Environmental Air Pollution

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Lecture No. 33

Air Quality Modeling – Maximum Ground Level Concentration

Yesterday, we were talking about the line source and we talked about infinitely long line source.

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C was… what was that? 2 times small q… sigma z times U exponential what was that? Z square by

[Conversation between student and professor - Not Audible (01:30 min)]

Generally from national highways or even things like GT road, the road is passing through this kind of thing formulation can be applied but if you have the road where you have the quick turns, left and right,

[Conversation between student and professor - Not Audible (02:02 min)]

Yeah, then it becomes difficult but for the large national highways, you can apply this particular model because you see here, most of the vehicles are continuously moving one

after another and this kind of thing can be applied; but if you have something like very a packed urban area with zigzag crossings, then we would prefer to model that as the area source but these are the large national highways you can certainly ….

[Conversation between student and professor - Not Audible (02:34 min)]

That will be difficult. The closed form solution that we have got sometimes is not applicable in very special situations –we have not talked about that. The model we have talked about so far is generally applicable in the flat terrain and there are ways and means to define what is a flat terrain. Obviously, when you say flat terrain, then what is a flat terrain? That slope should be less than 1 by 16 or something – that defines the flat terrain, there is a way to define if the terrain is flat. If you have valley or a mountain or things suddenly dipping and things like that, you can still apply this model to a certain approximation but if the situation is still more complex, then what we can represent through this one, then what we do is what we call as physical modeling – you create such a situation in the wind tunnel because you cannot write mathematics for such features, it is not easy to write the mathematics. You do the experimentation in the wind tunnel and then you can really scale down the objects like this – you can make the buildings, you can make the hill, you can make the valley and you can make a source in there and then you can do the measurements on how the concentration is changing; you can change the wind speed, you can change the turbulence, you can change the mixing height in the wind tunnel and then we do the physical modeling; there are certain areas where we cannot apply the model because these models are again based on certain assumptions and one of the important assumptions is that the terrain is flat.

If terrain is not flat and it has it its own complexities, then we go to physical modeling but that we are not discussing in this course but definitely wind tunnels are very extensively used to cover or to understand dispersion under complex conditions. As was pointed out by one person later, suppose this is your road and this is your wind direction, it makes an angle phi, so this phi should be in the denominator; you probably wrote it in the numerator but this should be in the denominator for obvious reasons. If phi is 0, what is the concentration? It is almost infinite, so you cannot use this particular formulation if the angle is very very small.

What it really means is that if the angle is very small, then your wind direction is like this (Refer Slide Time: 05:21), and then if the wind direction is like this, what is your x direction? It is like this… wind direction… see you will never make a mistake as long as you

understand in all the Gaussian kind of models that we have discussed, my wind direction is my x direction – I say it again and again; the moment the wind direction changes, it means my x direction is changed – do not forget that.

It means in a way I am calculating the concentration on the top of the vehicles and then you expect concentration to be very very large. If you go over the road just 2 meters and you see you are just on to the vehicle, then concentration is really large. To avoid that thing, the angle should be generally more than 20 degrees or so for this to be really very very valid – if it is very low, then you get very high concentrations. We will stop this discussion here but just see where this sign phi appears.

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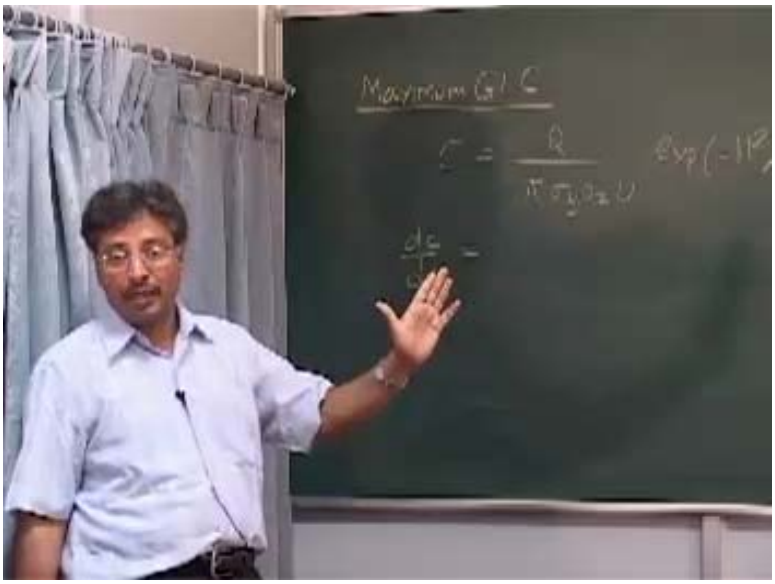

I want to do something using that formula again. Now, what we have not discussed so far is maximum ground level concentration. Many times, we are interested in what is the maximum impact, where it will occur, how much will be the impact and if I can take care of the maximum impact, my life is fine. Many times, we want to predict what is the maximum ground level concentration, where it is and how frequently it can occur – all these questions we have to answer. For doing that one, what was our equation? I am going back to our original model. What was that exponential? Minus?

