Environmental Quality:
Monitoring and Analysis
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Lecture No. 37
Transport of Pollutants – Dispersion

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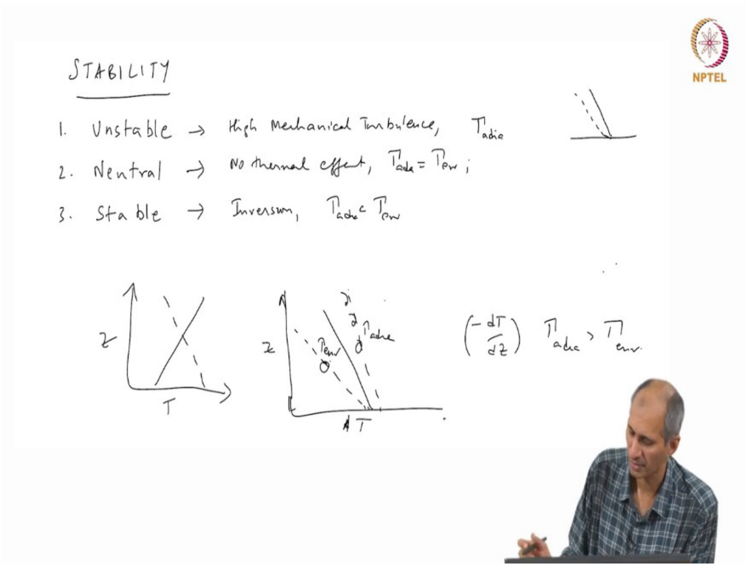
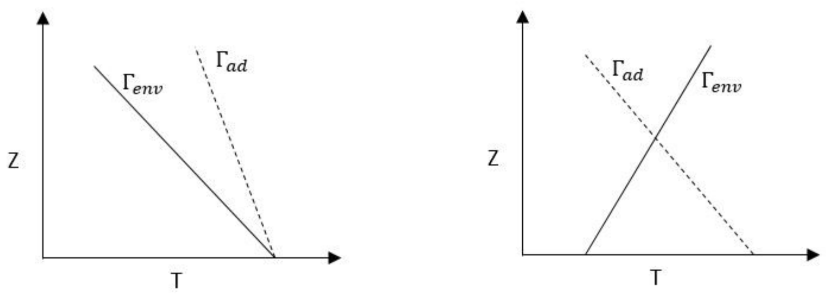
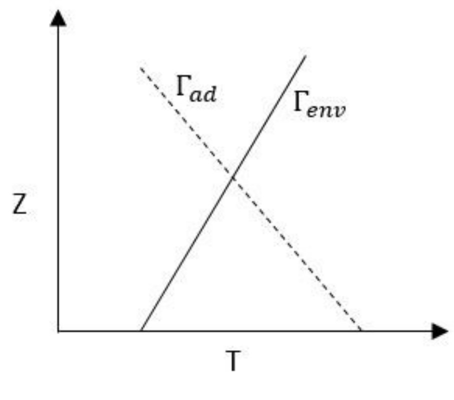


So, last class we were discussing the basics about transport of pollutants in air, the issues of stability. So, we looked at 3 different cases unstable, neutral and stable. So, unstable conditions, the essentially main conditions under which unstable atmosphere exist is we have high mechanical turbulence which means there is wind which is very high that is one. Turbulence essentially means wind is in all directions. The hallmark of turbulence is there is high velocity in the x direction, but in z and y direction also it is fairly high. Then the adiabatic lapse rate so, we see conditions like

the slope of delta. So, when we have unstable conditions, we see a scenario like shown in the figure.



So, if you plot the temperature as a function of height, there is a greater temperature decrease. So, it is essentially this T adiabatic is a greater than T environmental. So, in other case where we have neutral conditions here no thermal effect which means essentially T adiabatic is the same as environmental. So, it is purely dependent upon the mechanical turbulence that is there so just velocity. Stable conditions we have inversion. Here, T adiabatic is less than environmental which means that under stable conditions we have something like this.



So how does this affect pollutant transport? We started discussing this a little bit last class.

