Health, Safety and Environmental Management in Offshore and Petroleum Engineering
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Module – 01
Lecture - 06
Pollution modeling I

Dear friends, welcome to the online course on Health, Safety and Environmental Management in Offshore and Petroleum Engineering, which is abbreviated as HSE Management in Offshore and Petroleum Engineering.

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We are talking about lectures on module 1, which is focused on environmental management. In this present lecture, which is the sixth lecture in module 1, we will talk about pollution model. In the last lecture, if we rewind back slightly and see we already said the atmospheric pollution, which actually happening because of dispersion of cloud vapor from the processing centers, which are located on shore are affected by many factors. Out of which predominant factor is mind, direction and speed which can be obtained for a specific location that is specific time of interest from what we called as a wind rose diagram, which we discussed in the last lecture in detail.

We have also said the other factors which could be affecting the pollution modeling for atmospheric pollution. It can be the terrain effects, the stability classes which accounts for the weather conditions, humidity, temperature, etcetera. The momentum of the release of the material and of course, most importantly the height at which the material is released, we have discussed about this specific factor in detail in the last lecture. We will talk about the remaining one very quickly in this present lecture. So, let us focus on terrain effects, terrain effects actually refers to the ground conditions.

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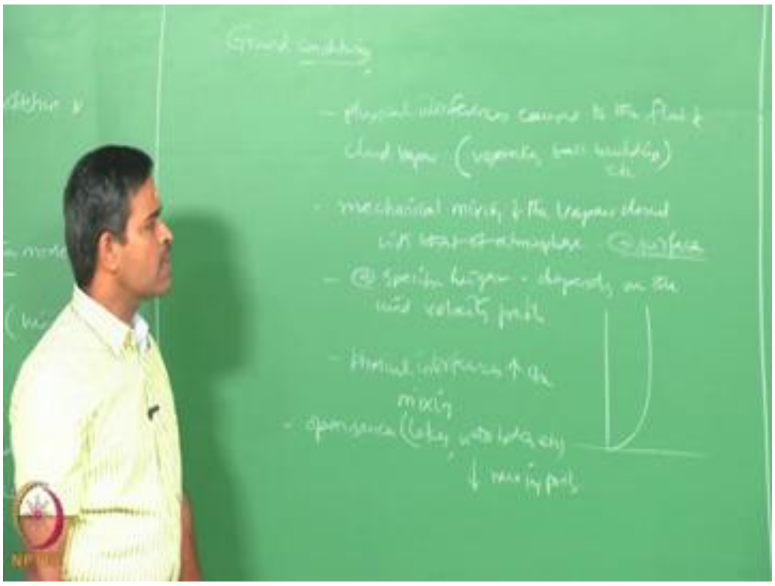

In fact, to be more specific not only the ground condition, but also the physical interferences cost to the flow of cloud vapor. This can be mainly due to vegetation, tall buildings or any other abstractions, etcetera. So, this actually effects the mechanical mixing of the vapor cloud which is dispersed from the external source of the polluting agent or the source with that of atmosphere. So, predominantly the mechanical mixing at the surface is actually affected. It is also challenged at a specific height because this depends on the wind velocity profile, the typical wind velocity profiles it can be like this.

So, we will discuss about this slightly in detail. The physical interferences caused by the presence of trees, buildings, etcetera actually they increase, the mixing increases the mixing probability other than that some open sources such as lakes, other water bodies, etcetera also influence and come under the terrain effects. They actually decrease the mixing probability.

Now, as we said in this present discussion we said mixing is disturbed mechanically at two levels, one at the surface of the ground because of the terrain effects. The second can be depends upon the height at which in the dispersion takes place. So, let us quickly see the typical wind profile at different areas from this figure. So, I want to pay attention to this figure shown in the screen now.

