Environmental Air Pollution

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Lecture No. 27

Examples: Solar Radiation based Stability Calculation

What we will do is look at a few examples and try to answer them.

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What does example one say? Several studies have shown that in power plants, 95 percent of the sulfur in the coal is emitted through sulfur dioxide. What you have to do is derive the expression for emission factors. We all know about the importance of the emission factors. We need to have good emission factors to estimate emission inventory. With this emission factor, you can find out what will be the emissions let us say in Kanpur area, you can find out the total emissions in the Uttar Pradesh state, you can find across India and you can do the comparison from state to state, inter-comparison from one country to another and so, emission factors are very very important. What you see is 95 percent.

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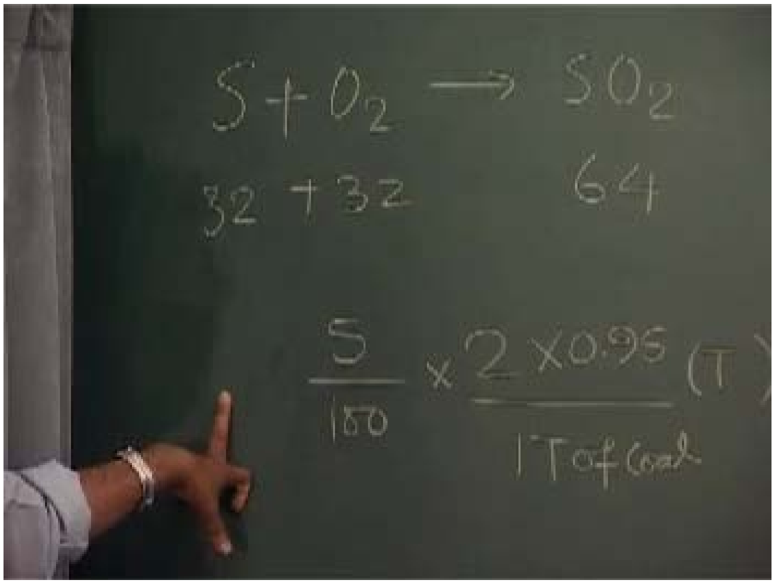

In sulfur dioxide, sulfur is present and if you recall, we said that in coal, almost the entire amount of the sulfur is converted to sulfur dioxide (if you recall the earlier discussions) and that forms SO_2. Here, if I take the molecular weight as 32 and this as 32, this gives you 64. Whatever is the sulfur, you get the sulfur dioxide twice of that. Let us say the sulfur content in percentage is S or the real sulfur is times…. This is sulfur percentage or this is the sulfur fraction in the coal. If you take this as 2 times of this, then it will be the sulfur dioxide that will be emitted; 95 percent of this comes out and not the entire thing is converted, as per our definition or as per the problem. This is 0.95. What are the units for this emission? It depends on the coal units you have taken. Let us say we are talking about 1 ton of coal. So this gives the tons of sulfur dioxide.

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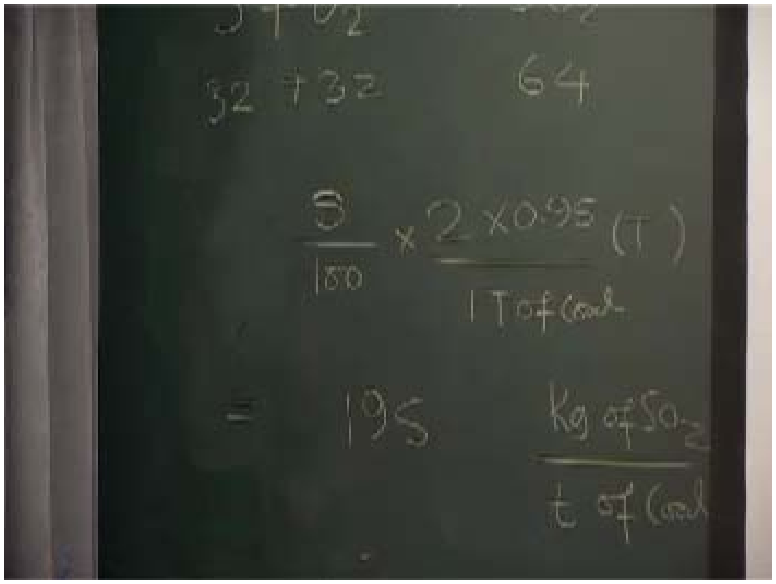

Can someone quickly convert this into kg of sulfur dioxide per ton of coal? We require kg of SO_2 per ton of coal having percent content of sulfur. What I want is in kg of SO_2. How much is it coming out to be? Quickly write that for me. This is the sulfur content S, which can vary from coal to coal and can vary from oil to oil. How much is that coming out to be? I have not done the calculation although I know the number. Can you can quickly tell me what that is coming out to be? S is a variable and in coal, the sulfur content will vary. If you take coal from Assam, it will vary; if you take coal from the north Indian fields, it will vary; if you take coal from lignite in south India, that will vary. What does that factor come out to be? What is that coming out to be? Quickly, can you do that? 19 S, correct? That is the factor I wanted you to do – come up with 19 S; that many kgs of SO_2 will be emitted by burning 1 ton of coal. Is that clear to everyone?

