Environmental Air Pollution

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Lecture – 26

Stability, Mixing Height and Plume Behavior - 2

Shall we start or are some of the students still expected? Anyway, what we will do is…. All right. We will still talk about the physics of the atmosphere and still talk in a qualitative sense as to what could happen to the dispersion of the pollutants in the vertical plane or in the vertical direction. Last time, we did say that depending on the stability of the atmosphere, the dispersion may be very good, dispersion may be neutral, dispersion can be very poor or there may not be any dispersion at all. We encounter those situations on a cycle of 24 hours and we also said that in the nighttime, the dispersion is very poor. We also said that as the earth gets heated up, the inversion is broken and the condition changes from stable to unstable in the daytime and gets back to the stable condition.

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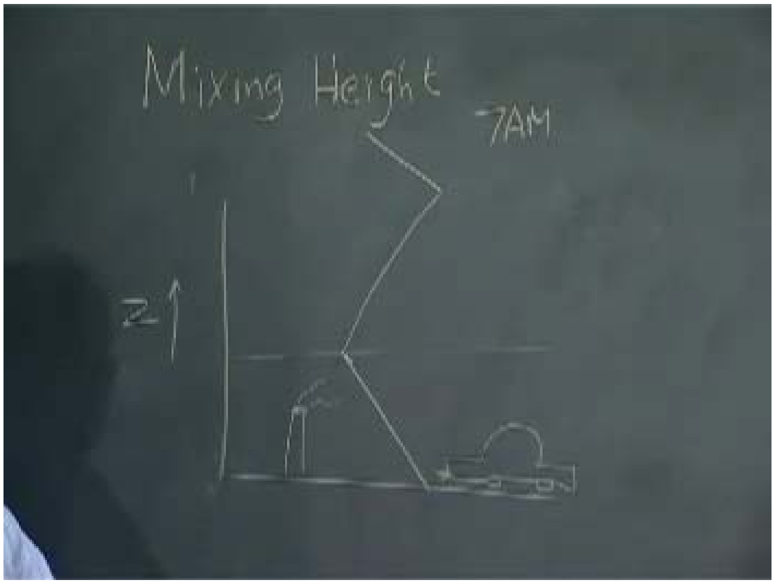

With that context, I want to define another term called – very important in air pollution, dispersion – the mixing height. The physical meaning or the meaning of mixing height is that it is a vertical distance up to which the pollutants will be completely mixed. It is like a mixing layer or sometimes, it is also called as boundary layer. We draw our favorite figure and this is Z here, this is T. Let us say we are talking about the situation 7 o'clock in the morning, 7 AM, let us write 7 AM. The source of pollutant is somewhere here – a chimney or even some kind of ground-level source like cars.

Now, with this knowledge, with this picture, what can you say about how high the pollutants will go? Will they go up to here, will they go up to here, will they go up to here or will they be here? Up to what height can they disperse? Up to what height is the turbulence there? [03:45] morning 7 o'clock, this is the inversion that has broken and yesterday, we got this picture. Up to what height do you think the pollutants coming out from the chimney can mix?

[Conversation between student and professor (03:57 min)]

First point here, excellent. There is no chance – there is a lid. We know that even if the pollutants go here, there will be no dispersion – pollutants will not even go there because no dispersion can take place beyond this point.

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If I draw the same picture.… What I will do is for convenience, I just draw the picture little.… Let us say 11 AM but then I will redraw this picture with some temperature like this, because inversion is broken. Now, let us say this is 11 AM. Obviously, now, you will say the pollutants can disperse up to this height. You see that the mixing height keeps on changing – depending on the hour of the day, the mixing height will change. You also see that when you want to model things and when you want to find out the ground-level concentration, you have to see to what extent they will go. Therefore, in the nighttime, the concentrations could be higher and in the daytime, there is larger volume for mixing and so daytime concentrations are likely to be low.

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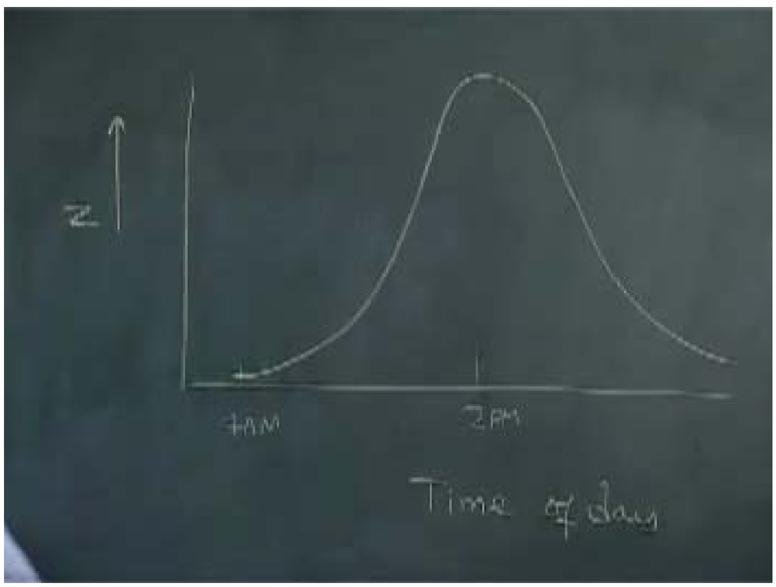