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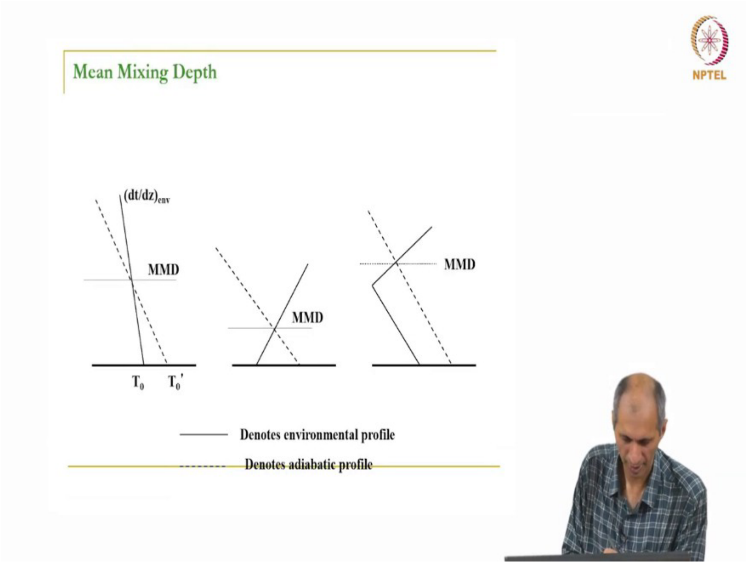

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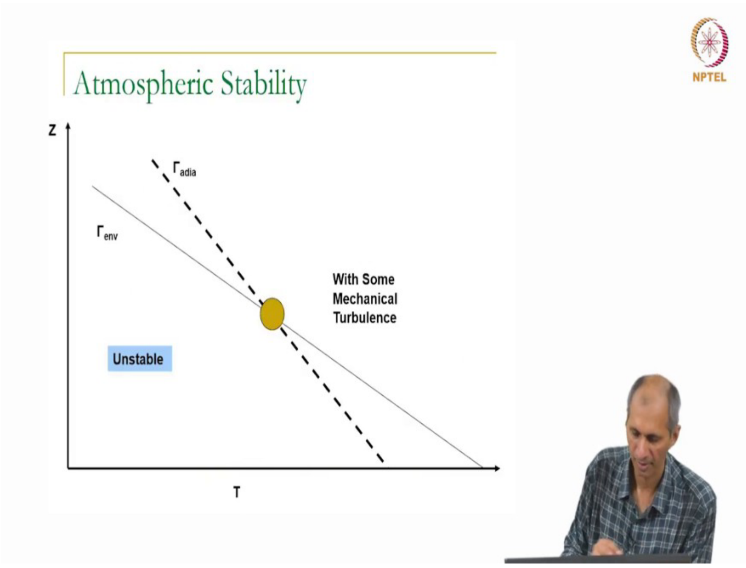

The unstable condition occurs in both directions, above the MMH (Mean Mixing Height) it is greater and below MMH it is smaller, so, it keeps going away from the MMH. Depending on where it is if you push it, it keeps going in that direction, depending on what the temperature profile at that point is. Now, the significance of this particular graph is essentially if you look at the relationship between adiabatic and environments it does not matter if it is lower or higher, if it gets pushed it will go to the other direction whichever direction is favorable. So, if it is on this one if it gets pushed it will keep going up, if it gets pushed it will keep going down ok. So with the relevance to environmental thing comes when there is a mixing height. So we will look at that in a series of images.

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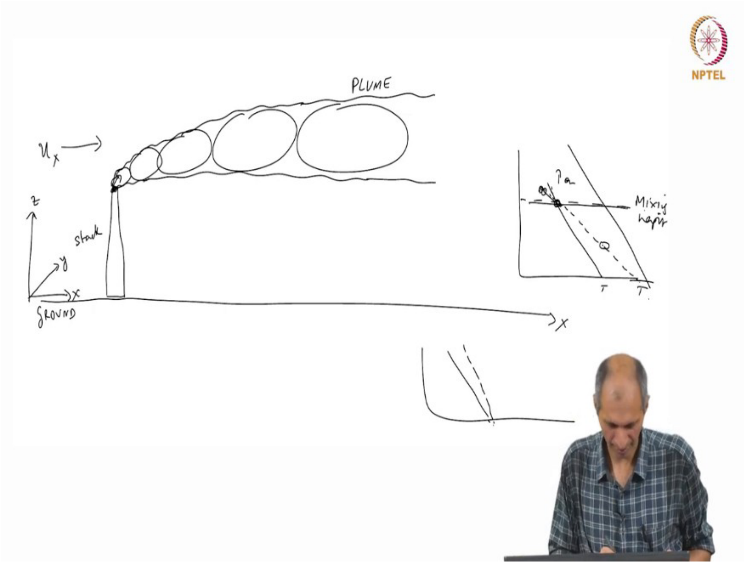
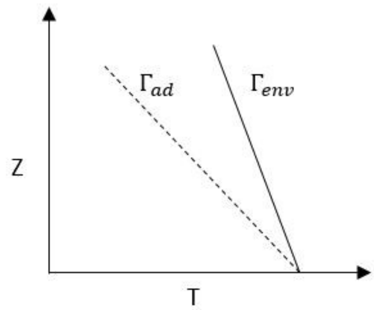