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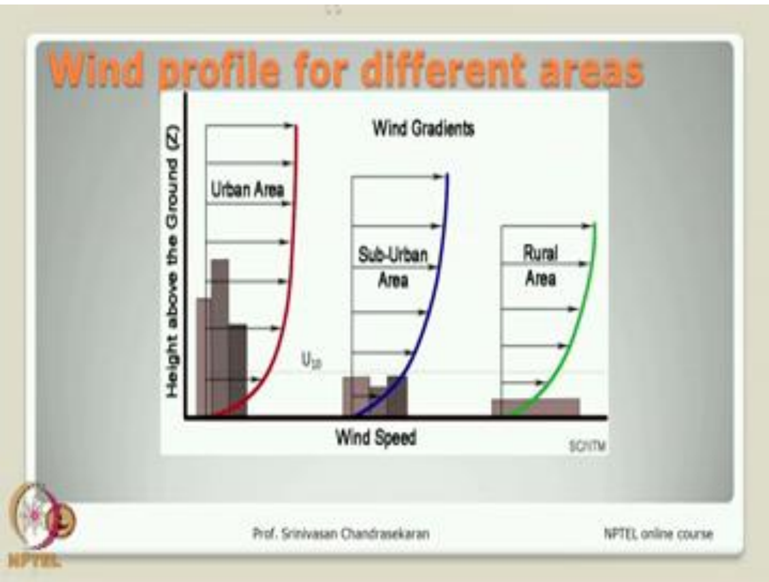

If we look at the figure shown in the screen, it can tell you the wind profile for different areas namely, the urban area, the sub-urban area and the rural area can always see U 10 is the wind velocity at 10 meter height from the ground which is taken as a reference for calculating the wind velocity or the wind speed variation whose equation was given to you in the last lecture.

So, the wind speed which is plot on the x-axis varies along the height above the ground, which is a variable in the expression Z. There are typical variation looks like this as you go taller and taller or as you go higher and higher from the ground as Z increases, more or less the velocity of wind gets stabilized and become uniform without any variation.

So, the variation is non-linear that is why we use power lot and p has been given for different conditions of urban, sub-urban and rural terrains, yesterday in the equation shown to you.

So, depending upon the conditions of the velocity variation, one can see the variation is quite non-linear up to specific Z value beyond which, it is more or less constant and this is how qualitatively the wind profile varies for different areas which actually influences as a part or the terrain effect because the wind velocity variation is also a function of terrain disturbances. As we can see here in case of urban areas you are likely to get tall buildings which interferes by the wind flow, whereas the sub-urban areas you may not, the taller buildings which are more than 10 meter height, whereas in rural areas certainly tall buildings beyond 10 meter height that is about 4 storey building are very rare.

So, considering this as a data which is pre-assumed in the whole theory, we consider that the wind velocity profile varies in the non-linear manner in all. Of course, all the three segments, but in urban area the interference effect is more severe which is indirectly effecting because of the terrain effects caused on the dispersion model. They does not talk about the stability class which is the third condition which I call atmospheric stability here.

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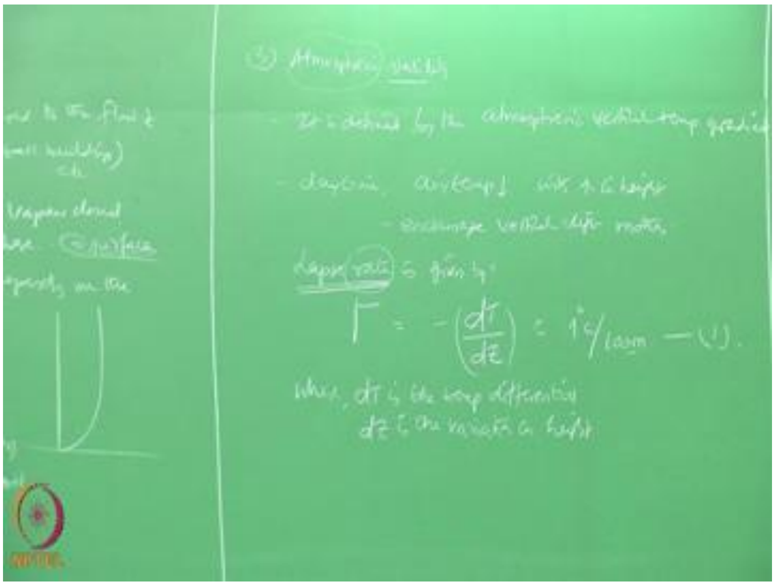

The terms stability does not refers to whether it is stable or unstable condition of atmosphere. It is actually referring to a specific temperature condition present in the atmosphere which either enables dispersion or disables dispersion.