Based on this 7 o'clock, 11 o'clock, I generalize the mixing height of the different hours of the day. Again, we are calling this as Z and here, this time, for a change, this is not temperature but time of the day. You say early in the morning at 4 o'clock, there may be very low mixing height. You go on and by the time you are here at 2 o'clock, this is the kind of pattern you get for the mixing height. The mixing height keeps on increasing as we have seen from 7 AM to 11 AM to 2 PM.

This information is very important because when you want to find out the concentration, you will say the concentration will be in this layer in the morning, as you go up, the layer will be like this, then in this layer, in this layer and by the time it is 2 o'clock in the afternoon, the mixing height is very high and everything vertically mixes up. Then again, things start getting compressed (Refer Slide Time: 06:49) and you again see that the mixing height is low.

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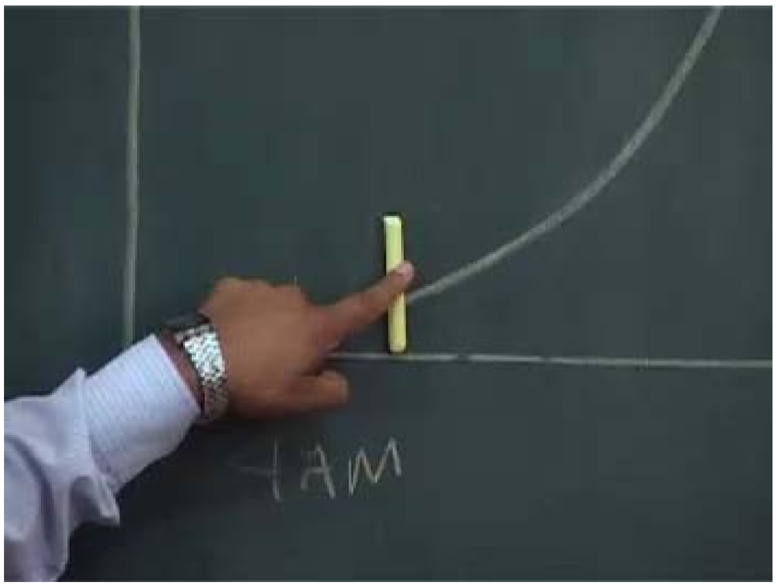

Let me ask you a question. Suppose this mixing height is low here – if I have a tall chimney that is at this height, what will happen to the pollutants? Will they come down to the ground or will they continue to go up? What happens?

[Conversation between student and professor (07:14)]

Down to the ground, one answer is they will go up. Do you want to change your mind?

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Suppose my chimney is here, it means I am going beyond my mixing height (Refer Slide Time: 07:31), it means my chimney is here now. What will happen to the plume? Will it come down? It will not come down because there is a kind of a layer – it will not disperse but it cannot come down here, because this will go beyond this. All day, it will simply be traveling within these two layers at the most but this will not come down.

The idea of a large or tall chimney is that under the difficult time when the volume of the air or the height of the air is very small for the dispersion, at least put a chimney that is taller than this particular region so that people are not affected at the ground level. By the time the chimney is like this chimney at the daytime, there is enough mixing height and the pollutants get mixed. Therefore, the chimney height is provided at 275 meters because normally, the lowest mixing height that we get is of the order of 150, 175, 200 or 500. Let us make a chimney that will cross this thing and the ground-level pollution is not so severe, but then, you remember all the ground-level sources like cars and domestic cooking will all be causing serious problems. Now, you have some idea of the mixing height.

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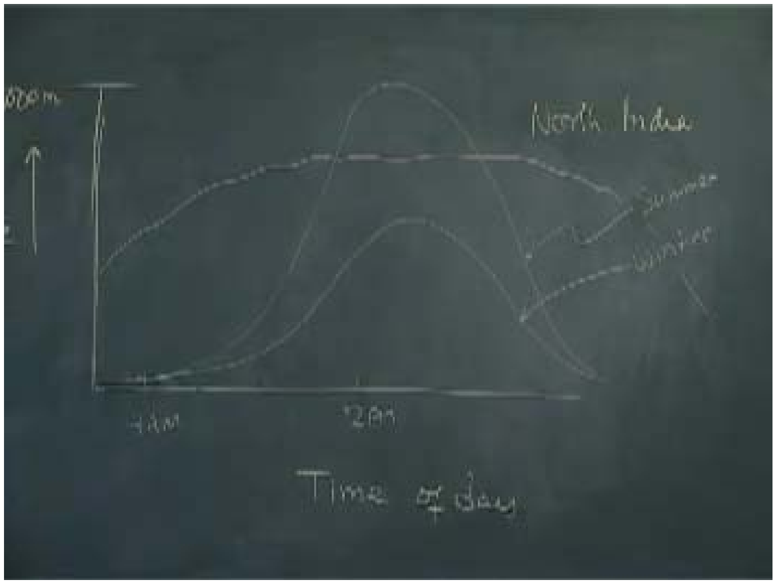