So in the last class we started talking about, this is a very classical stack that is given. So, this is ground level and the stack is releasing some pollutant in the general case we see is this kind of behavior. When we look at an ideal behavior of an exhaust emission coming out of any source something happens to it, it spreads over distance. So, if you call this as x and we define this axis as z and the transverse axis y to the long the ground.

So, the ground is x and y and the height above the ground is z. So the exhaust starts here (tip of the stack), it is coming as a pocket here and is expected to expand so, and it can go in any format and that we will see that in a minute. The boundary that sets a limit to the pollutant is called as a plume. So, the shape the plume takes depends on a few of the factors we have discussed whether there are stable conditions or unstable conditions.

And depending on where the mixing height and all that is, so, in terms of that, so, the relevance to mixing height is following. So, if you have the environmental lapse rate, and we have an adiabatic lapse rate like this so at some point here the intersects. So the air parcel is the adiabatic lapse rate is here the temperature of the pollutant source is here and this is the ground temperature of the environment, the parcel is moving in this direction, it will not go beyond this point.

That is the general idea. So, if it is on top here, we will keep going out if it is not bottom here, it will keep coming down, but it will not cross this line. So, this line here, if you look at that, this parcel as it goes up, it becomes heavier. So, it will come back here it cannot cross this so, that is the definition on this mixing height. And we saw because this environmental lapse rate keeps changing throughout the day this temperature keeps changing so, this line will change throughout the day and that because of that, the mixing height also will change. So, there may be a case where you may have the environmental lapse rate that looks like this,



most of the time it is the other way around, if it is here, then we have a big problem. So, this can occur sometimes in some cases where there is no buoyancy at all it will stay there. So, then thermal effect is not really felt in this case, but normally when you look at pollutants like exhaust it's higher temperatures than ambient, most of the times. So, it is very likely that a lot of times you will see this kind of behavior. You can see that sometimes they will diverge, which means that the mixing height is almost infinite there is no ceiling, it keeps going up, it can go as much as it wants the only limiting factor is the velocity, the wind. The wind will take it, if scale of turbulence is high it will keep going up as high as possible. So, keeping this in mind, there are a few cases of plume behavior that people have classified and we will just go over that a little bit. So, there are different scenarios, where we have the definition of mixing height, how it can occur and all that.

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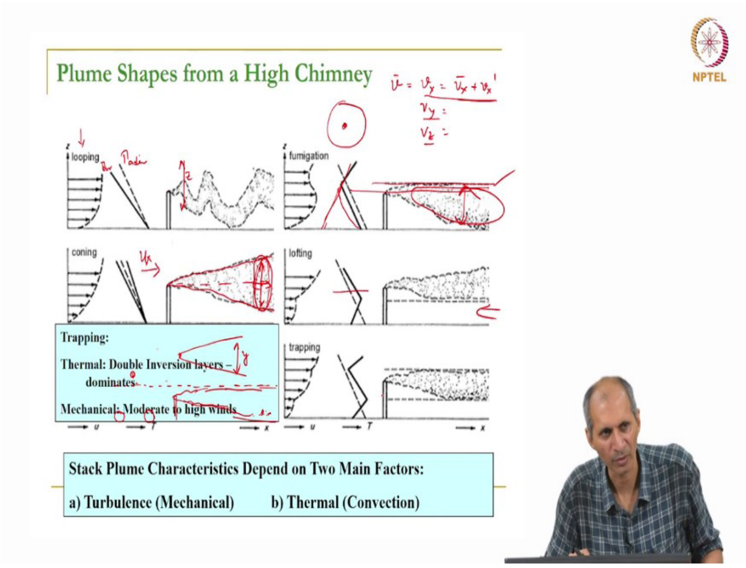

So we have different types of plume shapes that it can take. We will go over each one of them. The first one is called as Looping, it is a super adiabatic lapse rate, which means that environmental lapse rate is greater than adiabatic. Because this one does not change adiabatic lapse rate stays where it is the other thing changes.

