plume would be like this. So, we will observe this to be quite similar to this, okay. So, this is what it would be quite looking like. What is observed here is that what we have generally a more random or more vigorous, more vigorous this is along the central line, this would be along the central line. So, you know you can see this more vigorous and down movement of the, the gas plume of the gas plume, this plume is, this is called as looping, this is called looping. This is how the loops would be formed, this is how the loops should be formed.

So, on the other hand if you just observe this you know this is called looping and on this, on the similar, on the similar situation like this if we just observe this one where it is, where this adiabatic lapse rate remains the same, the adiabatic lapse rate say remaining the same, this one is what is remaining the same but if we just observe that this particularly the, sorry just one minute I mean at surface temperature at the, the both should be meeting at a one point I mean this is let me cancel this figure we just try to observe this, this is surface temperature in both the cases should be same. Isn’t it? So, we would start by if we just make this you know somewhere in the middle say here this is the adiabatic lapse rate remains the same, this is the adiabatic lapse rate and if you just observe that you know this atmospheric temperature profile the, the atmospheric temperature profile to be quite like this is quite like this you can see here interesting change here is, it is, it is decreasing here, it is increasing here.

So, the temperature this if there are the difference is that is this one is, this one is the sorry this one is the ALR that we have shown this is what is the ATP that is atmospheric temperature profile. So, we can find here in this case we can find here in this case the, the, this the plume would have a characteristic, would have a characteristic which is closed to this you know what is happening here is this should be in a situation like this, in a situation like this. There would be a relative, a sort of compression from, both from the, both from the up and as well from the below. So, this one is known as, this one is known as fanning, this one is known as fanning. So, you know here so whatever the hot gases that would come out of this smokestack, all this remember another important thing about this smokestack plumes are is that you know the, all these gases are hotter than that of the atmospheric temperature at that point. Remember this, this is also an important, important parameter or a qualification for this smokestack. So, this is how it would be you know the fanning would take place where the zones you know this the plume would not would be able to, able to be distributed, I mean in a more vigorous way as it has done in the case of coning and looping in the fanning. It would be more or less a, it would be something like a band instead of a loop or instead of a cone that you can observe here, this coning that takes place. So, this is, this is what is, this is the fanning coning looping fanning that we can see. There are few, there is another important changes that we observe here is this.

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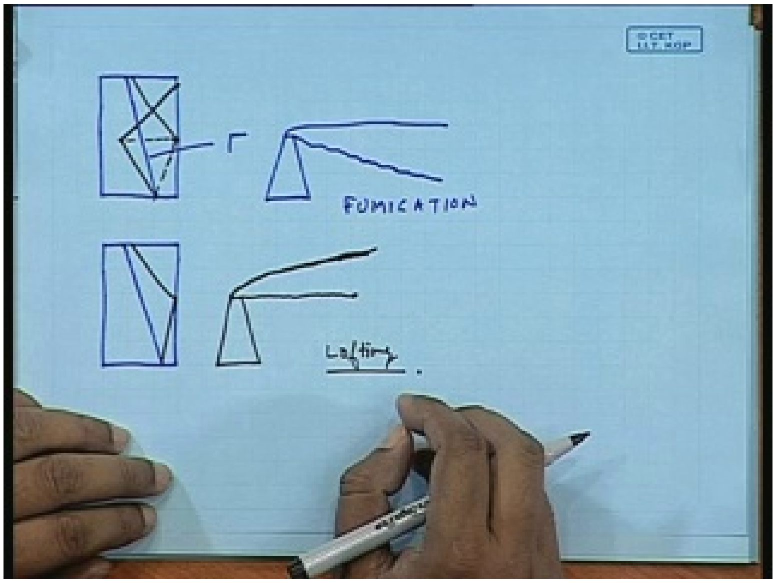

This one is particularly also quite important is that this is as I have already said this is ALR, this is ALR as you will, we will find out like this the ALR as you would say and here on the other hand this is one, this one is interestingly see this atmospheric temperature profile here is like this. It is almost following is quite closely following this adiabatic lapse rate but then again at a certain altitude it changes course and it goes like this. In such a situation if we observe here the plume this you know the stack at this point of time, at this place if you see this stack here at this height, what we observe here is that you know this the plume pattern would be like this, it would be. So, as the plume the surface on the top surface becomes continuously hotter. So, there would be you know this the gases, the gases, the gases, flu gases that would come out would eventually feel, would eventually be denser than the atmospheric, atmospheric at that condition at that point in the atmosphere, at that height in the atmosphere.