You get this kind of typical picture, but I will tell you the little experience that we had here is that when you do in the wintertime…. This height can typically go up to let us say 3000 meters. Typically, even during rainy conditions or cloudy conditions, you see the cloud at a particular height and flat kind of thing and when you go beyond those clouds, the sky is again clean. So that is up to what is the mixing height. What do you expect – will the mixing height be more in wintertime or in summertime? Summertime. In the summertime, the mixing height will be more.

You get a sharp kind of thing. In summer, it is like this and in winter, it might just be like this. This may be typical summer and this can be typical winter. Then, let me also ask you – will this kind of pattern that you see be similar in north India vis-à-vis in south India? No sir. It will not be, right? In north India, you will get the sharp because there is a lot of difference in the daytime temperature and the nighttime temperature but in south India, the daytime and nighttime temperatures are similar.

Typically, in north India, you get this kind of pattern or in the coastal area. Let me draw another picture in another color, if I can. This is typically what you get in south India (Refer Slide Time: 11:10). Typically, you get this and there is not much of variation between winter and summer in south India, because there is hardly any winter or summer difference. So you see how important the mixing height is to a specific location – the location you are talking about. Based on this knowledge, I also want to define a situation for a chimney that will be the worst situation.

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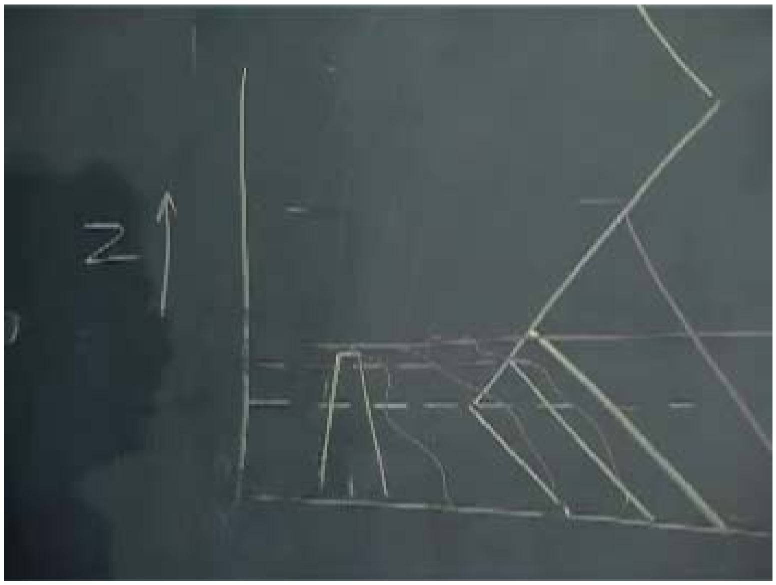

Suppose my chimney height is fixed, chimney height is fixed anywhere and you have a situation…. Any problem with the chimney? Not much of a problem, because things will continue to go up. After some time, the picture will be let us say…. After some time, the picture will be like this and so, the mixing height is here. After some time, the mixing height will rise as you have seen – with time, it rises. So after some time, the mixing height will be like this. There will be a time when your mixing height will be exactly equal to the chimney height. What happens under this situation?

Earlier, you did not face any problem because it was going outside your lid as if it was penetrating the ceiling and going out. But now, there is a ceiling and everything is within the ceiling. Then, things will mix within this particular zone because this is the mixing height. What happens under this situation? All the pollutants immediately disperse in this region. So as soon as the mixing height is just at the top of the chimney, you see the pollutants just disperse and that typically happens in the morning around 9 o'clock or so.

It happens for a short while because after a little while, the mixing height is going to go up and then, you have a larger height to further dispersion.

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I can redraw the whole clean picture now for you. The pollutants simply disperse within this zone because they cannot go up – they are trapped within this zone and this is what is the situation. All the pollutants are a little distance away from the source and we call this situation as fumigation. This happens – it happens for a short time, but it happens and the pollution level will suddenly go up very close to the source. We are still staying with qualitative sense. Plume behavior.

[Conversation between student and professor (15:09)]

Conditions are calm above this and conditions are unstable below this – you can see here. We have defined the rate and this may be something like this – this may be your dry adiabatic lapse rate. Normally, what we have said is that if turbulence is there, it is a very good situation but just look at this particular point of time – up is stable, so it cannot disperse up and so it is bound to disperse underneath. Once it is bound to disperse underneath, then this is the area where it can disperse (Refer Slide Time: 15:56) and so you get a fumigation. This is because of the turbulence and in fact, the pollution level is high at the ground level because we are all the time thinking about the ground level, because people live at the ground level. In fact, there is no problem here. If I can put something beyond this, there was no problem but because this thing is unstable, you see that there is a turbulence and this thing; nothing will happen anyway, it will not even go up.