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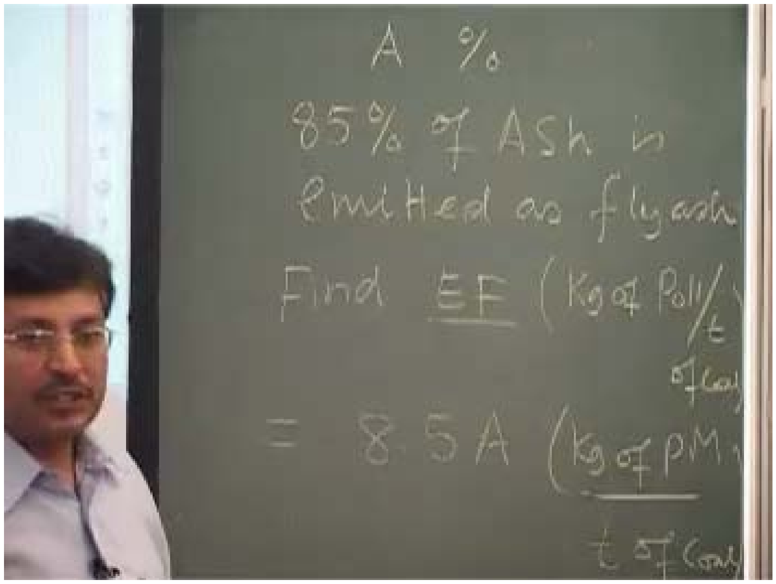

Suppose I had the same example and I said the coal has ash content of A percent and I also gave you the example that 85 percent of ash is emitted as fly ash. Find the emission factor and generally (it is not a standard thing), we write the emission factors in kg of the polutant we are talking about per ton of fuel or coal. Then, why am I writing 85 percent? You might remember that when you burn coal, there are two types of ash that come out. One is the fly ash that goes up through the chimney and there is something called bottom ash, which falls at the bottom of the boiler. Generally, the bottom ash is about 15 percent. So the same way we developed the factor…. I am not doing the calculation, but this will come out something like…. A is in percentage of ash. Ash will come out as particulate matter and so I can write kg of PM (that is particulate matter) per ton of coal and we can check.

That is how the emission factors are developed or derived. I just extended the example from sulfur to particulate matter emission that may come out by the burning of coal. Somebody can ask why it is 95 percent. They are based on a lot of experimental studies that have been done and they found out that theoretically, all sulfur should burn to sulfur dioxide and in fact, it does but in the process of combustion process, some is converted into SO_3 and part of the sulfur dioxide is absorbed by the fly ash – very little amount and somehow, that gets removed. That was just an idea of how the emission factors are calculated.

Let us have a question two. It is an oil refinery and what is important is in the bracket – the isolated source has been accused of contributing serious air pollution to the ambient air in the surrounding area. The following information is available. Only four wind directions are available – north, east, south, west and the wind speed in kilometers per hour is in this range. When wind is from north…. We always remember that when wind direction is from north, it means wind is to north or from north? From north. From north and so when wind is blowing from the north, around 70 percent of the time, the wind speed range is this, for 20 percent of the time, it is this and around 10 percent time, it is this. The frequency of wind blowing from north is 50 percent and the mixing height – that is defined and that you know very well now – is the vertical distance up to which the pollutants can disperse. Evolve an impact factor for each direction based on the linear sum of the inverse of the mixing height. I will write the factor for direction N.

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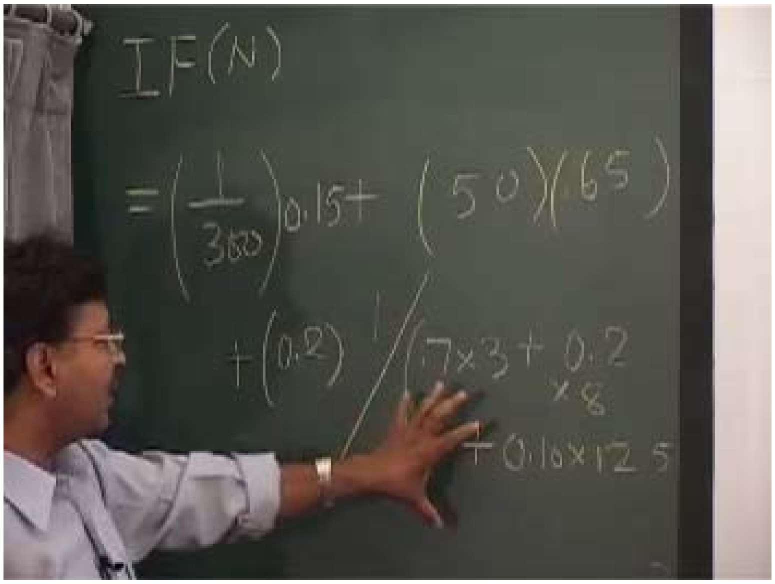

I can write the impact factor for direction north this as.… Whatever it says, we will do. So inverse of the mixing height and whatever units are given – you do not have to change. Inverse of mixing height, so 1 by 300 linear combination.… Linear combination of what? The second thing is percent frequency of the wind direction, so percent frequency is 50 plus the third thing is what? Inverse of the mean wind speed, so we have to calculate the mean wind speed for the… we are talking about the north. What you can do is 0.7 times 2 plus 1, 3 plus 0.2 times – you are finding out the mean wind speed in the direction north and 0.2 times what do I write here? 8 plus 10 percent, so 0.10 times the average wind speed in this range will be 12.5.