So, it is defined as or it is defined by the atmospheric vertical temperature gradient. Of course, during the day time the air temperature decreases rapidly with increase in height. We know that the air temperature decreases rapidly with increase in height and as a result of which the consequences this will encourage the vertical lift motion. So, ladies and gentleman, it is very interesting and important for us to know what are those atmospheric conditions prevalent when the vapor cloud is dispersed in air and what height this dispersed. So, this is given by simple expression which is given you the lapse rate is given by the following expression minus d t by d Z which is approximately 1 degree celsius for every 100 meter height that is the lapse rate.

I am saying rate because it is respect to the temperature or gradient. So, in this case where d t is a temperature differential and d Z is the variation in height because this is equation number 1. So, atmospheric stability can also be quantified in a different manner. To quantify this let us first classify them into three groups.

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The atmospheric stability is classified into 3 groups; namely unstable, neutral and state. So, 3 classes, 3 groups, now let us quickly see the influence of each one of the condition on the dispersion model, under unstable atmospheric condition one can notice that the sun heats the ground faster than the heat can be removed.

Now, the question is what is the consequence of this specific scenario in the dispersion model? So, therefore, air temperature near the ground that is near the surface is higher than at higher elevation, the higher elevation that is one important consequence we learn, when the atmospheric class is denoting and unstable condition. Now, how do you actually classify them? How do you know whether the given condition is unstable? How do you quantify that the sun gets heating the ground faster compared to that of the different elevation? Let us quickly see them slightly later, now under the neutral condition, the second one under the neutral stability class or under the neutral atmospheric condition.

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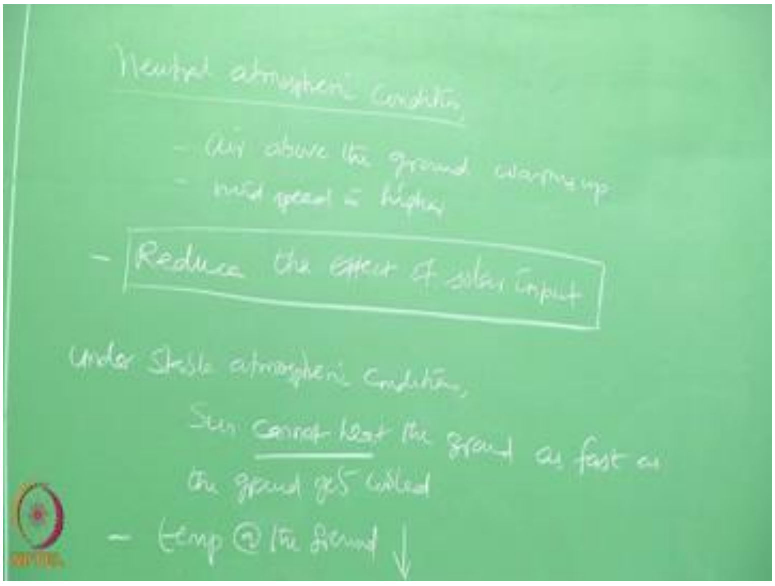

Air above the ground warms up and wind speed is increased, what is the consequence of this will reduce the effect of solar input? We should be considered in the dispersion model. So, that is the consequence which one should account for when you looking for and neutral atmospheric condition. There you are going to apply your pollution model under stable conditions sun cannot heat the ground as fast as the ground gets cooled, which is converse to the unstable atmospheric condition.

Now, what is the consequence of this? This will result in the temperature at the ground will be comparatively lower with other temperature above. Let us quickly see them in a graphical form, all these three conditions with respect to their temperature, humidity and other relationships. I request you to pay attention to the figure which is shown in the screen now.