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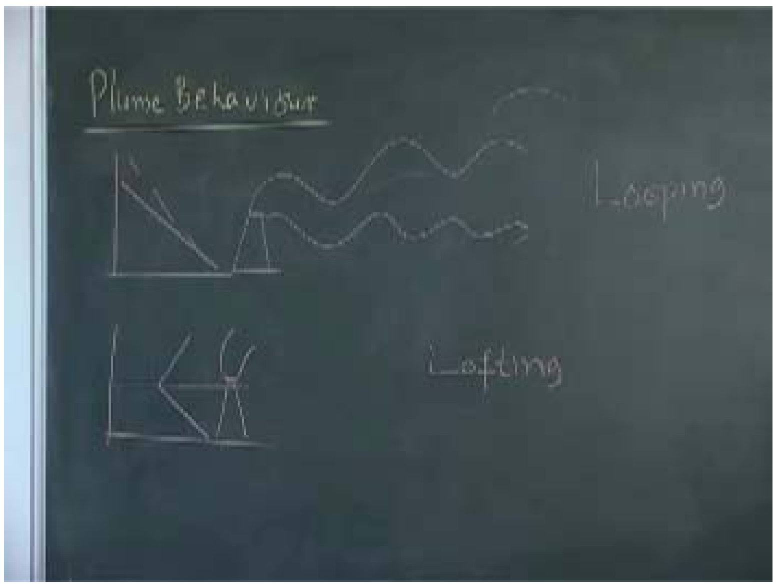

We well do it very quickly now. Suppose the situation is like this and the chimney height is somewhere here. Let us draw a better picture. The conditions are unstable, so there will be lot of diffusion – unstable conditions. This is what we call as looping. The situation can be like this – what we have just now talked about. My chimney is here, the chimney is beyond this actually. What do you expect? It will not go up. Very nice. So this is what it will be and it will not come down or let us put it this way – it goes like this and this is what we call as lofting. If you notice, if you spend some time watching chimneys, sometimes you can see this situation – lofting. This situation we have talked about, fumigation – that is situation number three. So under the same heading plume behavior, you can also see fumigation, which we talked about separately.

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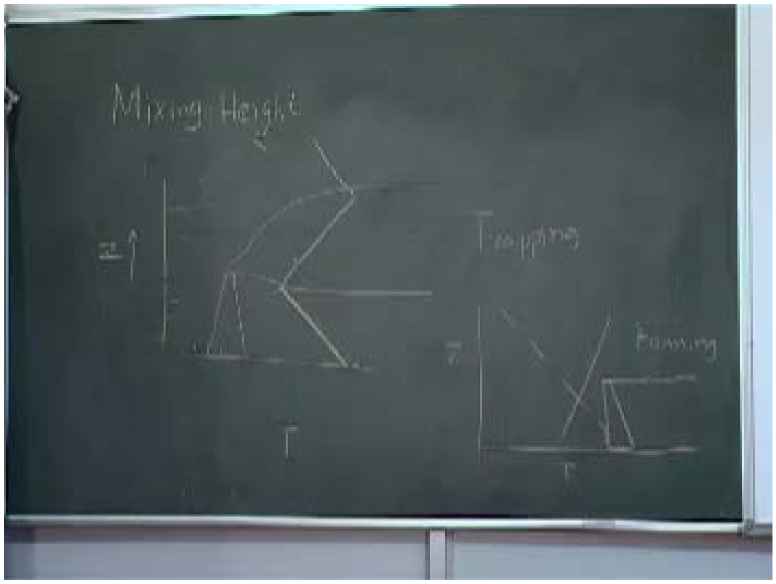

Let us talk about another situation where my chimney is…. What do you expect? My plume will be… cannot go this side, cannot go this side, it will just be trapped between these as you have seen this one. This is what you call as trapping. What else? One more situation. Even if I am not writing, you all know that I am referring to Z and T, Z and T. We have situation where this is your adiabatic lapse rate and the situation is like this. My chimney is here. What will happen? Thin layer because everywhere, there is no chance of dispersion. This is what we call as fanning; this situation called fanning.