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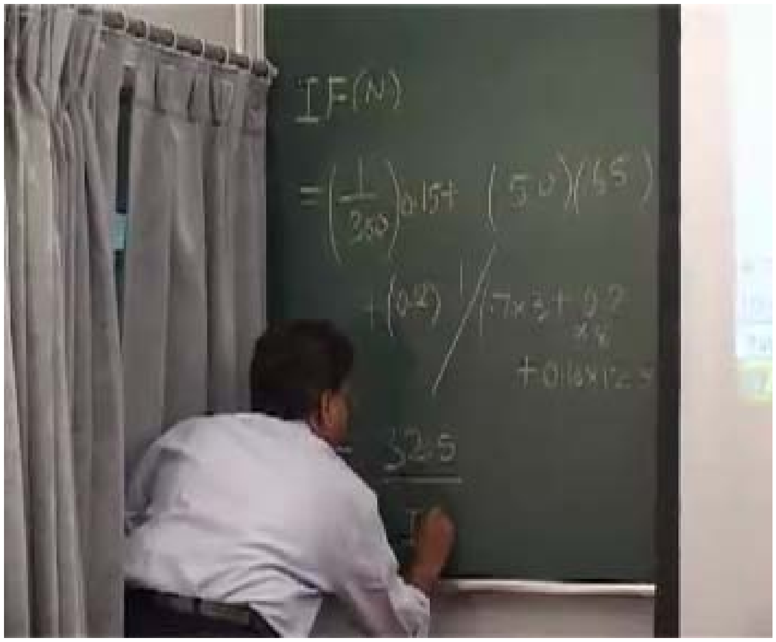

The range is 10 to 15, so average is 12.5 – I do not know if you can see that. I have to write everything in inverse because it says this is inverse and so, plus 1 by this. Then, what does it tell you? With the obtained impact factor, with weights factor of 0.15, 0.65 and 0.2 for three terms – first term, second term (Refer Slide Time: 11:07) and third term. How much is the weightage for this? 15 and this is 0.65. How much is this? 0.2, so this is the impact factor for north. I thought the problem is very clear and straightforward. That is what you have to do and that way, you can find out the impact factor for various directions.

Very quickly, you can see at least for this example, this is going to be a very small number, this is going to be a very small number – fraction of something, 0.7 into 3 and this and that and that comes out to be 4.5, the large number will be this. You can do the entire calculation or simply you can ignore these for simplicity. Actually, you should find out the full term but if you really see, how much will this come out to be? Close to 32.5. The impact factor is largely depending on the wind direction and it will be 32.5. What will be here? Can anyone give me the number? 20

into 0.65, that is about 13, right? 13 and then you have 10 here, so 10 into 0.65, that is about 6.5 and this will be again 30.

What you can write is that the maximum impact factor is from north and the minimum impact factor is at south. If you recall, I said in the class that when you want to find out the impact of a source, what you do is you try to look at the downwind direction where the wind is blowing most of the time and the direction in which the wind never blows – that will never have an impact on this. To see the impact of this, where should I put my station? The question asks you what should be the two locations. With the obtained impact factor, find the directions of 270 locations, which would assist in reaching a just conclusion if the industry is really contributing to the air pollution in the area. If I have to see the maximum impact, where must I go and put my station? North or south?

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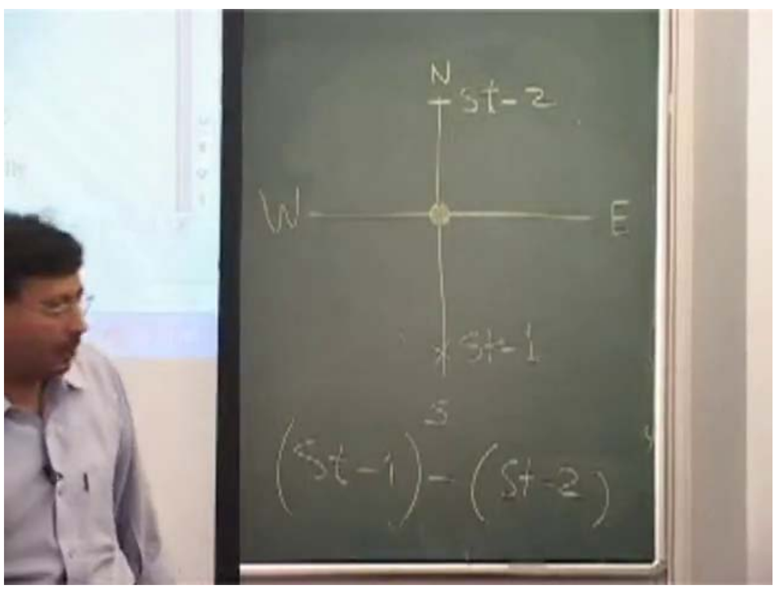

South, because when the wind is blowing from the north, the impact is maximum, right? I have to put one station here and that is my station 1. Where do I put the other station? In the south because that is where the impact will be minimum – when the wind blows from south, the impact will be minimum; when wind blows from south, it means the impact will be in north and I can put the second station in the north direction. Then, I have to see the difference of the levels that one obtains at St-1. If this difference is too much, then the industry is causing problems; otherwise, it is not causing. Some of you have got this one right. Is this clear?