[Conversation between student and professor - Not Audible (07:34 min)]

If I am saying the maximum ground level concentration, it means… [07:42] y I have to assume as 0. As I move away from the plume centerline, my concentration will drop off, so to do that one, I will take y = 0, so I will not even write the term containing y. What was that? H square by…. Obviously, I want to find out the maximum concentration with respect to my downwind distance, so I can differentiate this function with respect to x. Then what are the things that are the functions of x here? sigma y, right? sigma z. Is H also a function of x? Although we have not talked about it, you can think if you want to make things very complicated, then H also will be a function of x because you see many books, advanced books talk about ….

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You have this one, then this is my x, my H is constantly changing as X, it is only after certain distance of x, this kind of stabilizes, the x stabilizes but here H is different (Refer Slide Time: 09:22), H is different, H is different, H is different, so some people who want to really do things very precisely would like to take this as the function of… even the H as the function of x and in more sophisticated models, this is taken this as the function of x but for simplicity we may not really do this one.

[Conversation between student and professor - Not Audible (09:46 min)]

We will change under what condition?

[Conversation between student and professor - Not Audible (09:57 min)]

Yes

[Conversation between student and professor - Not Audible (10:02 min)]

Fine, fine. What could be the primary reason for the delta H to change? [10:08] Atmospheric stability. So at least I will say this thing is I am writing for A stability, for a particular stability.

[Conversation between student and professor - Not Audible (10:20 min)]

Yeah, you do that one if the stability is changing and you want to compute hour to hour, you compute hour-to-hour concentration that you compute hour-to-hour concentration. What will happen? You are saying in the first hour, this stability was C, then you are computing it for C, you cannot say you want to just do it for 1 hour and you want to extrapolate for 24 hours – you cannot do that. So you will have to do it if you want to do the changes in hourly concentration, then you have to consider the hourly change in the stability, hourly change in the wind speed hourly change in the effective…

[Conversation between student and professor - Not Audible (10:59 min)]

No, you cannot predict, but you can with your previous background data you know that in general what the stability of a particular hour of the day will be.

[Conversation between student and professor - Not Audible (11:15 min)]

Yeah, uncertainty is always there in the model, uncertainty is always there in the model. In fact in any model you take, you talk about the water quality model, you talk about the ground water movement of the model, uncertainties are there and if the uncertainties change, then they change the model is still… you have to account for that uncertainty and you say this concentration could be plus or minus this particular thing.

[Conversation between student and professor - Not Audible (11:46 min)]

Yes.

[Conversation between student and professor - Not Audible (10:53 min)]

Yes. At the ground level, the plume that is being affected… which is subjected to dispersion, there is nothing happening here, this is what is the thing which is happening, so we assume

that stability above this one is the main cause of the dispersion and then this dispersion may cause an impact at the ground level.

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Eventually what will happen is if I draw another picture, the plume is travelling and then it comes like this, then it will come like this and at some point, you will see the concentration will start increasing and what is the plume in general? The centerline of the plume is affected by the stability that is there or the conditions that are inside the plume. Then, we see the impact of this dispersion or this expansion of the plume, what will be the impact at the ground level – this is what we are seeing. Suppose this was a… you say there was some wind speed or some friction here, that may not affect this one and that is how we have gone for this one.

You may be saying that there is an inversion layer here underneath this one, then the modeling can be a little different but in general that is why it is even more important to do the calculation hour to hour; but again, sometimes you just want to get the 24-hour average – then you can even average these things for 24 hours. Then we will see one example hopefully when you can find out even the annual concentration, the annual mean wind speed is like this, annual wind direction is like this, the frequency of the wind direction is like this – you can even account for the annual levels and you say mean annual concentration will be like this; in fact, you will be surprised that mean values are sometimes more comparable to instant values because the mean value is sometimes… of course, you write the physics, you write the

mechanics of this one or the mechanism of this one, but at the mean values, many things cancel out from each other, which we do not know sometimes and then we are still happy, so always remember that the mean values will probably be much better than your instant values, but it is true that you can do it for 24 hours and if you want to get better and accurate results, then you model hour to hour, you supply the data to the computer because simple calculations we can do on the board but if you want to do a more precise, more accurate measurement or concentration or predictions, then you have to use the computers, supply the data – what is wind speed every hour, what is the wind direction every hour, what is the stability class every hour every hour, what is the mixing height – and then you can use the model.