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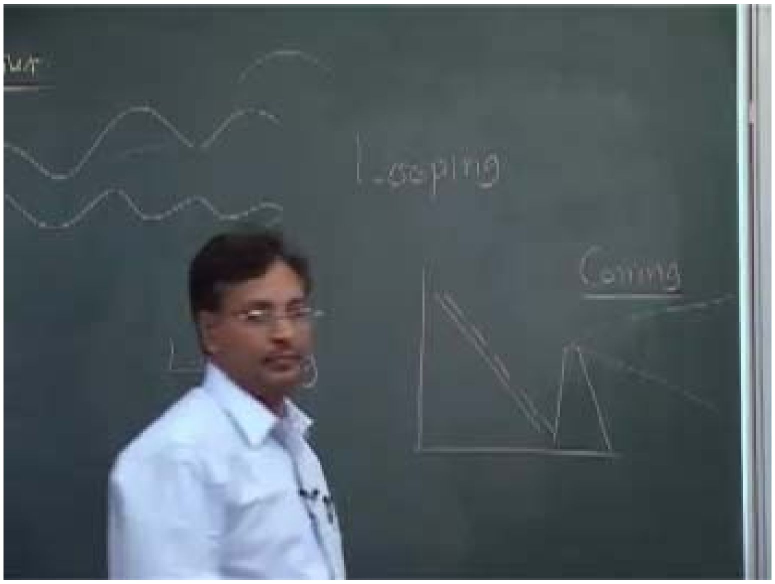

The last is.… What do you expect here?

[Conversation between student and professor (20:25 min)]

Stable was this – you know the stable condition, this condition is neutral – neutral means in a conical way, on its own, because of the concentration gradient, it will keep on slowly going up and so it will just go like this and it forms like a cone – so we call this as coning. We call this as coning because it forms like a cone.

[Conversation between student and professor (21:07 min)]

The thing is it should go up, but once the.… What you are saying, that we call as the thermal buoyancy and I have not shown that thermal buoyancy here. Initially, some rise is there and after that, the temperature is more or less the same. I should have really drawn it with a little bit of thermal buoyancy and then dispersion. That initial buoyancy is always there because of the temperature difference, but after that, you see the temperature more or less stabilizes with the atmospheric temperature.

Now, you can also see.… With your knowledge, you can say what situation will be there under what time of the day or at what time of the day. In fact, this is one of the assignments we used to give earlier – go and watch the chimney and write down what is happening and what is the time of the day. Let me also ask you with the knowledge what we have.… This condition we have said it is normally later in the evening or early in the morning – around 7 AM and 7 PM or 9 AM or 7 PM (Refer Slide Time: 22:27).

Suppose the conditions are very heavily overcast, the conditions are heavily overcast, you have a very thick layer of cloud, what kind of conditions do you expect? The heat is neither going in nor going out. So under very heavily overcast conditions, you would expect conditions to be like this (Refer Slide Time: 22:48). Sometimes, the problem is just defined thus: under heavily overcast conditions, what will be the dispersion like? That is a little thing you should understand with your knowledge of atmospheric physics or the temperature or temperature gradient and all the focus that we have made in here is based on the vertical temperature gradient and vertical movement of the pollutants.

In the process, what we have done is we have been, all the time and in some sense, talking about stability, is it not? We are broadly using the terms stable, unstable and neutral. What essentially stability is indicating is the turbulence of the atmosphere, is it not? That is the turbulence of the atmosphere. In order for us to get finer details of this, this stability is further classified. From the broad term, you want to come to the micro level.

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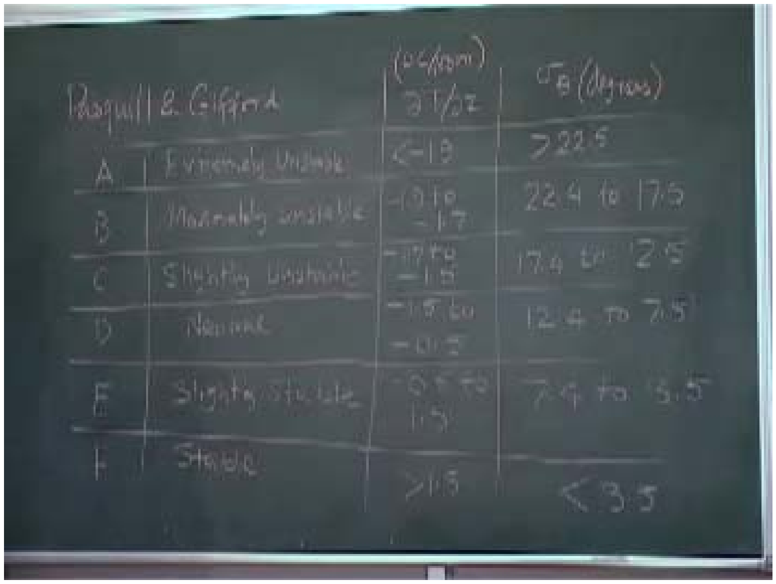

There were two people who said that the stability must have finer fractions rather than stable, unstable, neutral and so, they defined the stability in six classes and they gave the name A, B, C, D, E and F – that is the nomenclature they gave. This they called as highly unstable or very unstable, let us check that. I have the terminology as extremely unstable, so we will write extremely unstable. This is moderately unstable, slightly unstable, neutral, slightly stable and stable.