[Conversation between student and professor - Not Audible (15:34 min)]

Here? What do you say? If we take it as 25?

[Conversation between student and professor - Not Audible (15:56 min)]

It will not matter. You can apply your mind but the question is asking you to formulate a problem and you formulate the problem the way it is asked. You may disagree with the problem, you may say that the wind direction is not important and you say that mixing is important – that is your understanding and logic, but when we are trying to do a problem, we try to do exactly what the problem wants us to do. This is just to give you some idea of how air pollution could be related with mixing [16:33]. How to really find the impact in terms of the quantification, those things are more complicated, but this was just to establish what is the direction where we do the sampling to establish if the industry is really causing a problem or not causing a problem. In this figure, remember that we are assuming the oil refinery is here.

[Conversation between student and professor - Not Audible (15:56 min)]

You convert that too but unless you have been asked to do that, you take the numbers the way it is given to you. The factor is dimensionally not correct – arbitrarily, a factor has been decided. Even if you take that in kilometers, your answer will not change because purposefully, lot of weightage is given to 0.65 to the wind direction – that was the idea. Let us try to do the next problem. This one of course required some formulation and some thinking but then, it was not so difficult either.

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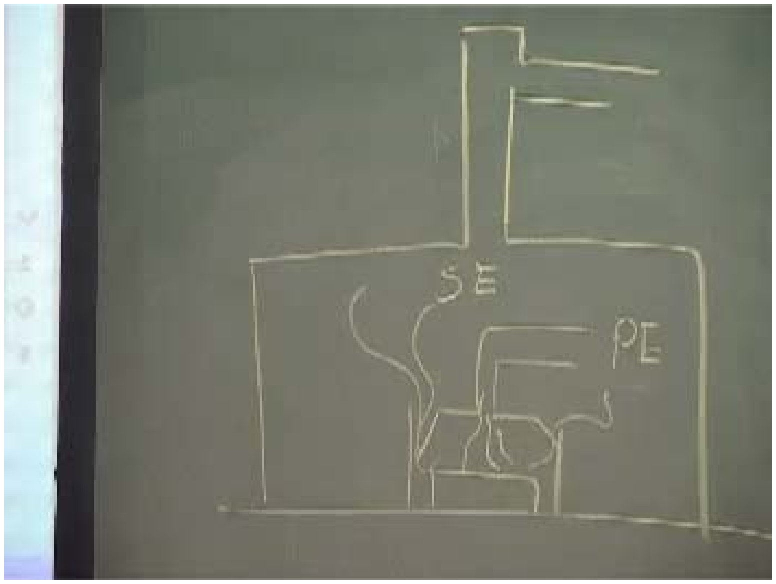

This is the aluminum refinery – all of you know that, this is your production part, this is what we call as primary emissions, if you recall. This is a kind of hood, if you recall and these are the emissions that are going through the hood, but some emissions as you see will escape and that is what we call as the secondary emissions. Then, this will go for the primary control and these emissions that are secondary go to the secondary control – we have discussed that earlier. Now, the problem says so much of tons per year, the aluminum plant are 20 kg of fluoride, ft here is the total fluoride – ft represents particulate as well as the gaseous fluoride for every ton of the aluminum produced.

The industry wishes to install both primary and secondary treatment control systems to attain an emission standard of 1 kg of ft per ton of aluminum produced. The following details are given: gaseous component is 40 percent of the total fluoride, removal efficiency of the secondary control system for both gaseous and particulate is 60 percent, removal efficiency for primary control system for gaseous and particulate is 98 percent and the collection efficiency for gaseous and particulate provided at hoods varies. If the collection efficiency of the gaseous fluoride is 90 percent, what should be the minimum design efficiency for particulate fluoride so that the industry meets the emission norms? If you understood the problem, what it is saying is that the collection at the hood varies for gaseous and varies for particulate. Is that clear? When we did earlier, we showed that the collection efficiency was the same. Now, let us talk about the uncontrolled emission first.

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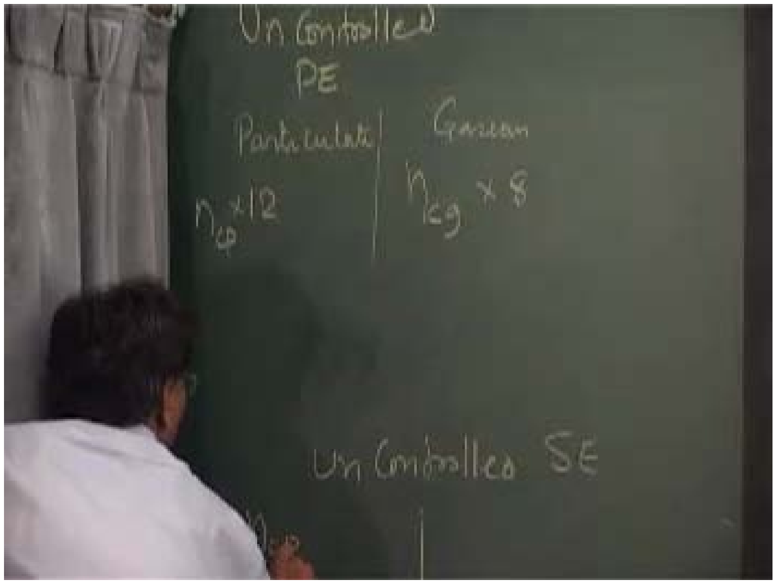