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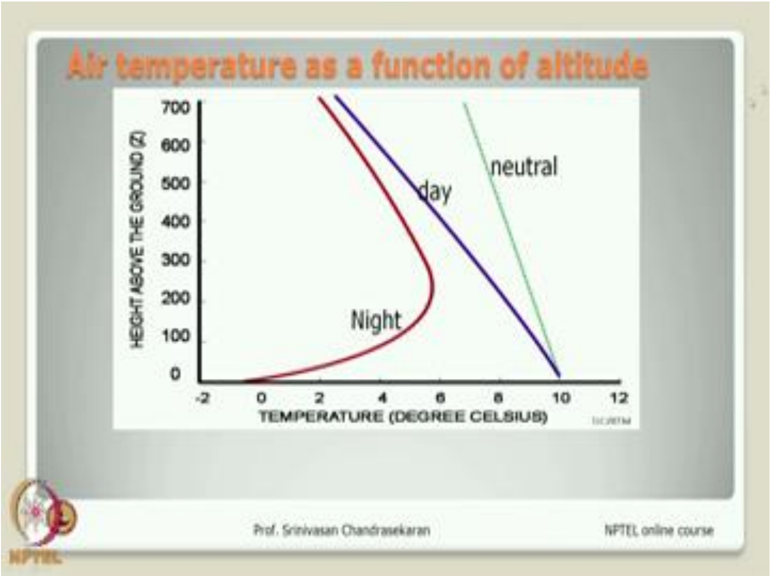

The plot in the screen shows air temperature which is a function of attitude, the x-axis plots the temperature and degree celsius varying from approximately about 0 to that of 12 degrees and y-axis plots height above the ground as Z value.

Now, the plot shows the variation for all the 3 cases of night, day and neutral. So, one can easily see the variation is linear in case of day and neutral, but for only one change that the gradient in both these cases are different, whereas in the case of night the stability class is different. Therefore, the temperature keeps on increasing up to specific height beyond which the temperature decreases as the height increases. So, this follows the trend as similar that of day and neutral only after a specific value beyond which this is true up to which the temperature increases as the height increases which we discussed in the previous cases.

So, we have discussed the plots, they have a specific adiabatic temperature gradient based on which they are plotted. So, what is the humidity of air? In the whole discussion of these graphs, the graphs assume the adiabatic temperature gradient for humid air as 0.5 degree celsius per 100 meters.

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Based on which these three curves are actually plotted, let say the temperature and the height in Z and this is for the night, this is for the day, this is for the neutral case.

If one feel is any alternative of explaining the stability class other than comparing only with the temperature increase because the temperature seems to have accounted for all variations, which include the humidity, the air density everything into account, but however, what is effect of sun or solar radiation on the ground? What is the effect of day and night lighting on the dispersion model? What is the effect of presence of for rainy season on the dispersion model? However, one can agree that these graphs include them implicitly, but we can also expressed atmospheric stability class slightly in a different manner given by Pasquill, this is called Pasquill's stability class of atmosphere.

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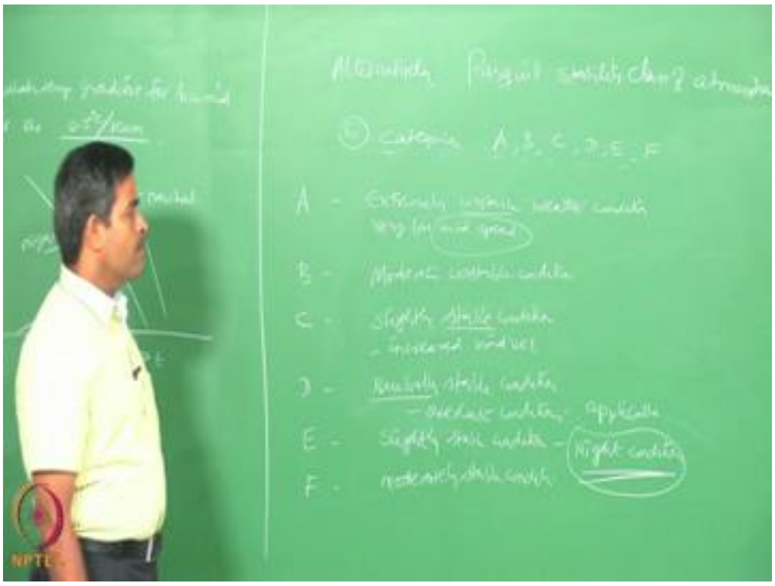

So, alternatively Pasquill's stability class of atmosphere is also popular in dispersion models. The Pasquill stability class divides the entire range into 6 categories. The earlier case, you saw this is divided into 3 categories; unstable, neutral and stable and whereas, in this case Pasquill stability class divides the whole issue 6 categories namely; A, B, C, D, E and F. So, they are letter given classes which can be explained as below. Let us say, A refers to extremely unstable whether condition with a very low wind speed. B refers to moderate unstable condition. C refers to slightly stable condition with increased wind velocity. D refers to neutrally stable condition which is used for over cast conditions. E refers to slightly stable condition which is used especially for night conditions. F refers to moderately stable condition.