Then of course if you want to find out the 24 hour, you have the 24-hour data of every hour, take the average of that. I am saying whatever is the stability but we are doing it for a particular stability – it may be A, B, C, D, E, F. So let us say whatever is the stability, I can differentiate with this one and then you find this is the function of x (Refer Slide Time: 15:34), function of x. What else? Again, the function of x. Differentiate this one and I can put this equal to 0 to find out the maximum concentration.

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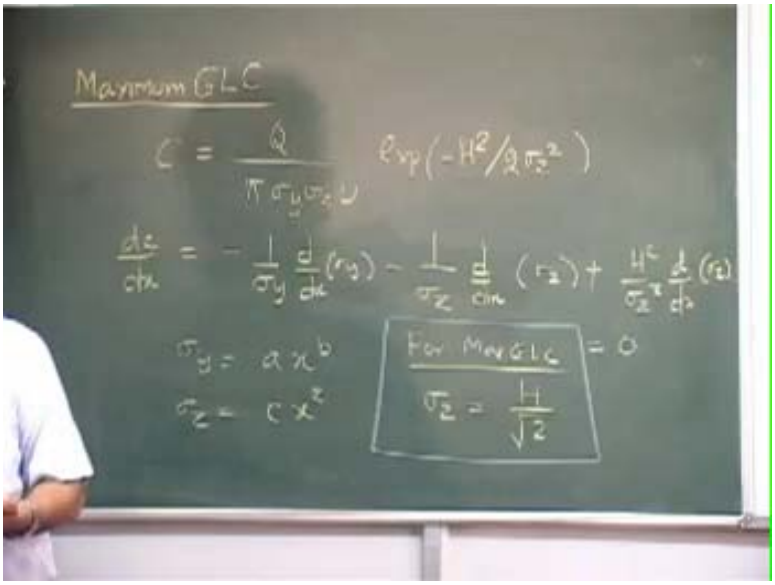

This will be… I am writing the final form, you can see for yourself, something like this… and I am not considering…. I can write another expression for d H also if I take H as the function of x but just for simplicity, let us not get into those sophistications for the time being; I can put this equals to 0 to find the…

[Conversation between student and professor - Not Audible (17:01 min)]

dH by…?

[Conversation between student and professor - Not Audible (17:04 min)]

I am not considering that, I am not considering that H is the function of x, but you can consider it if you like because after a certain value of x, which may be of interest to me – 500 hundred meters or so, then this particular thing will not be the function of x.

[Conversation between student and professor - Not Audible (17:27 min)]

What will happen to the exponential term, can someone…?

[Conversation between student and professor - Not Audible (17:34 min)]

Have we considered that or not in this one? This is equal to 0, that term will come everywhere and that is equal to 0, so I can take the common out and get that one out – you can try doing this one. If you recall, I gave you the thing that sigma y… they were related to x in this form and let me again tell you that many people have come up with different kinds of forms, not that this is the final form; essentially, you had those graphs and they have fitted some particular equations to that graph, so I can put in place of sigma y I can put this, sigma z equal to this one and then differentiate this one and then finally what you will see is that when you equate this to 0, this condition comes out to be that sigma z equal to… for.… I am giving you the final answer to save time but when sigma z is equal to H by square root 2, that is where you will get the maximum concentration.

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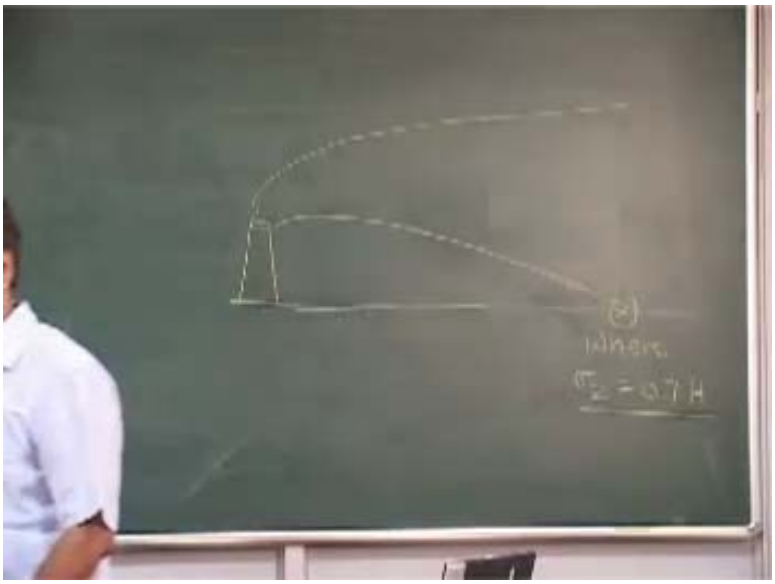