So, if it is forming denser it will find it to a, to be denser, so it would generally come down. So, you can see this you know this is what would be the pattern in such case this pattern is known as fumigation, this pattern is known as fumigation. On the other hand the last one that we would explain this is also there is another variation to this, another variation with this adiabatic lapse rate and that of adiabatic lapse rate and that of the atmospheric temperature profile we can observe is if this is the, this is a case and say they can, can observe it like this we can find it like this here in such cases we would observe this to be okay. If this is, if this is, this is just the other way round you can see this whereas here it was if we just from see from the former this one is it has actually I mean if I just change this plot here, it has actually on the other hand here the temperature profile is like this. Here, it has changed like this. Till this time it contradicts or it is completely different than the adiabatic lapse rate. It is an increasing curve and on the other hand as it comes to a stack height, comes to the stack height it is essentially changing and where it begins to follow the adiabatic lapse rate, right. This is what is the plot I have made.

You see this it goes against the adiabatic lapse rate till at the smokestack height and then from that height onward it begins to follow the adiabatic lapse rate again it come begins to come closer to the adiabatic lapse rate. In such cases we observe that you know this the, the particularly the, the smokestack pollution this, the smokestack emission would form a plume which would be like this, which would be like this. Since it would be, since it would be just the other way round, it would form it will find lighter. Here, it was denser which was being discharged from the atmospheric air, here it is lighter than the atmospheric air at present at that point of time, present at that place.

So, here it would be, it would be rising so it is generally called as lofting, is known as lofting, is known as lofting okay. Now, having to say this these are the typical characteristics of typical characteristics that we observe in cases, in cases like you know the dispersion of this air pollutants across you know from emanating, emanating from a smokestack emanating from a, from a say the power point plant discharges that you observe. Next time when you, you know take a travel you know wherever you find a power plant you start to observe you know how these plumes actually behave, what you will finds some interesting observations in that, you know many of these cases you will find this is being this patterns are being followed, this patterns are being followed.

So, what we begin to say some from this now onwards is that you know as we can find out, we have found out that you know the different profiles that it would have. See, the mostly this coning, looping, fanning, fumigation and lofting. So, having to understood from here that we can go into this the Gaussian plume distribution model which is, which is goes like this. This particularly you know beginning to understand this you know it would require a certain amount of drawing here we just you know as you can see this one would be okay.

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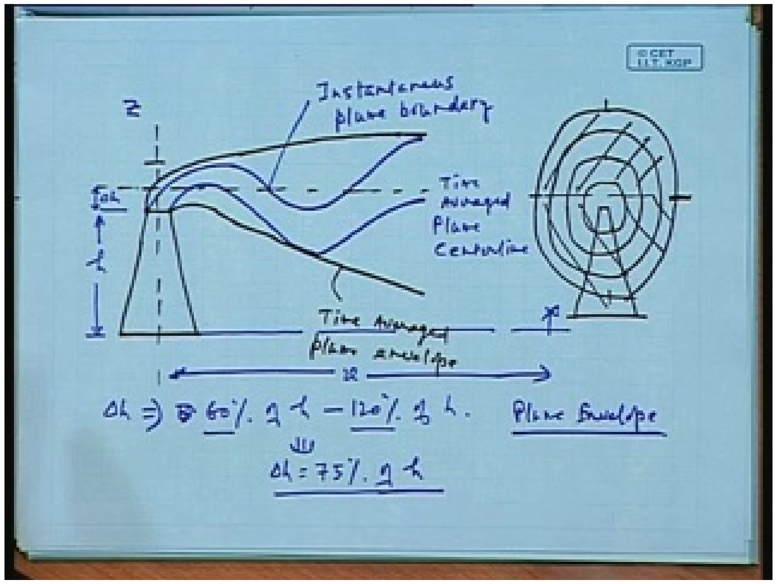