Which emissions? Primary emissions. What can I say? I have two components. I am talking about uncontrolled primary emissions in the particulate side and here, I write gaseous side. It depends on the collection efficiency of the gaseous, so I can write this as cg and here I can write particulate. How much is the particulate emission? 20 is the total and out of that, how much is the particulate? 20 is the total ft, 20 kg of total fluoride and you say that the gaseous is 40 percent. So how much is the particulate there out of 20?

Are you sure? 12 kg. 12 kg. 40 is gaseous and so particulate is 12 kg. As I have told you over and over again, in the aluminum industry, we always do all calculations based on kg per ton of fluoride – even if you want to talk about the gases required, you say kg per ton of fluoride required. If you agree, then I can write that as 12. What do I write here? 8. This is the uncontrolled primary emissions. I also want to write uncontrolled, let us write a little below here, secondary emissions. Again, we can do separately for particulate and gaseous. Here, what I do is I write 1 minus n_{cp} – this has gone into the primary and so whatever is remaining, that is 1 minus n_{cp} will go through my secondary emissions uncontrolled – we are not talking about how much is the controlled.

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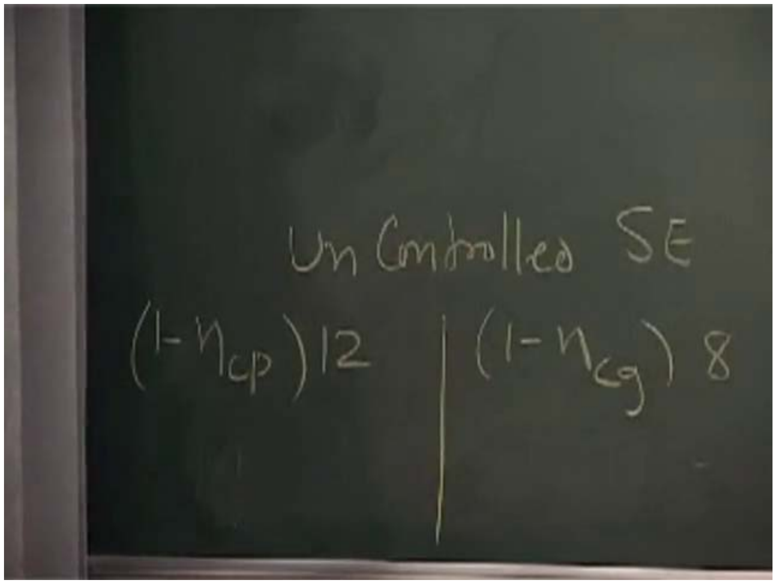

I can write this as 1 minus n_{cp} times 12. Here, I can write 1 minus n_{cg} or eta_{cg} times 8. So far, no problem? If you have a doubt, ask me. Now, what I am really interested in is after the control device. Once I am controlling this (Refer Slide Time: 24:03), let us see after control how much will be left over. Control efficiency or removal efficiency or the primary control system is 98 percent. How much is the emissions from the particulate?

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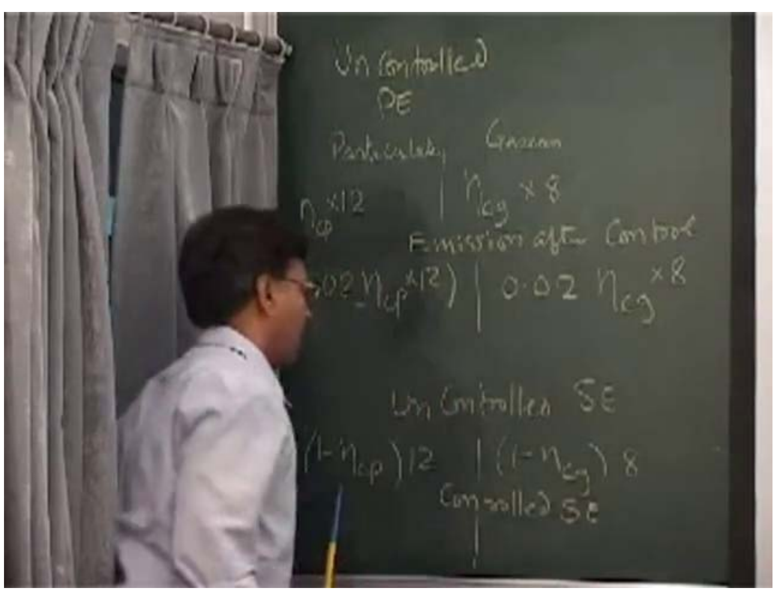

If you agree, I will write the numbers 0.02 times n_{cp}. Agree? It is because 98 percent is removed. Then do not forget that what I am trying to do here is emissions after control. This is the particulate – 98 percent is removed and what is left is 0.02. Here again, 98 percent is removed, what is left is… into 8. Agreed? Similarly, what do I write here? Out of this, how much is controlled in secondary? How much percent is controlled in secondary? 60 percent. 60 percent. I can write here for the gaseous side. Now, what I am trying to do underneath this is controlled emissions – controlled secondary emissions.