One can easily see there is of course, a correlation between the Pasquill stability defining the atmospheric condition with that of the earlier case, you can always see here unstable stable at neutral. They anyway inbuilt, but in addition to that Pasquill stability class also addresses wind speed, the light conditions about night, day, etcetera which was not explicitly present in the earlier case. I want you to pay a attention to the table which is being shown in the screen now.

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Table shows the Pasquill stability classes for day and night conditions

Surface wind speed	Day, incoming solar radiation			Night, cloud cover thickly overcast		Anytime heavy overcast
	Strong	Moderate	Slight	>1/2 low clouds	<3/8 clouds	
<2 m/s	A	A-B	B	F	F	D
2-3m/s	A-B	B	C	E	F	D
3-5m/s	B	B-C	D	D	E	D
5-6m/s	C	C-D	D	D	D	D
>6m/s	C	D	D	D	D	D

If we look at the table shown in the screen, the table shows the Pasquill class stability, classes for day and night condition, one can very easily see here in the condition instructed are the surface wind speed, which varies from 2 meter per second or lower than that to as high as more than 6 meter per second.

Now, it also includes for the solar radiation during day time and the night cloud cover which is thickly overcast. It includes both these atmospheric conditions as well you have to also apply this for any time heavy overcast and when you talk about day time, one can say strong, moderate and slight variation talk about night cloud cover, one can always say is it more than 50 percent of the clouds or lesser than 3/8 of the clouds present. Once you have these surface indications which can be physically notified, which can be also measured using meter. So, the wind speed is concerned then one can easily categorized different stability classes varying from A to that of F, as you see in this matrix as shown in the screen and of course, the alphabetic letters A, B, C, D, E and F in this particular table refers to a discussion what we just now have on the black board. So, A refers to extremely unstable, whereas F refers to moderately stable condition.

So, friends one can describe the presence of atmospheric condition which is very important to calculate the interference of the atmospheric condition, in terms of pollution caused by the dispersed cloud, vapor cloud or gases which are produced from the source which is nothing, but your processing plants located onshore to use an atmospheric solution model. You have to also include the atmospheric conditions which are also one of the important factors that govern the dispersion models used for air pollution the fourth factor which we saw is as follows.

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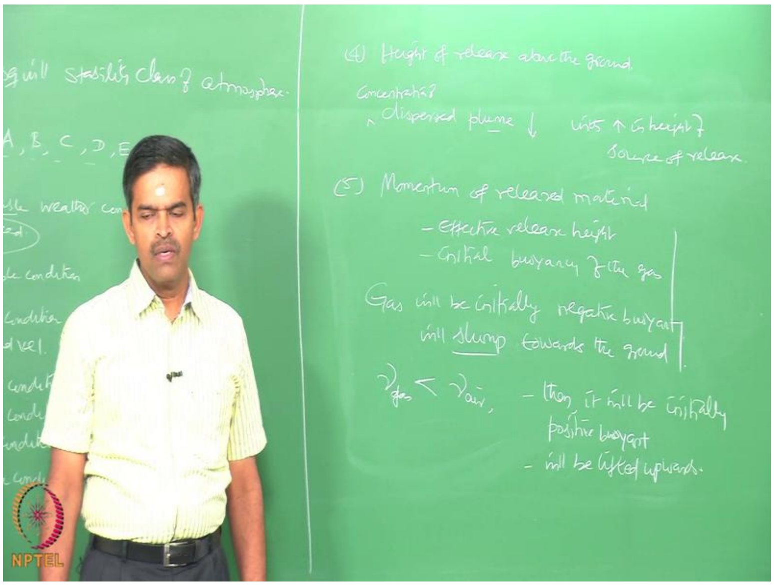

The fourth factor which governs is the height of release above the ground. The ground level concentration of the dispersed plume decreases with the increase in source of the release site. So, the dispersed plume decreases or one can say the concentration of the dispersed plume decreases with increase in height of source of release I want to pay attention to the figure shown in the screen now.