Then, they defined the things on the way, del T by del Z. I will take the help of a document that we prepared sometime back for the Central Pollution Control Board. You do not have to remember the numbers, but I will write them. That is the classification they gave based on the temperature gradient. Let us simply not call them under these conditions as stable, unstable and neutral, but let us specify them depending on the temperature gradient the atmosphere is having. Obviously, —1 degree per…. We have made some mistake. Can you figure out what is the mistake?

What is the condition that came up for neutral? Reduction temperature of 1 degree Celsius…? Per 100 meters. Per 100 meters. You see I have forgotten the per 100 meters there – we must specify that as per 100 meters. I must specify the units here – that is very important; otherwise, I am not correct; we should specify the units. Why are we introducing this? Eventually, we are going to use what Pasquill and Gifford did and they did it sometime in 1928. We still use the Pasquill and Gifford stability classes to do all our calculations – that will follow in the coming lectures. Now the problem was that this was fine but it is still not easy to do the measurement of the temperature at various heights and to do it consistently, because it costs lot of money and lot of instrumentation.

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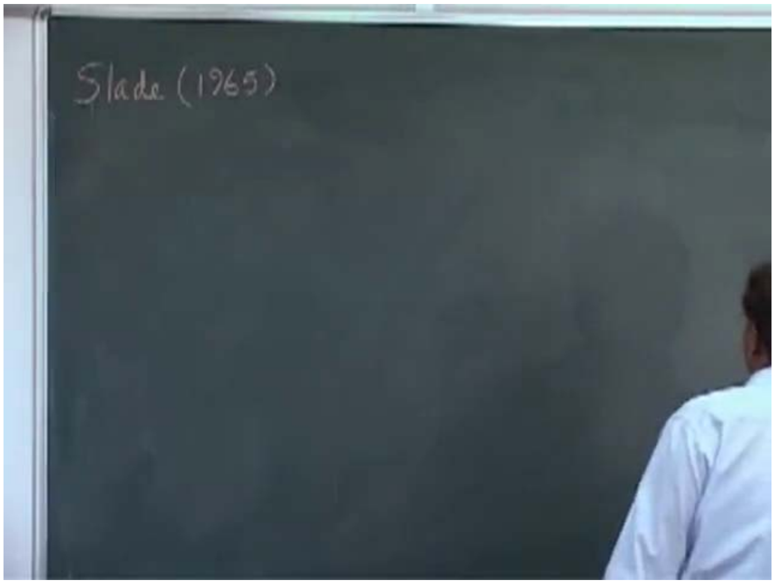

There was a person called Slade. In 1965, he said that you do not really have to measure the temperature. We will talk about somebody else also in a moment. He said you do not even really have to measure temperature. You are measuring the wind speed and wind direction and you see the fluctuations in the wind direction, which are the indicators of turbulence. He said that we can do the measurement of the wind speed and wind direction (which we normally do and is very easy to do) and based on the fluctuations in the wind direction.… If there is no turbulence, the wind vane will be like this and when there is lots of turbulence, it just moves….

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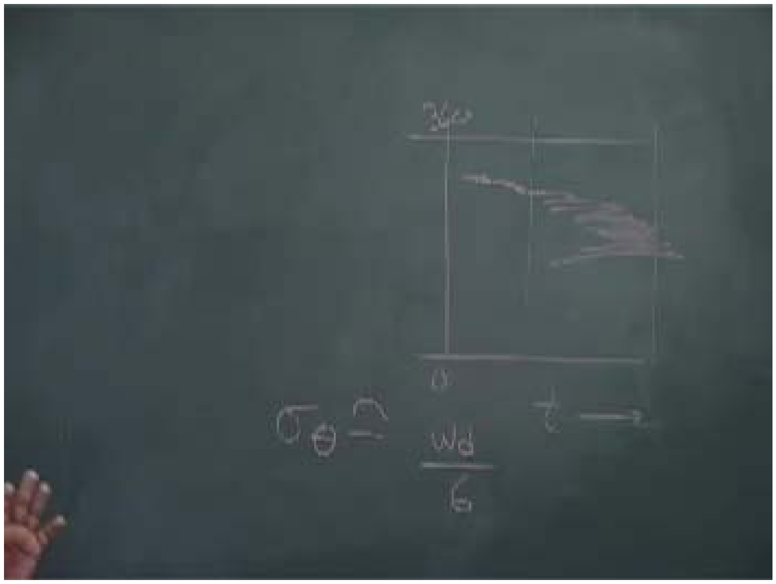

Let us draw it here. If you look at the chart that we have discussed sometime back about the wind direction 0 to 360 degrees, this side is your time and you see here that this is in a way showing you the stable conditions. After some time, this obviously is the unstable condition. He concurrently did this measurement along with the measurement of the temperature with a lot of statistics as we do. He said that you have to really measure the hourly $sigma_{theta}$.