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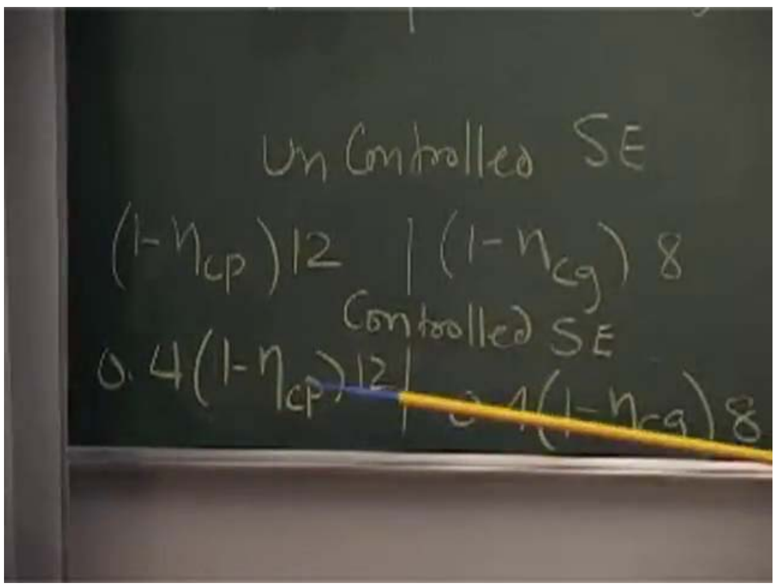

If 60 percent is removed, how much would go out? 40 percent, so 0.4 times 8 and here also, it is the same and so 0.4… and I leave you to see this. Again, 60 percent is removed, so 40 percent. We are talking about controlled secondary emissions – so much emissions are still going to the atmosphere as particulate and gaseous; in the primary also, particulate and gaseous. Do you know n_{cg} or eta_{cg}? Is it given to you? How much is the number? 90 percent. There, you can write 0.9 (Refer Slide Time: 26:38). This one is also 0.9, this is also 0.9 and then I will find out the total emission.

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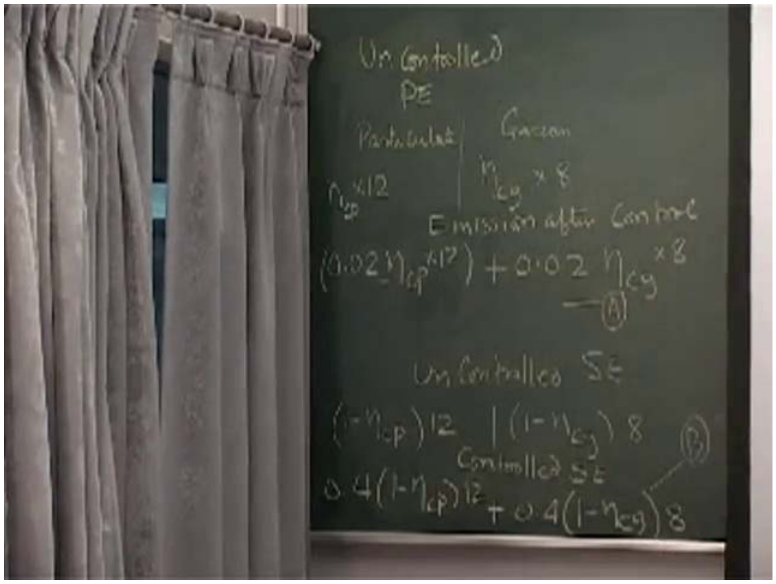

What is my total emission through the primary source? Particulate plus gaseous. Same thing I will do here – particulate plus gaseous. Now suppose I am calling this as A and this as B. With the definition or with the problem, A plus B should be equal to or less than 1, right? That is the allowable emission. Where do we see that rule? So that the industry meets the emission norm. What is the emission norm? The industry wishes to install both systems to attain an emission standard of 1 kg, so this is equal to 1. I am not writing the units on purpose.