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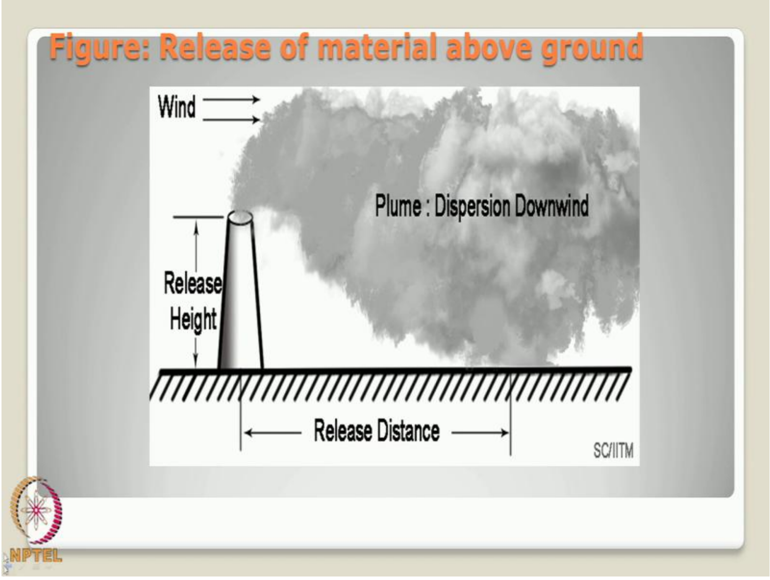

The figure shows release of material above ground. So, one can see here, if this is chimney or a stack, this is realizing the gas into the atmosphere and if this is a predominant wind direction as you can see from the wind rose diagram, one can see the released vapor or the gas goes high and it takes a specific distance to touch the ground. It means this is what we called as released distance.

So, one can very easily interpret that the effect of the dispersion downwind because of the blue model will be significantly affecting their population of the society located in this area and beyond which is not effected and below which it is not affected. However, the effect of this plume dispersion on the downward direction is unimportant over a specific height universally with the atmosphere. So, we are now talking about two issues here, one the concentration of the dispersed vapor cloud nearly surface the concentration of disperse vapor cloud or the vapor or the gases above a specific height on the atmosphere.

So, the released distance can be designed in such a manner depending upon the released distance fixed by you. One can always fix what should be the height of the stack which is going to release the gas, which is one of the important designed parameter in any affluent design systems especially for controlling air pollution in plume models. The fifth factor what we discussed is the momentum of the released material. Of course, it depends upon the effective released height and of course, what is the initial buoyancy of the gas which is being released.

Say, for example, if momentum of high velocity jet will carry the released material with a velocity higher than the point of release. It is very interesting to know certain common properties about gas, gas will be initially negative buoyant and we will slump towards the ground. However, if the gas has lower density than air, if the density of the gas is lower than that of air in the case of release then it will be initially positive buoyant and will be lifted upwards. So, these are the five factors which actually effect by dispersion release model. In case of both, intermittent release and continuous release what we call otherwise as plume and puff release models as we have been discussing in both these lectures. Now, let us talk about dispersion model for neutrally and positively buoyant gas.