Let me draw it from here, this is what is a say is smokestack. This Gaussian plume distribution is as basically following the normal distribution, this is a, all a basically following the normal distribution and how it looks like. This is what it would look like. So, here in this case is you can observe okay this would be, this would be the plume, this would be the plume, this would be the plume, right. This is what is the plume. See, this you know this as you can observe here, if you just try to observe this like this you know it would be see initially if we just make a cross section, if you just make a cross section like this, this would be forming like this initially then it would be forming like this. Then it is as with the distance the plume is taking a shape like this, this is what is the plume would take, look like this physically with distance starting from, starting from this place here if you just try to observe the plume you know facing the plume, facing the plume, if you just try to observe say here it would begin to disperse the, the pollutant should begin to disperse like this, the pollutants should begin to disperse like this.

So, here as, as you can see the, that the concentration here would be higher concentration it would go to lower concentration, higher to lower concentration but it would spread like this, this is the spread this is what is known as the plume. If you make a cross section along this if you make a cross section along this, it would look like this or quite look like this. So, here you can see this you know this one important thing here is you know every plume generally for the Gaussian plume we would, would understand that this would be forming a centre line, is not necessary that all plume should follow centre line but we would observe for this Gaussian plume distribution to have a centre line and this would be I will come back to this, this would be forming an symmetrically distribution on both sides.

So, you can see these are, these two end, these two sides, these two sides are, these two sides and these two sides, these two sides, this one and this would be identical, this would be quite identical so you know what this is the plume boundary. So, this is known as this time averaged, time averaged plume envelope, time averaged plume envelope, time averaged plume but instantaneous plume would be like this, instantaneously plume would not be quite like this. The instantaneous plume would be okay instantaneous plume would be quite like this. It would begin to spread, it would begin to spread but it would remain confined within the plume. So, this is called instantaneous, instantaneous plume boundary, is known as instantaneous plume boundary. This is time averaged, this is time averaged, time averaged, time averaged plume centre line, time averaged plume centre line and this one we would require this explanation, this is the h is the stack height. This is the above the centre line, this about this position here this one would be known as del h, h and del h. So, this one is del h that is the lift as they are you know these are very hot gases as I have said all of these are hot gases they will have certain buoyancy in them essentially. Isn't it? So, the surface, the temperature of this emitted gases or this particulates would be more than the ambient temperature at that point.

So, as a result of this, this would form a certain kind of buoyancy on that, this buoyancy would take them a lift, buoyancy would allow them to get lifted. So, this buoyancy you know here I was though we have written this del h to be, del h to be as if to suggest you know del h is very small compared to h it is not so. In most of the practical cases you know we would see we find say the del h to be about 50, 60%, 60% of, 60% of h, 60% of h and this the range is about 60% to in sometimes it can be up to 120% of h, h. So, it can be sometimes even more, it can be sometimes even more, it can be sometimes even more. So, you know say we can see this more than the h you can see this. So, though we have said this to be, this to be like this so you know mostly it would be somewhat you know the value is quite substantial, it's not like a del h that we generally know off.

See, this del h the for most of the cases you can find if you are, if we are working out in the examination or any other places you can generally estimate this h, del h to be if it is nothing else is given about del h should be about 75%, 70% of h, so which would makes it is a, is a, is a quite, a quite an, quite a big value by all means, quite a big value by all means. You can see this one would be, this would be the height is the z axis that will come back to talk about this is what is the x, this is the along this line, along this line, along a distance at the point of, point where we would measure this, point where we would try to understand the concentration this one is this distance the distance would be known as x. This is the x from the point here okay and this one is known as, this is what is the instantaneous, this is the plume envelope, this plume envelope under Gaussian plume dispersion model will, will have certain assumptions we'll talk about that in the next class okay right.

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Right, so we begin this you know again you know 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.