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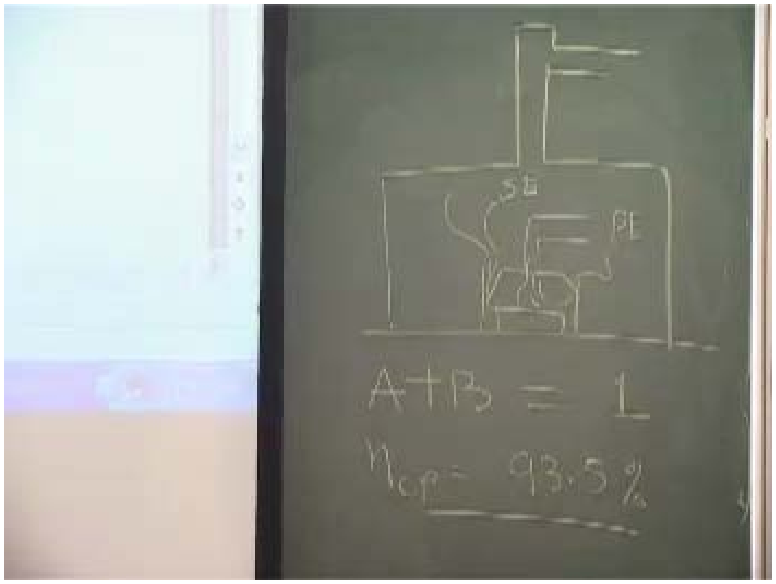

The only unknown that is there is n_{cp} or eta_{cp}. That answer comes out to be.… We are not running through the calculation part, but that came out to be…. Many of you have done that correct. Is that part okay? All right? Clear? Very good. The problem was simple but it needed to be formulated properly. Given a situation, we expect you to be able to formulate the problem. No one will ask you a straightforward question saying this is the formula, put in the numbers. You have to spend some time understanding the problem. In fact, formulating the problem is sometimes is more difficult and more important than getting the solution because you will know the solution once you write the problem properly – it is sometimes simple and it could simply be algebra, but the formulation comes from your understanding of the problem.

I want to spend a little time talking about something that some of you might know rather well and some of you may not know at all. For the benefit of everyone, if you recall, what we were trying to do in the last class was that we were trying to estimate the solar insulation – how much is the amount of radiation that is reaching the earth. We said that if we know that, we know our stability – with the tables that we discussed last time, but to get to the incoming solar radiation, we have to spend some time understanding a few terms, not into great detail.

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See the picture here. There are two terms that we are trying to define here: H and alpha. You can see here north, east, south, west. Take this as the horizon. What do we mean by horizon? The horizon is a plane passing through your eyes. Clear? Whatever the star you might be considering…. Suppose you are standing at the center – for the time being, I can assume I am sitting at the center of the earth. If I am standing at the center of the earth, will the equator plane and my horizon be parallel or not parallel? They will not be parallel because the equatorial plane is inclined whereas my horizon is horizontal. If there is the sun or whatever the star is there, this angle that I make is H from the horizon or if I drop a perpendicular from here to here – the angle that I form is my H.

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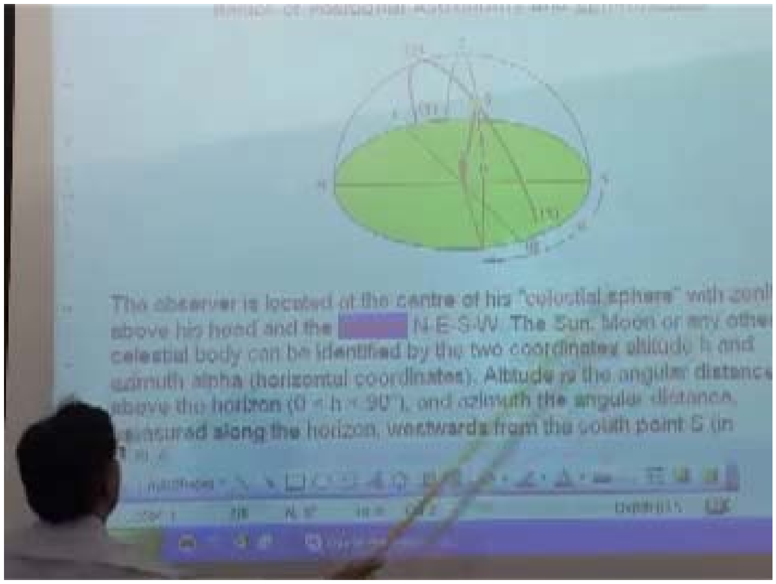

I read this to make it very clear – the observer is located at the center of his celestial sphere with the zenith Z is above his head (that is there) and the horizon is NESW [31:54] this plane – that is his horizon. The sun, moon or any other celestial body can be identified by the two coordinates altitude (that is H) and azimuth. Altitude is the angular distance above the horizon and will be between 0 and 90 degrees, while azimuth is the angular distance measured along the horizon westwards from the south point. There are two things here – azimuth and the altitude H. Why are we defining these things? We will need them in a few derivations that we might do.

Let us also quickly read. Some people measured it through eastward also from the north – it should say somewhere north… from north… different things are there. The daily movement of an object resulting from the rotation of the earth on its axis starts when it rises at 1, 2 and sunset is 3 – that is what he is referring to. The daily movement of the object resulting from the rotation of the earth on its axis starts [33:37] and it passes across the observer's meridian – wherever I am standing, I will have the meridian at that point, reaching at the maximum altitude above the horizon and it sets at 0.3.

Now, I am slightly changing things. What I am changing is I am no more talking about the horizon – I am talking about a plane of equator. There is a clear difference between the plane of horizon and the plane of equator, because depending on your location, your plane of horizon will vary, right? You are close to the North Pole, you are in America or you are in India – your horizon will change and if you are in Australia, your horizon will be entirely different, but then we want to have a better coordinate system and so what we are taking is not the horizon but the equatorial plane – the plane that contains the equator will be the equatorial plane.