What is $sigma_{theta}$? The standard deviation of the wind direction. We all know how to find out the standard deviation of the data, is it not? You find out the simple normal standard deviation. What is theta? Theta is your wind direction. You find out the $sigma_{theta}$ because you do the measurements. Suppose this was 1 hour, your computer will record every minute what the wind direction was. With that wind direction, you can also find out what is the standard deviation of the wind direction. He said if you have the $sigma_{theta}$, then you can correlate that to the Pasquill and Gifford stability classes. I will also give you the number with respect to $sigma_{theta}$ – again, you do not have to remember the numbers nor do I remember these numbers but let us write them for your information.

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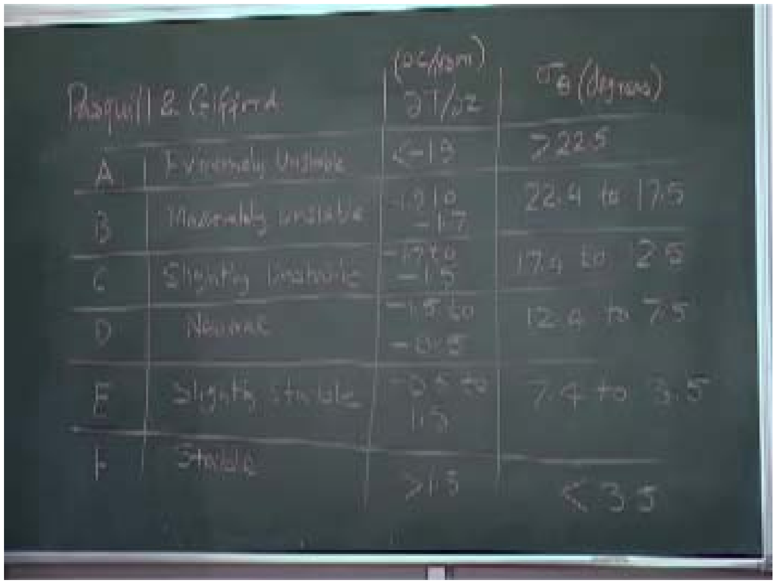

The units will be degrees. Let us extend this. More than 22.5, 22.4 to 17.5, 17.4 to 12.5 and then 12.4. Are we at D? Yes. 12.4 to 7.5, then 7.4 to 3.5 and less than 3.5. That is what Slade had to do – this was published in 1965. Somebody found out an even easier way because again you do not want to… Nowadays, we have computers but in '65, there were no computers and so they said whichever the hour you are looking at, you take the width of the direction within this hour.

What is the width of the direction? It is this much in this hour. The wind has changed from here to here and so they said $sigma_{theta}$ can be approximated as the width of the wind direction divided by 6 (Refer Slide Time: 34:08). It is a very very approximate thing to find out the $sigma_{theta}$. Now, we do not have the wind measurement device right here in the lab but we have it somewhere there.

You can look at the chart and then say the wd has been about 36 approximately and so the $sigma_{theta}$ is 6. If $sigma_{theta}$ is 6, then maybe I am talking about the stable conditions. These things are very important and always remember that we are trying to develop a relationship between the source and the impact. To develop the relationship, we need to know meteorology because meteorology is the transport mechanism – it is the one that is transporting the pollutant. We still have not come as to how this is what is happening but we are just studying the atmosphere. These are the Pasquill and Gifford stability classes. If you want, we can put the word stability here (Refer Slide Time: 35:12).

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Turner, 1968. He said you have the two methods but sometimes, even this information may not be there and you still want to know about the meteorology. He came up with a method – that is what we will discuss and let us see how far we go. He discussed the method and he said that if you go to an airport, nearest airport, the measurements done by the airport as a matter of routine measurements – that is the information that will generally be available.

Suppose you have to go to a remote area. You have to see whether a power plant should come or not but you do not have the ways and means to measure this nor can you do the long-term measurement because you have to take a decision nor can you run through your wind direction this thing. Then, he says we should go to the nearest airport and get some data – that data will help you to find out the stability. In fact, before we had our wind speed, wind direction system here, the students used to go to Chakeri Air Force Station and always use to bring the data and do some analysis to get to the stability class. Again, there is a table for the stability class by Turner. Since I do not have the slide to put here, I will have to draw that.

He said if we can somehow measure the insolation…. What is insolation? It is the amount of heat that is reaching the ground – it is not that which is going away from the ground. He said that if we can somehow measure or rather estimate the amount of heat that is coming down (we call that as the insolation), the classification can be done based on the insolation.

Insolation somehow is not directly measured at the air force station or even your normal civilian airport, but they do something else. Let me make this table for you and this table was given by Turner. He said first of all, it is the surface wind that everyone measures at the airport – they measure the surface wind as a regular thing; the units here are meters per second. When we say surface wind, normally we are referring to the wind measurement at the height of 10 meters – that is a standard thing. Even if no one tells you the surface measurement, it is implied and it is understood that the measurement is 10 meters.