What does it means in the physical sense? The H is fixed and sigma z is changing with respect to this one. A situation will come where your sigma z, which is constantly changing with x, will be equal to H by square root 2; there will be some distance…. Let us make it another picture and make it slightly different [20:24]. Let us just look at the physics part of it: where you expect maximum concentration to be? Somewhere here because the plume is almost touching here. What condition it tells you is… and here you say the sigma z is changing because sigma z is a function of x, so the place, the x where sigma z has increased to such a level that it is equal to H by root 2 is where you are likely to get maximum impact of an elevated source, maximum impact of an elevated source. I am just telling you that this situation may be somewhere here where sigma z has become equal to… what is 1 by square root 2? It is 1.41 and 1 by 1.41 is 0.7, so you see here that sigma z, which is constantly increasing with respect to x, is nearly equal to somebody said 0.7 or something, so I will write that number. There are many questions actually. Will the maximum ground level concentration vary depending on what stability I am talking about? Yes or no? Yes because sigma z is functional stability also; if my stability is A, my maximum ground level concentration will be something else; when it is B, then it is something else; for C, it is something else. Now you have to tell me if this is the situation, how can I find out the maximum ground level concentration and the location where it will occur? That is the question.

[Conversation between student and professor - Not Audible (22:42 min)]

Initially, what do we know? We know the sigma z now, right? sigma z is very simple; we have estimated H and now we know the sigma z and as it has been suggested, we will go to the, the Turner graph for sigma y and sigma z – not sigma y but first we go to the sigma z graph.

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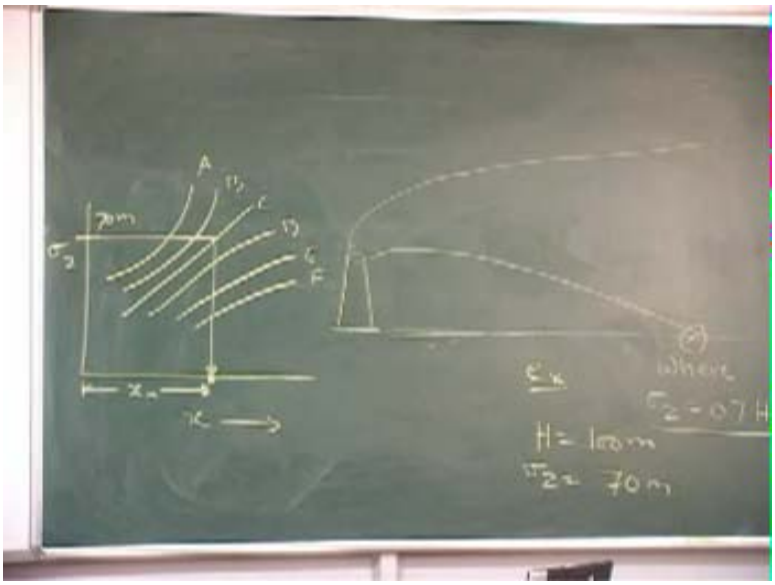

We go to the sigma z graph. This is your x, this is the sigma z and the graph if you recall, there was something like this; very poorly drawn but you can remember that what the graphs were. Suppose my condition was C, suppose my H was equal to 100 meters for example; we will do a little thing, small thing; you can calculate H – that was your physical stack height plus delta H, so my sigma z for maximum concentration will be 70 meters. I go on to here and strike 70 meters and my stability was let us say C, so this is my distance where maximum ground level concentration will occur (Refer Slide Time: 24:27). Does everyone agree?

Now you know the distance and we can call this distance as x_m. Now it should be very simple for you to find out what will be the maximum concentration. What you have been able to do is you have been able to find out the distance at which maximum concentration will be there and once you know where it will be, it is simple calculation to find out what is that concentration. So with this x_m, you will go to your graphs of sigma y and then go in the reverse direction and find out the value of sigma y. Clear? Then, you can fit in the value of sigma y, sigma z, you know U, you know sigma z and you can find out the maximum concentration but to find out the maximum concentration, you have to do this exercise for A,

for B, for C, for D, for E and for F because you want to really find out the worst scenario – it can be A, it can be B, it can be C, it can be D, or it can be E or F.

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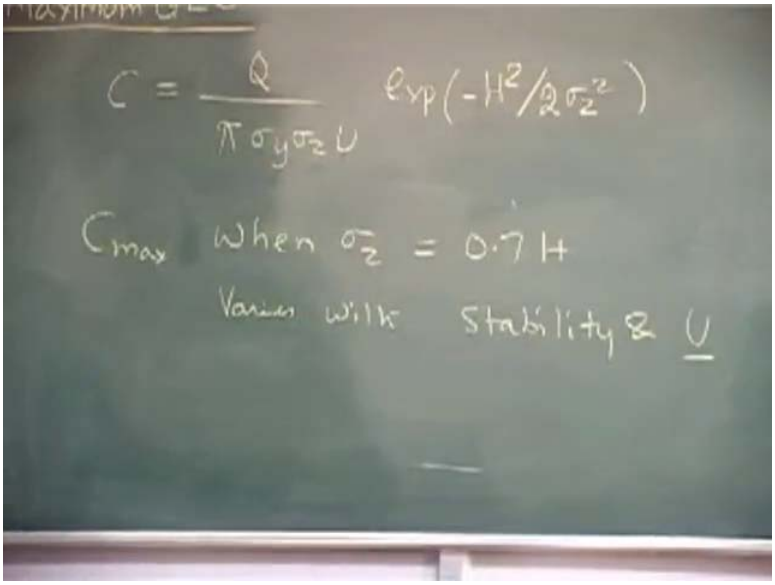