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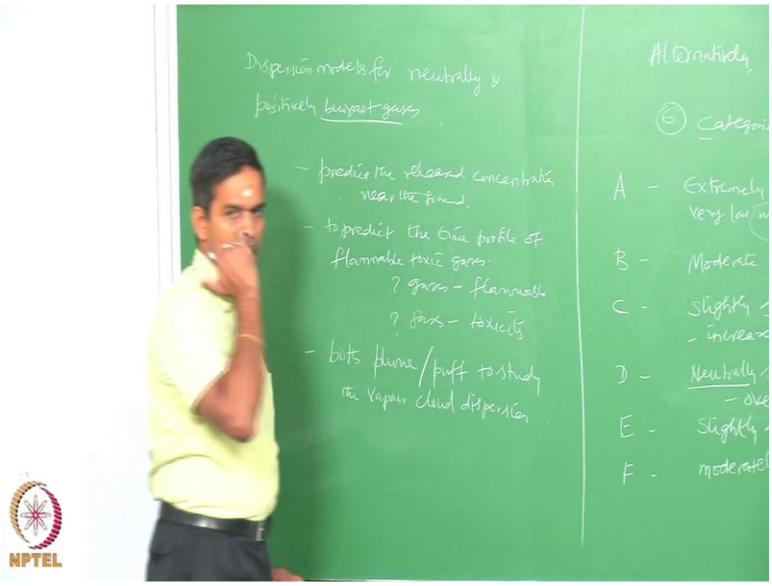

Neutrally and positively buoyant gas dispersion model are very useful to estimate the average concentrations of the respective released gas near the ground surface. So, they are useful to predict their released concentration near the ground. The second could be they are helpful to predict the time profile of favorable toxic gases. It means under what conditions the gases will become flammable, under what conditions the toxicity of the gases can become severe both can be interestingly studied and this can be predicted from this model. So, one can generally use both, plume and puff released models to study the vapor cloud dispersion we all know.

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It has been explained earlier plume models describe the continuous emission of material from a steady height above the ground. Let us try to explain this graphically, let us take the wind direction be along x-axis. Kindly pay attention shown on the screen shown on the screen now.

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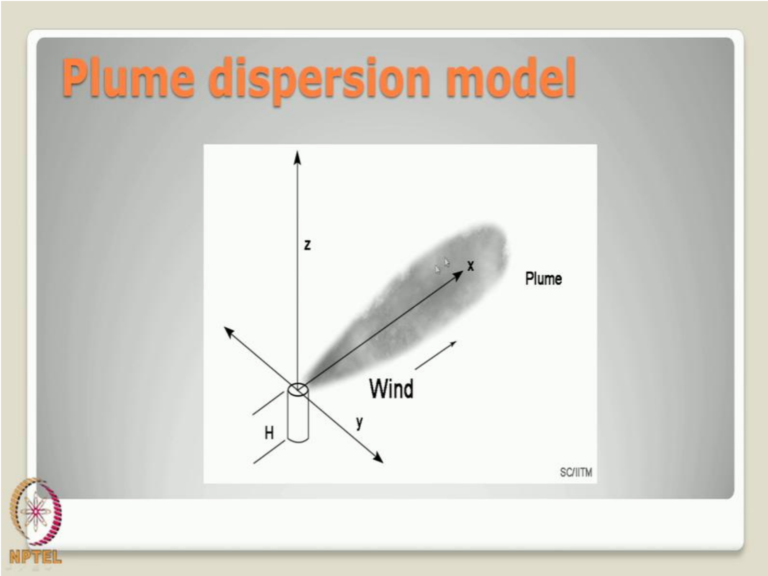

Which is a classical plume dispersion model used in the literature as explained. This is the point of release of the gas which is at a constant height H from the ground and the wind is blowing predominantly in the direction along the x-axis.

So, this x-axis and we are now showing in the figure the dispersion of this in terms of the y, z and x planes which is a plume model, which is used for the continuous release or continuous emission. So, when the emission is continuously coming out from a stack whose height is H from the ground which is constant, how this model will actually spread or dispersed in the atmosphere is what we are all talking about in physical terms mathematically.

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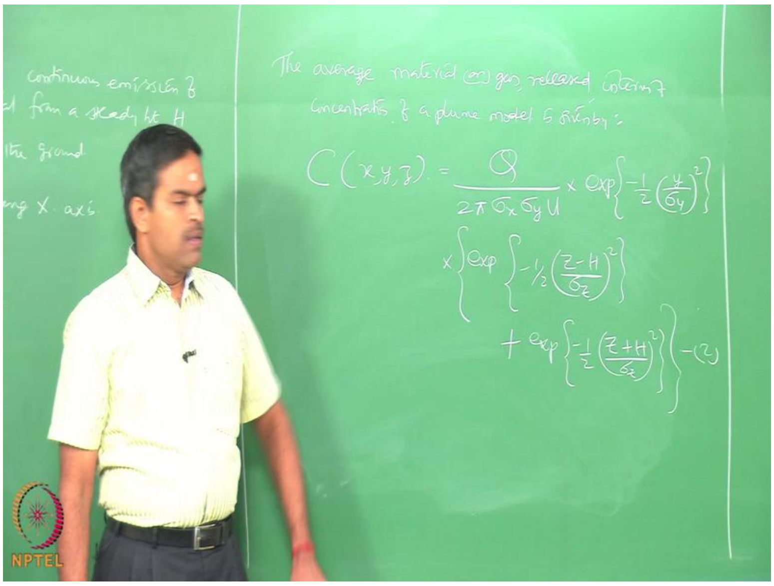