So, you can see that this is the environmental lapse rate and this is the adiabatic lapse rate ok. Now, here you can see that the wind speed is quite high, in this left hand this part of it indicates the wind speed so it is very high, high winds large Eddies what you can see is as soon as it gets out, because of the super adiabatic lapse rate, which means very unstable conditions, it is going to exaggerate wherever this thing is going, it is going to move up and down accordingly.

So, it pushes it up, it goes down, it goes up goes down goes up, the Z variation of the plume is very high because of this particular this thing. In the next, this one is called as Coning. This is neutral, which means there are thermal forces don't play a big part in this. The environmental lapse rate is almost the same as the adiabatic lapse rate approximately.

So, there is not a big exaggeration of the vertical of the movement caused by wind. So, the turbulence of the wind results in large Eddies. When you have turbulence the velocity fluctuates in all directions, there is v_x component and there is v_y component and v_z component, we have a mean v plus fluctuation in all 3 directions. The velocity is not just one single average single number it is a fluctuation of these two things in all 3 directions.

This is the direction of the wind, but there is also a fluctuation in the other two directions. And the extent of this determines what is the amount of mixing that happens and this in general terms called as dispersion in chemical engineering literature. This is all back mixing, presence of any Eddies results in them back mixing and that is termed as dispersion. This not to be confused with another term called diffusion.

Diffusion is a different phenomenon, dispersion is mainly because of the eddies, the circulation patterns that are formed. So, the amount of spreading as a result of this eddies is occurring because of the velocity. In addition to that we have thermal forces that may exaggerate it or suppress it both of these things can happen. Ok. So there is dispersion in the x direction, there is dispersion in the y direction and the z direction, all these 3 are there.

So in coning, we don't have this thermal so there is no thermal effect on it. So it is just a dispersion. This coning will give you what is the effect of only velocity ok. So this will give you this very classical plume shape, it is increasing nicely in the direction of wind, the wind is in this direction in x direction, and it is going in that direction, and it is spreading. So this spreading is not just in z, as shown in this picture but it is also in the y direction. So normally, we will come to the shape of the plume. The plume itself is a 3 dimensional, it is like so in the cone. The reason it is called coning is if you look at it from along the x axis inwards you will see that it looks like a cone, it takes the shape of a cone and so in the center of the cone is your source it looks like this.

I don't know if you can imagine the shape of this, so in the center of the cone is your source. So, which means there is a certain amount of y dispersion there is some certain amount of z dispersion also. Here you can see again that there is no mixing height, it does not come into play here because there is no ceiling they did not intersect at all, so again, there is no limit to this.

The third condition is called Fanning and now you see here that the adiabatic lapse rate and environmental lapse rate intersect but they intersect right below the source just below the source. These are all different scenarios and you can create any number of scenarios depending on where the source is and what is the lapse rate. These are just examples of some possibilities common scenarios. So you can see that this is the mixing height. So the pollutant source is right about this mixing height ok.

So if a pollutant is released, it is following this line. And you see that in this particular instance, the temperature of the plume is less than that of the environment. So it tends to sink back to its source point, or it sinks back to the mixing height. So it stays very close to the mixing height, and it goes in this direction. The reason it is called fanning is the z dispersion is now suppressed because the thermal adiabatic lapse rate and environmental lapse rate such that it does not allow the parcel to go up, but it can still disperse in the y direction.

So fanning is if you look at it from the top in the top, it looks like this this is a source. It is still fanning out this is this is y direction is fanning, but the z direction dispersion is very very small. So in this zone, the concentration is likely to be very high, but it does not spread a lot. It does not spread in the z direction, it does not spread in down below also, it is there. Sometimes you can see this very clearly on certain days, in this case, you can see that when this kind of scenario occurs.