It will be different for distance stability and different set of value of U, right? If you have one value of stability and one value of U, you can say under this situation this is the maximum impact but the stability will change hour to hour as has been pointed out – the wind speed may change hour to hour, so our maximum concentration can be very variable depending on what stability and what [26:55]. If that is clear, I want to get to something still more important and still more interesting to note.

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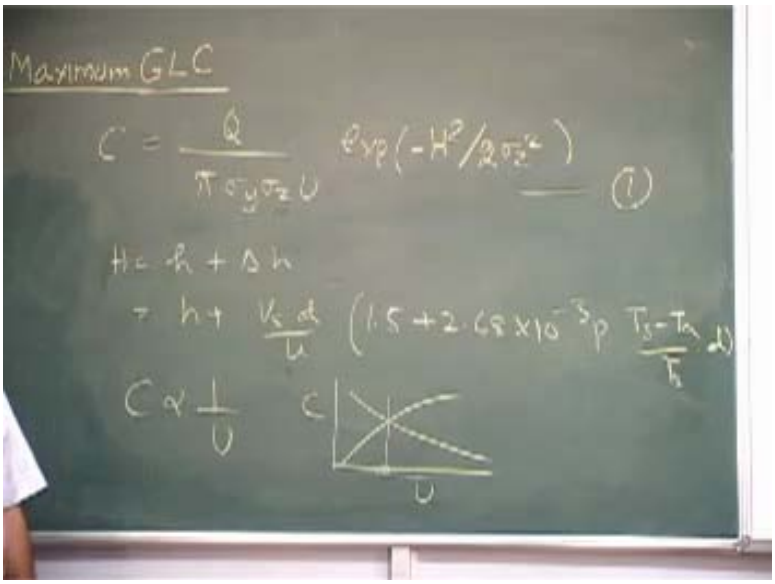

If you recall, our H was h plus delta h, which was nothing but h plus… Correct me if I make a mistake. What was that, 2.15? [27:44] 1.5… minus 3 p T_s minus T_a by T_s times d. If my U is playing a role, the first thing I wrote was stability, let us say we are not talking about stability but U is certainly playing a role but you see here the contradiction and pay a little attention here. If you look at the picture or this equation, C is inversely proportional to U – from (1), C is inversely proportional to U or proportional to 1 by U, so more is the wind speed, less is the concentration. Immediately when you look at this equation, that is what you are going to say but do not forget this equation (1) has the built-in feature of equation (2).

Where is this one? This delta h is somehow appearing here (Refer Slide Time: 28:58). Agreed? Do you still agree with this statement or is there more complexity involved than writing a simple statement like this? Much more complexity; it is not a complete picture because if I take the whole thing here (Refer Slide Time: 29:19) and put it in this one, then I am also finding U again, so the picture is complex. U is not as simple as it appears that C is inversely proportional to U and what you see here is if I plot this one, only this equation, then you have this C and you have the U. You might find that as the U is increasing, C drops down. This is what is something like this, right? What will happen to my delta h if U increases? My delta h will…? Speak out; I want you to speak; delta h will…? Decrease. Decrease.

Once my delta h decreases, my h decreases; if my h decreases

[Conversation between student and professor - Not Audible (30:16 min)]

Then my concentration will increase because negative of exponentiation. It means what the U has done one side, U is saying that concentration will drop as U increases, but another term in the product tells you that concentration will increase – if you increase the U, concentration may not decrease but it may increase. If I somehow plot only this function, then you may find that as the concentration increases, you will see that the concentration may increase as the U is increasing because of the U being there in the exponential trend, which has come by virtue of delta h being considered. What you will find is that a maximum concentration may occur at some particular U, so U is not as simple a term as we thought – U will be there will be a particular wind speed for any given stability where the concentration may be the maximum and such wind speed we call it U_c or U critical.