The average material or gas released in terms of concentration of a plume model is given by C that is a concentration on an x, y, z plane is given by Q by 2 pi sigma x sigma y u exponential of minus half y by sigma y square multiplied by I mean, I have multiplication here exponential of minus half z minus H by sigma z square plus exponential of minus half z plus H by sigma z square call equation number 2, where C (x, y, z) is the average concentration of the released gas which is usually consider in kg per cubic meter.

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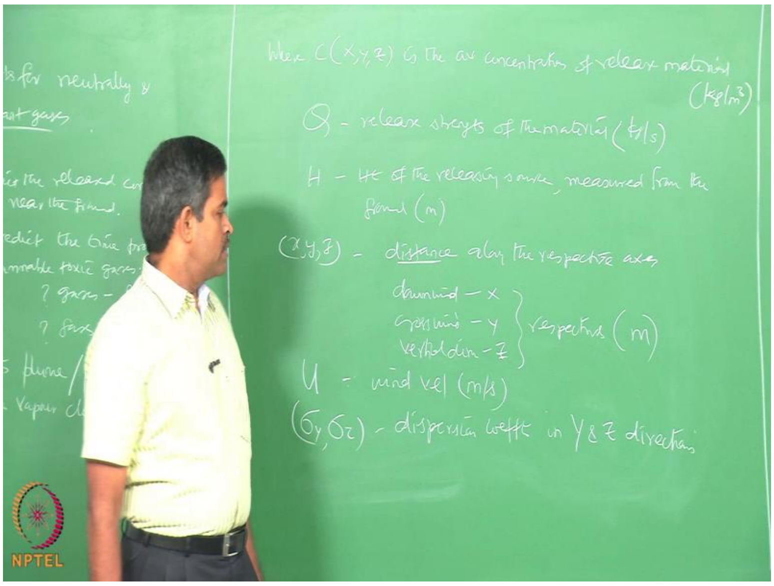

Q is the released strength of the material which is expressed in kg per second; H in this equation is the height of the releasing source or at the height at which the gas is released measured from the ground.

Of course, the units will be in meters x, y and z are the distances along respective axis. Please note, wind is blowing along the x-axis. So, therefore, one can say down wind that is x-axis, cross wind that is y-axis and vertical direction that is z-axis respectively and we are talking about distances. Therefore, the unit is going to be m meters, U in this expression is the wind velocity which can be obtained from the wind rose diagram for a specific location expressed in meter per second and sigma y sigma z are what we call dispersion coefficients in y and z directions respectively, sigma x of course, is considered implicitly in the model itself.

So, we will talk about the discussion of this model in terms of its application in specific cases in the next lecture. So, friends in this lecture we discussed about the factors which effect the dispersion release model, which can be used for understanding the atmospheric pollution caused by the vapor or the gas released from a specific source, which essentially if comes from, let us say in other case of understanding or interest comes from a processing industry which is actually a crude oil refinery which is located onshore.

So, the factors which affect them individually, including the wind, velocity and direction or the wind speed and direction then the climate effect what we call atmospheric stability, which can be defined by 3 classifications or by 6 regions of Pasquill stability class, which includes the day, night, weather, solar radiation, etcetera above the height of the source of the material released about a terrain effects and of course, the momentum of release which is being done in the dispersion model.

In addition to that we have been discussing in detail about the gases released, which is positively buoyant which is now used for a continuous release model with a plume model we are presently discussing, which we will continue to discuss in the next lecture also.

Thank you very much.