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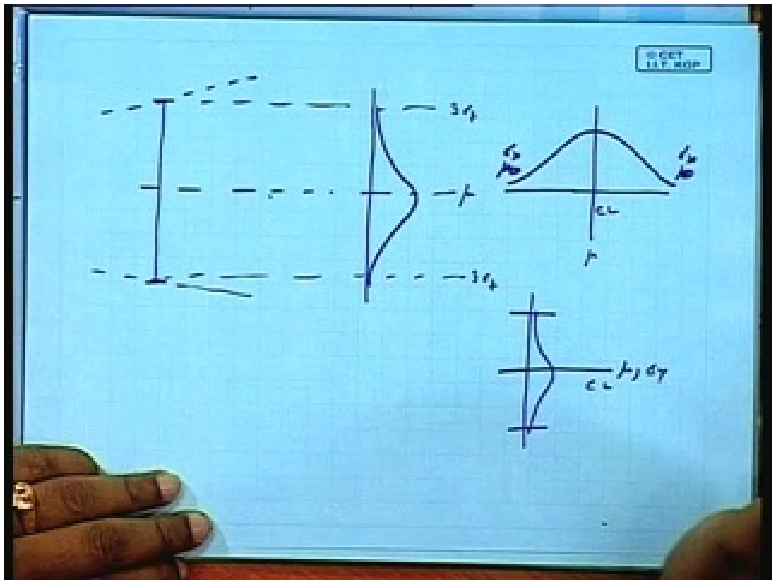

At any point you are taking a cross section of the plume, you see cross section of the plume along its line of travel. So, you know this is, this is travelling say the plume as we have, as we have already discussed about the plume taking a shape like this, plume taking a shape like this. Let me consider that you know we are taking an imaginary cross section inside this. So, what we observe here is what is under this Gaussian plume distribution is one thing that it says is that you know across this say here this particularly at this point if we just observe in this projection here, if you just make a projection, here it would be 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 just say 3 sigma, this is 3 sigma here. This 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 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 you 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 it observe is across xyz direction.

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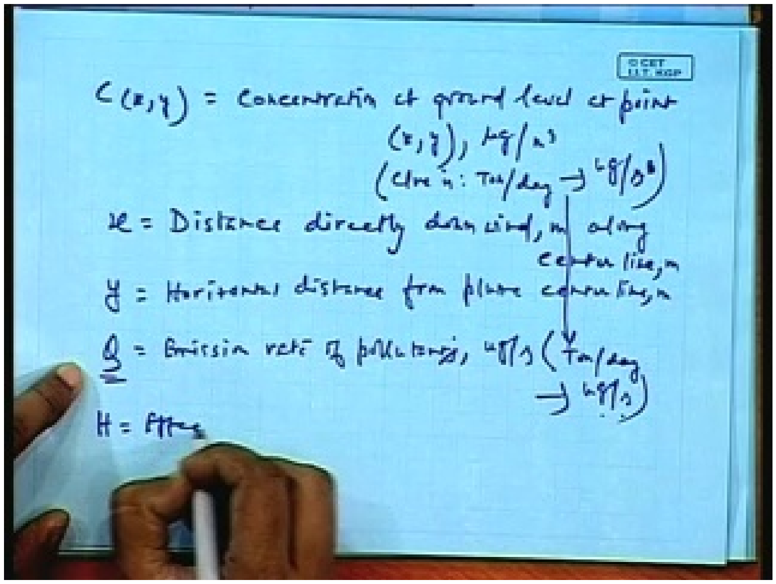

Say, the mostly the power plant the discharges would be in terms of tons per day a power plant usual power plant essentially emits to the tune of 20 to 50 tons of say tons of sulphur dioxide right a tons of particulates. So, you know in such cases we have to change it to microgram per meter cube remember this, don't ever confuse this x, x is equal to the distance, distance directly downwind, directly downwind, this is m distance directly downwind, 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 in 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 it is microgram per second. Say this is something I am, I am I made a mistake here second here you can see just make a correction tons per day can be only be converted into microgram per second is converted to 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 to 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.