You can see if you look at chimneys sometime, you will see a very straight plume like this. It is very rare to see it but sometimes you can see it if you are going in factories in certain seasons, probably. So this kind of behavior occurs when the source is very high temperature. And it is at a higher height and then see this behavior occurs only during inversion, so early mornings, so you can see that sometimes very early mornings.

But it is not really bad because from a point of view of exposure, if it is going to stay like this, your receptors are somewhere here on the ground. So it will not come down it will stay there, this will be a problem if the source is below the mean mixing height. If source is inside below the mixing height, then it will go up go up, then it has nowhere else to go and mechanical turbulence will spread like this. This particular case where we have called as Fumigation, where it is exactly the opposite.

There is inversion there. So it doesn't matter whether this is like this or it is like this. That is the same thing. What happens here is the ceiling is right above the source. So whatever is released will now get contained in the zone because it has to spread even if the thermal spreading is not there mechanically it will spread and this is called fumigation, this is the most dangerous of all the cases where this is the volume, say our goal is to maximize the volume in which the pollutant is contained and this is limiting the volume which means that concentration will be high which means effect will be higher.

And this occurs during inversion, in all kinds of inversion this is there this is true this is not just this particular case, it is also this kind of behavior also will then there is this cake scenario where it is called as lofting. It is similar to fanning but the mixing height is below the source which means that it will not come below that but on above the source it is like neutral or unstable environment so it can spread nicely there.

So, this is a good scenario because it is not coming anywhere near the ground when it is spreading upwards. So, even at some point if it comes down it's concentration is already reduced quite a bit and the last one is called as Trapping in which there are two inversions, double inversions and therefore, there are two layers and if the source's in between that it will get trapped there so, you can derive a large number of scenarios where this can happen.

The environmental lapse rate keeps changing, usually this double layered inversion doesn't happen that often, under very special circumstances of weather it happens, but normally this regular interaction happens on a daily basis in very cold places. But this double inversion is little rare. So, it gives you some idea about how to predict what will be the general behavior of the plume given a set of conditions. Ok.

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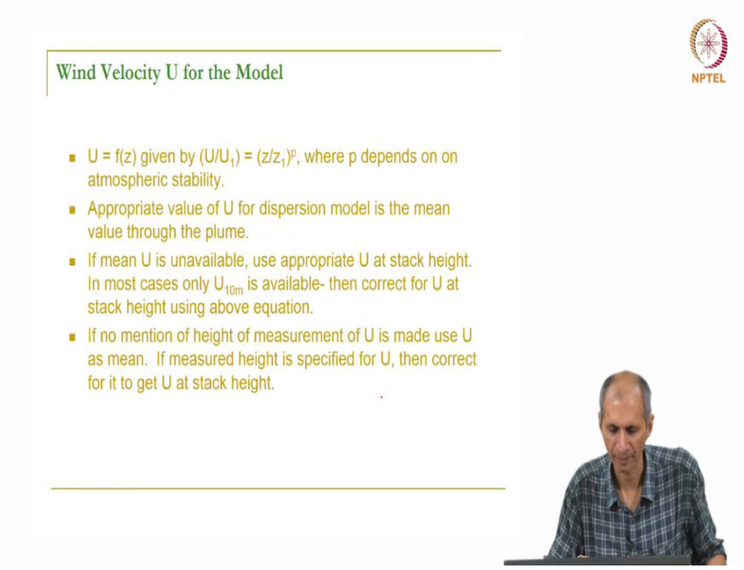

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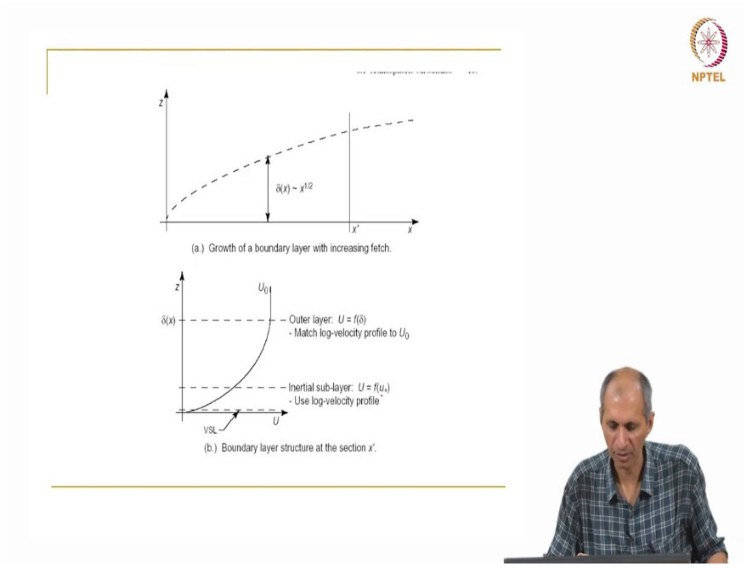