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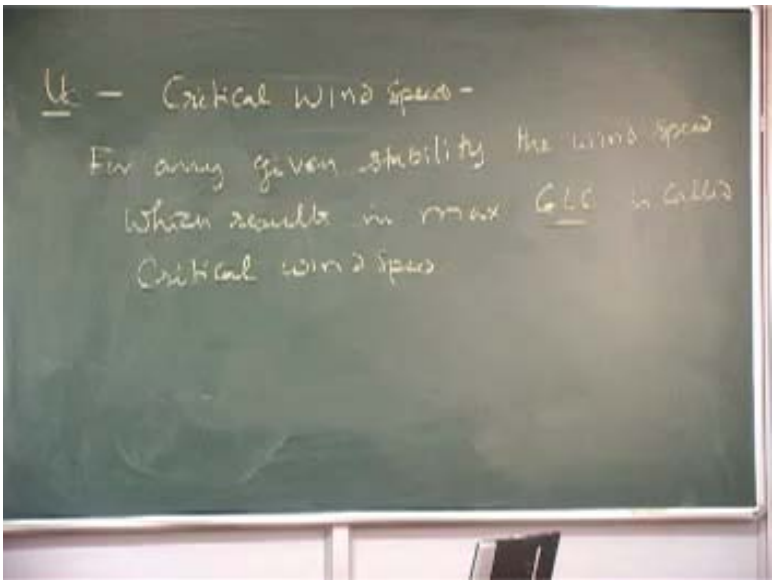

Let us see what is U critical. What do we do? All the time, what we are interested in is where is the maximum concentration that will occur, but what I do not know is that critical wind speed. Although there are many formulations that have been developed where you can find out mathematically as to where the concentration will be, what you need to do is that you differentiate this one again with respect to wind speed and find out the this thing and put the formulation for the maximum concentration – we will not do that one but at least you have got the feel that there will be or there can be and there is a critical wind speed where the conditions can really be very very bad and that is what we are interested in sometimes.

Suppose you are planning a power plant or refinery or a sulfuric acid plant, then you want to see how far… what will be the maximum concentration under any given conditions. As somebody said, you do not even know what is going to happen in the next hour but if you know, if you can find out the critical condition, this is almost like predicting the global ever maximum concentration because this is not based on the measurement. Is U critical based on measurement? It is not based on the measurement. You can find out the critical wind speed whether the condition may occur or may not occur. I will make it more clear to you how in practice, how in actual we try to find out the maximum ever global concentration because of an elevated source – how it is actually done in practice.

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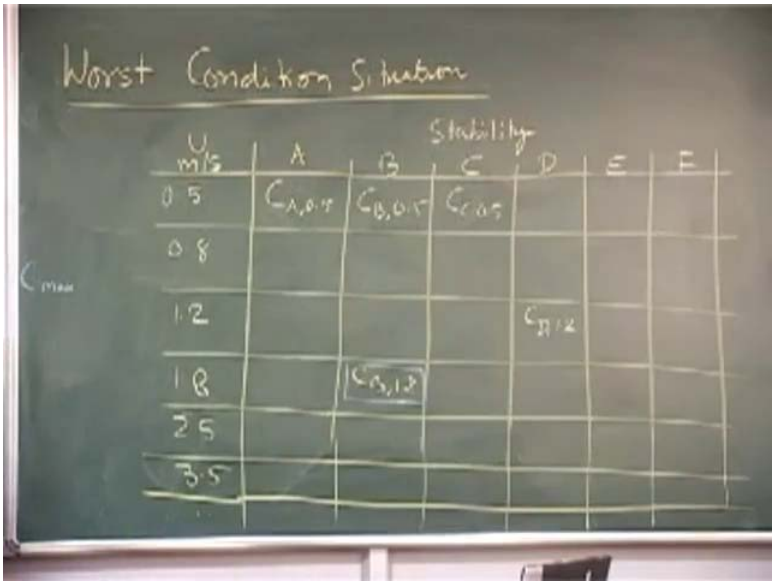

If I can use the terminology worst condition situation, I do it by trial and error. There are ways we can do without trial and error also but one of the simplest things is to do by trial and error and what you do is make a table. What I want to do is I take some wind speed; suppose I took the great wind speed of 0.5, 0.8, 1, 1.2, 1.8, 2.5, 3.5 or more number in meters per second. From here, Q is known to me; a power plant is there, refinery is there – whether it is existing or proposed; if the refinery is going to come, I know about h, first of all I know the physical stack height – they are going to provide a stack height of 100 meters, let us say; this is fixed, delta h can be variable – how delta h will be variable we will see, the pressure can be variable (Refer Slide Time: 28:15), but this variation again may not be so much because this is about close to 1,000, this is a parameter that is fixed – they know that the temperature of the exit gases will be 100 degree Celsius, T_a could be variable, this diameter is fixed because

they have designed the chimney already, this T_a can be variable, this fixed and V_s the exit velocity is fixed because they have designed the [38:42] fans and [38:43] fans, at what velocity they are going to push things out. So this is fixed, the variables are this and this; then you see here when will be the situation when will delta h will be small? When T_a is large because higher is the difference, higher is the h, so criticality will occur when T_a is high in the summer conditions, so you can assume this to be high – in Indian condition, the ambient temperature you can take as 40 degree Celsius.