Let me make this slightly better. This is the daytime insolation. He simply defined insolation as strong, moderate, slight, thin overcast that is what is I mean to say CC… let us quickly write the numbers here. We will come to how the insolation is to be calculated, estimated, measured. Let us just complete that table because we want to spend just about a minute on this table now. Do not misunderstand – this is not 7 (Refer Slide Time: 41:56) but this is more than 6. I want to explain the terminology CC – that is a new variable that you see here. In this case, CC stands for cloud cover.

What do I mean by cloud cover? What do you see if you look at the sky and you divide the sky into 8 equal parts? It is just a synoptic measurement – you do not even need an instrument. The person physically goes up (of course, nowadays you have the instrument) at a particular time of the day, looks at the sky and he says out of 8 divisions that he can make (equal divisions), how many divisions are filled with the cloud. Simple. How many parts or how many.…

Suppose this is the sky that you see, it will look circular to you and you divide this into 8 equal parts. Are there 8 parts or more? I do not know. 8 parts. Then he says out of these 8 parts, this was filled and this was filled – the cloud cover is 2 by 8. Simple. If we say this was filled and this portion was filled, the cloud cover was 3 by 8. The airport people record this regularly every hour. This wind speed is measured by the airport people anyway. This is also measured by the airport people – they do this.

Once you know this…. I have not still told you as to what is strong, moderate and slight, but if you know these things, you can define this. The other thing I need to point out to you is that and that is somehow…. Why is it that when the wind speed is more than 6 or 5 to 6 or 6, why is it D all the time? What is the guess? Calm condition. More is than 6 is not calm condition, but the wind is very high; you can say it is a very high wind – 6 meters per second is a reasonably high wind. It could be any time of the day but still you see that even if the insolation is strong or moderate, it is D; bright sunshine, high wind speed, you are not getting to A, you are getting to D. The answer is….

[Conversation between student and professor (44:45 min)]

No, we are not talking about the pollutant – we are talking about the atmosphere. Forget about the pollutants. Even if there is no chimney, we are sitting at the North Pole, for example, even then, if the wind is 6, you will say the stability… you will see the temperature that time will be something like this – temperature gradient. What happens at that particular wind speed, which is high, you have the gradient and whatever gradient that is established because of the influence of the ground, that is broken.

That kind of variability in the gradient in spite of very high, strong daytime insolation because the wind is so high that the gradient of the temperature is broken. Once that is broken, what do you come back to? Neutral conditions, which is the standard thing. So you see here, when the wind speed is…. By the way, I can share with you – I myself used to wonder when I used to look at the book, no book about this, they simply gave this. But then, when I spoke to someone when I was a student like you, then came the explanation. Unfortunately, it is not given in the book. At such high temperature, you cannot sustain the kind of temperature gradient that is for A and B, but C or D will be all the time prevalent.

One thing you can check quickly is that if somebody says this is the stability (because we will use stability so much in the coming lectures), wind speed is more than 6, just use D. For example, I can ask you a question: the wind speed was 6 meters or 7 meters per second, strong, bright sunshine, do this calculation, then obviously, you should assume stability as C or D – that is what the idea is. It is seen and you can still examine that – you can still examine how much is the cloud.

It is a synoptic measurement done every 4 hours and then, they are able to… either with the machines or now, they have the equipment and with the equipment, you can just scan and give the number. But otherwise, in the daytime and other times, people were doing synoptically and there were people experienced in this – their job was only this, they were trained on this.

[Conversation between student and professor (47:23 min)]

In the daytime, are we considering the cloud cover or are we not considering the cloud cover? We are considering, slight. It means things are cloudy – that is why the solar radiation that is coming is slight. Otherwise, in the daytime, you do not expect this to be slight. So, in a way, the cloud cover is covered here. I will just make one more little comment and then we will stop. We will just make a small table and then…. What is insolation measured in?

[Conversation between student and professor (48:09 min)]

Watt per meter square or another unit is Langley per hour – meteorologists measure it in terms of Langley per hour. I will again give you a little table – insolation category.

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Again, you do not have to remember it – you do not require this but we will still write it. Always remember that the insolation even in the nighttime is never 0 – some solar radiation is coming in. I will write this here: Langley. I will define what Langley is. R is the solar radiation here. R is more than 50 here; here, it is when R is more than 25 but less than 50; here, it is when R is more than 12.5 but less than 25 and in the nighttime, R is less than 12.5.

1 Langley is equal to 1 calorie per square centimeter – that is how we define Langley. Now, you know the numbers and the next job in the next class will be how to calculate or estimate the R. From R, you define your solar radiation and then, with this, you combine…. The Turner thing is very frequently used because it is so easy to get not only the present data but you can also get the historical data. In fact, the Bhopal thing when we wanted to find out what is the wind speed, what was the direction, there was no measurement – we went to the Bhopal Airport asking for all the data that we needed. The airport is a very important place for meteorologists and for air pollution engineers.