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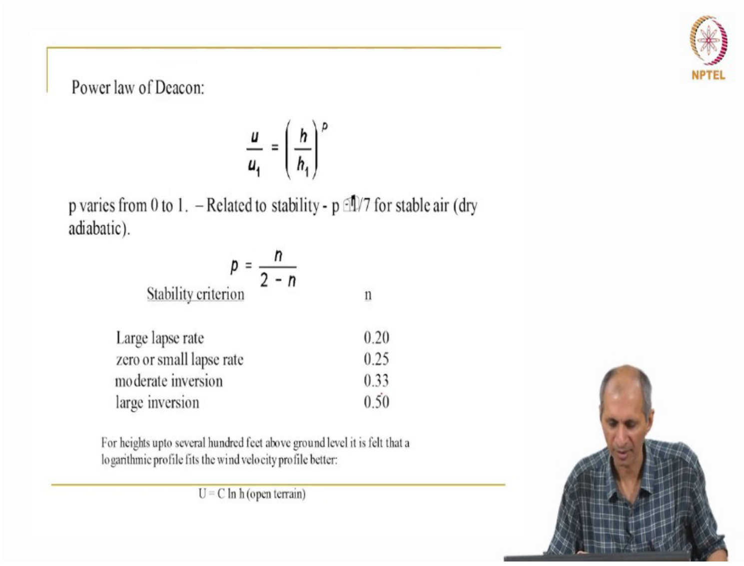

So, now, I will go back to your this thing.

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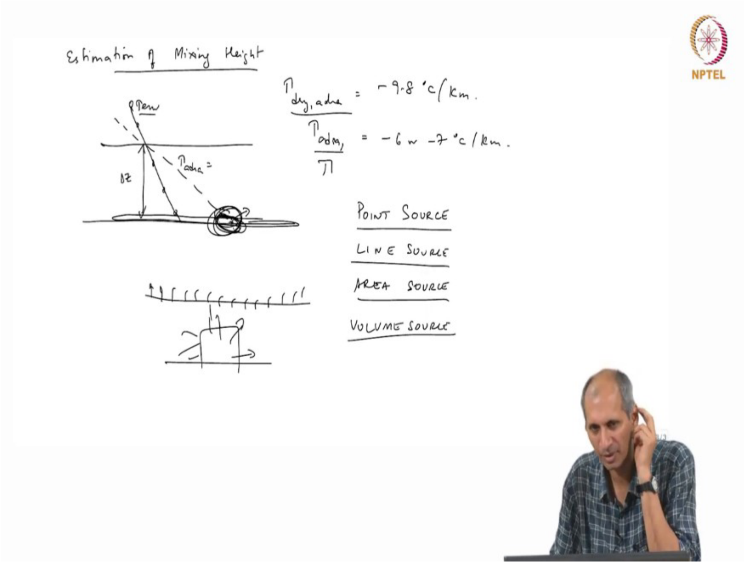

So, sometimes you have to calculate the mixing height. The estimation of mixing height is simply this you have to take the environmental lapse rate at that point and the adiabatic lapse rate. Let us say that you have some scenario like this. So, which means I need environmental lapse rate the temperature profile is measured on a daily basis usually.

People measure this by sending out balloons and all that so there is the balloon that will go up it will measure temperatures profiles every day. Meteorological department does that and a few other labs around the world do it. So, there is a report of temperature profiles and velocity profiles everything like that is measured. And so, there is seasonal record of it in a given location. So, people have this kind of information, dry adiabatic lapse rate of course is a fixed thing and it is - 9.8 degrees centigrade per kilometer, this is a theoretical number, but the adiabatic lapse rate that you normally find in the environment changes from place to place. Sometimes it is the air mass is wet, it is not dry, which means that there are other processes that may happen so the actual adiabatic lapse rate will not be - 9.8 it will be less than that it could be around 6 or 7.