In a way, I have got this one fixed (Refer Slide Time: 39:15), this one also is fixed – nearly 1,000 milliwatts or something. What is not fixed really here is U and the stability, which by virtue of the matrix or the double array, I am varying both of these. What am I varying? I am varying the stability and I am varying the U. Then, I can fill these little arrays as you see them. What I can do is take this stability A and another important thing is I am not going to a meteorological office to get any data. Have we gone anywhere? Have w gone to the airport? We have not gone to the airport to collect any data. We assume and suppose the situation was A and if this was 0.5, what will happen? We are not requiring any data from anywhere, except the data from the plant – those data are fixed.

Again, I repeat that we do not have to run to find out the worst condition situation – I do not have to go collecting any meteorological data. Clear? I have assumed the condition. Suppose the conditions were A and wind speed was 0.5 meters per second; these two things are fixed, can I find out the maximum ground level concentration for stability A and wind speed 0.5? Clear? I can write some number here and I can ask my computer to do the same calculation for stability B and… or let us write here if you like. We are talking about C max at A, 0.5, right? What is this? What is this concentration? This concentration is the maximum concentration for this situation. How did we get the maximum concentration? We have implied sigma z where sigma z is 0.5 h, so this is already maximum concentration for this condition.

I can also find out $C_{B, 0.5}$ and so on and so forth $C_{C, 0.5}$. Just to give you a little feel, suppose I want to say here… if you agree, I can write here $C_{D, 1.2}$, so I can fill this table, which is already maximum ground level concentration for the given condition – simple thing. Now I want to find out the worst condition. The idea is picking up the maximum out of maximum, picking up the maximum out of this maximum. These are already maximum situation and then you say what we found out, this situation, which is let us say $C_{B, 1.8}$, was the situation

where my conditions were the worst. You fill all these things, just quickly write a small two-line program to find out which block or which situation is giving you the maximum concentration – you can even do it manually. What we can say is C max under the worst conditions or under worst-ever condition, if I can use the word, will be… because out of this table, which already had the C maximums under this situation, suppose that came out to be C_B, I am just giving you an example, I think I have done a great job by saying that the maximum ever concentration that can ever occur because of some plant will be like this – very good prediction to do, we call this as a screening model.

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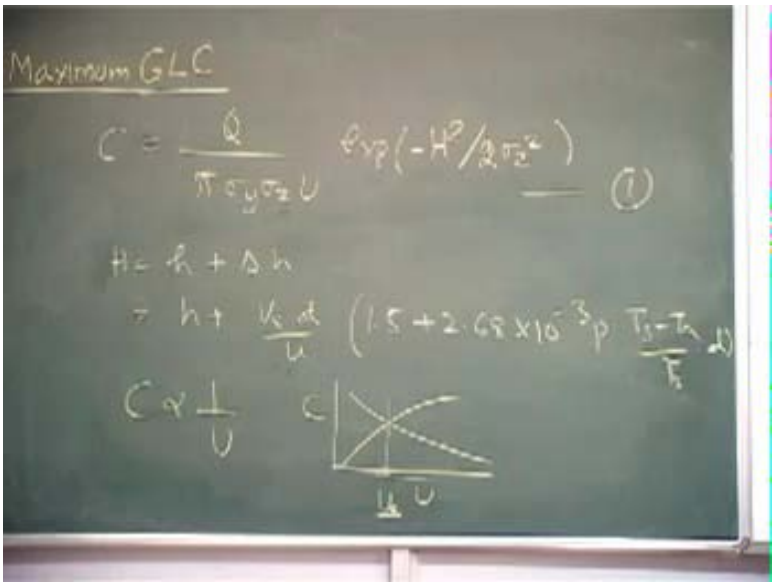

We do not do any field work but we can say that this can be the worst-ever situation but this may occur or may not occur, this may occur or may not occur but if it occurs, the scene can be as bad as what we have predicted. It is just an example, this will go beyond this, do not misunderstand that we have to just consider 3.5 – it has to go beyond this and suppose you got situations like this, you can fine-tune this one by slightly increasing and decreasing this one – you can do at 1.725, 1.81 and like this you can still do finer grading of this one and find out the maximum concentration that is likely to… or that may occur. Then the other thing is now if I ask you what do you think are the chances of the situation occurring, how would you do that? Then you will go back to your original data from the meteorological office or from the airport and see the probability of getting the situation, which is $C_{B,\ 1.8}$.