This has to be measured or you can model it if you know enough about the system. It is still assumed to be adiabatic sometimes this you can even get rid of the adiabatic you can simply say that the lapse rate itself, this is lapse rate of any pollutant mass. If there are ways to measure it, you can actually get the lapse rate there. So, you have to understand one thing that because there is a lot of fluctuation, lot of error in this kind of estimations it is very difficult to estimate this accurately.

So you get a fair idea that you know where it is going and that I think is reasonable because like, you are now getting into weather prediction because you are predicting meteorology, environmental lapse rate prediction is meteorology and prediction of adiabatic lapse rate also is meteorology in some sense, because it is influenced by whatever is going on around it is linked to what is there in the environment to some extent. So, we have to start somewhere so this is an ideal way to do it is the dry adiabatic lapse rate but we aware that you may not have - 9.8 degrees centigrade per kilometer all the time it will be something else. But it will give you a fair idea of whether what will happen to a pollutant what is likely to happen to pollutant and what are the general scenarios and then you can build upon that scenario by making more accurate assumptions. So, usually we just calculate the height at which these two intersect that is the mixing height. Ok. So, you can do it graphically or by finding the intersection of these 2 equations.

I do not think I need to give you an exercise we will have a small exercise problem later in the tutorial just to calculate this. So, typically what we do is the environmental lapse rate is based on measurements there are, people measure at different heights. The adiabatic lapse rate is based on the surface temperature the temperature at which the source is originating. So, if it is and this is a bit tricky because there this it is ok if you have this the sources is from a single particular location, this is where I think we need to define something about the sources.

This particular source, if you can pinpoint what the sources ok, is coming from one particular facility or a factory or a process, we call it as a point source. So, for example, if you have a big factory and there is 1 stack, 1 chimney that is releasing all the pollutants from that factory so you know that is a re specific source it is a point source. But if you look at some other kind of sources look at a road for example, the road, it is a long road lot of vehicles are moving around. Ok. So if you look at it from the point of view of a map, you are looking at a map road is a line and there is emission coming at each point in the road, every point in the road and the amount of emission depends on the number of vehicles that are moving and the emissions coming from each of these vehicles and whatever that is so there is an overall emission rate that is coming from this entire line source ok. So, these kinds of source is classified as a line source.

And then we have area sources, which means that an entire city can be an area source, or you have a very large cluster of industries, there all releasing next to each other ok . So, this is an area source. You also have something called as a volume source but it is very rare volume source means you have a large volume from which emission is coming out. Typically, things like a land fill or some such thing, you can consider landfill as area source or a volume source depending on how you are looking at it.

But volume source is significant if there is a significant amount of y, z direction also volume sources something like this, if you have a big chunk like this and emission is occurring all through all over all 3 dimensions in the x, y and the z then you may have to consider it as a volume source. For example, if there is a big mountain and then there is a lot of things going on, there is a forest fire or some such thing. So, it is just big mountain, at the volume source.

Usually volume sources are rare but for completion people have added this. So, point sources are something very specific. You can it is there, it is coming from there and it is not anywhere else does not move in place and all that. So, if you have a point source, you know exactly what the temperature is and where it is and all that what the height is, but if you have an area a line source for a road for example, you do not know the you know the exact emission temperature, but this emission is mixing with all the other emissions and then going up it's a combined emission so, people generally cannot take the temperature of that exhaust there. So because it is mixing as a group, it is going out and this is not very well understood, but people have measured temperatures at the surface of road ok, this is not the temperature of the environment ya. Temperature of the environment is there are no vehicles and you measure the profile where you will get one reading.

But as soon as vehicles start moving, the road temperature will change surface temperature 1 meter above the ground where emissions are all mixing temperature is slightly higher than the if you go and measure the environment temperature at say, for example, if I measure temperature on Sardar Patel road, the main road outside our campus and then I come inside and measure it in a ground where there are no vehicles, it is going to be different profile is going to be different.

There will be a slight increase in temperature at the surface because but that is not to be considered environment temperature that to be considered as the starting point of the adiabatic line ok. So this is a very difficult thing especially for area sources to fix what number but that should be based on measurement. But for points also very straightforward. You can go put thermometer there are a thermocouple there and measure what is it the temperature of the source.