Now you go back and say the probability of this situation occurring is really once in let us say five years. With historical data, you can say that it means the situation may occur once in ten years or you might say such kind of a situation may occur once in two months. Then, you have a problem or having done that one, you can go the other way round; out of this situation, you can find out which situation under this is most likely to occur – the reverse way. Then, it came out to be the situation that is most likely to occur as per the wind records, which we have as this (Refer Slide Time: 45:53). Then, you are likely to have the maximum concentration at this value. It is just a matter of the information you have and how you are interpreting them, making sense of things – the calculations are simple but you have to apply them and get an answer that will help you make a right decision.

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This is all we are doing for some decision making – how much pollution is to be controlled, whether the plant can come up or not, where can it come, will its maximum impact be in the vicinity where people live, so this kind of situation we do and in this way, you can even find out the worst-ever possible maximum ground concentration. Do you have any question?

[Conversation between student and professor - Not Audible (46:36 min)]

Yes, that will be maximum, go ahead.

[Conversation between student and professor - Not Audible (46:46 min)]

For that, you have to see the probability. One of the situations will always occur – you are right but sometimes the situation can be this, sometimes it can be this, so what I am saying is out of all these situations, try to find out the situation based on your records – which one out of this picture you see, 10 by 10 matrix or whatever, is likely to occur with more frequency. Then, you can design something for this one. Sometimes, it is very difficult to design something for worst scenario. Suppose you are designing the pollution control or you are designing a stack height let us say, you can even go back and do all the calculation to find out what should be the physical stack height, is it not? If you know the maximum allowable concentration is like this, then you can do the reverse problem and find out the h, which we people do. People say my maximum concentration should not exceed 100 micrograms, then you say the worst ever is 100, then whatsoever the wind speed, wind direction you know this thing and then you can go and find out the h by putting the worst maximum concentration here.

[Conversation between student and professor - Not Audible (47:58 min)]

What do you say? What should we do? Should take the most frequent value or take the worst-ever possible scenario? Suppose you are an engineer, what would you do?

[Conversation between student and professor - Not Audible (48:19 min)]

Other value

[Conversation between student and professor - Not Audible (48:28 min)]

Normally, it is very difficult to design something for the worst-ever scenario –we should not do that. These are the stages of modeling. Suppose something is proposed by let us say a proponent that wants to have such a power plant – NTPC comes to you, then you run through this calculation, which is hypothetically maximum. Suppose that concentration itself is very low, if this is very low, all others will be smaller than this one, then you will say ‘Do not do anything, just go ahead and build the power plant’, right? Because under the worst-ever condition also, they are not going to be causing serious problem to you; you will not do any calculation, you will not use the computer, you will not do sophisticated modeling, you do not want to find out the A, B, C, D because they themselves have proposed some h or some pollution control device and that itself will contribute much smaller than the maximum ever

that you can think of, so do not increase your work unnecessarily, just say “That is all right, go ahead come up with your plant.”

Suppose that maximum concentration came out to be higher or that thing came out to be this value (Refer Slide Time: 49:49), which was higher than this, then what you will do is you can run another analysis where you can find out which set of this situation has the highest probability. Then you came out to know that this situation is most likely to occur with probability of let us say you said 50 times in 10 years. Then you say “Let us design the thing for this situation.”

Then, the designing part: how can you design the things? You have only two things in your control; the control you have is on this Q – you can ask them to control the pollution, you can ask them to use better coal, you can ask them to go for a better technology or you can say increase the stack height – both the things you can do.

As an engineer, you will say “Improve your Q or decrease your Q or increase your h or other variables” because you have to optimize the variables. The other variables you can say…. Suppose they say “We cannot control our coal qualities like this”, then you say “What about increasing the h?” and they say “We cannot increase the h because civil aviation authorities tell we cannot increase the h” because there is an airport beside this one. Then, what can you do? Then you will say “Play with this, play with this or play with this” – these are the options that people do exercise while designing for pollution control or air pollution control, these are the options you have. So for screening purposes, use this one to take a quick decision ‘Yes’ or ‘No’ when you say nothing is required, fine; when something is required, then you do the further analysis of this table or you say which situation is likely to occur more.

I agree with you because we cannot design something that occurs once in 10 years; if that occurs once in 10 years, we cannot design for that but all this matter of decision making, developing an argument and argument comes always by virtue of knowledge, by virtue of understanding, by virtue of the physics of the system as you understand it – so arguments can only be developed if you know the subject. Therefore, we say that you have to always know the physics so that you can develop the argument. You may be on the side of the let us say power plant or on the side of an NGO or on the side of a government body – everyone has their own point of view. You have to make a decision and one person who will win the

argument will be the one whose has the clarity of the subject and has a good knowledge of the subject.

We will stop this discussion here but you can appreciate as to how things are done and how you can find out the maximum concentration. If you need more information on this, more mathematics part of this, because I feel to give you more qualitative feel is more important than mathematical feel because mathematics is there in the books and sometimes with books, you do not get the qualitative feel of things. Senfield as our main reference that we have given you in the beginning will have even more equations and complications based on this.