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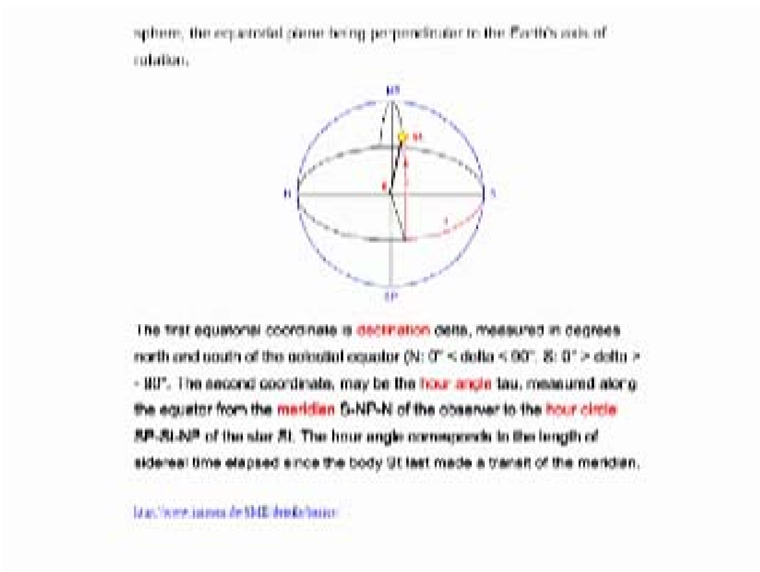

What you see here is the equatorial coordinate system. The horizontal coordinates of the object depend on the location of the observer on there that we saw in the astronomy because you want to have these things without any ambiguity and confusion. Equatorial coordinates are commonly used when giving the position of an object of the celestial sphere. What is celestial sphere? The sphere that passes through the star and through the zenith – that will become clear here.

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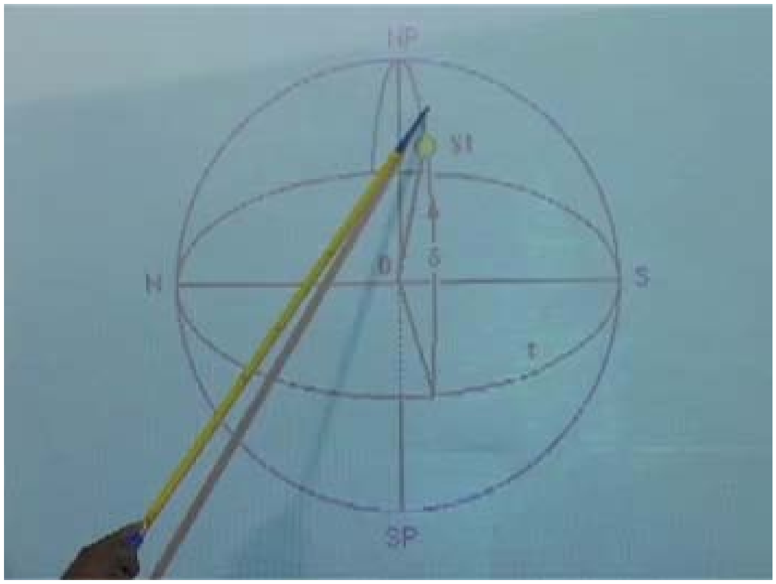

For a moment, I can give you this picture. You see this is my equatorial plane, the earth may be here and the plane that is containing the equator or the complete equator surface is this plane (Refer Slide Time: 35:49). Then, the sphere or the circle passing through the… or the sphere that will contain the… onto the surface, the star (the center being the same) we call as celestial sphere. Now, we want to define two things. What we defined as H, now we are defining as delta and we call it declination. But now, this is defined on the celestial equator. The earlier thing was on the horizon. Similarly, we defined the azimuth on the horizon before and now, it is on the equatorial plane – this angle starting from south, the tau you see here is called hour angle.

Do you think the hour angle will change from time to time, every hour? That will change because what it is doing is it making the angle from the sun's position to your meridian and as the earth is rotating with respect to the fixed sun, suppose the fan is my sun and I am rotating, my hour angle is changing – this angle is changing with this thing, the hour angle changes. What about the declination? The declination will not change in the day but then, the sun's position is changing every day – that declination change is a different thing.

With this background… are commonly used when giving the position of an object on the celestial sphere. The equatorial system is based on the celestial equator, which is the great circle obtained by projecting the earth's equator to the celestial sphere – the earth's equator plane you extend it till it comes within the larger sphere of the celestial sphere, the equatorial plane being perpendicular to the earth axis – it has to be; our equatorial plane is perpendicular to the axis of the earth.

The first equation coordinate is declination – that is our delta, measured in degrees north and south of the celestial equator. That again is something very similar to H, but our plane on which we are measuring is different. The second coordinate may be the hour angle tau this thing of the star St. The hour angle corresponds to the length of the sidereal time elapsed since the body, the star last made a transit of the meridian. The sun may be fixed but as it is rotating, my position or my meridian is making a different angle all the time and so tau is changing. This is the Web site if you want to look at this – I will pass on this information to you.

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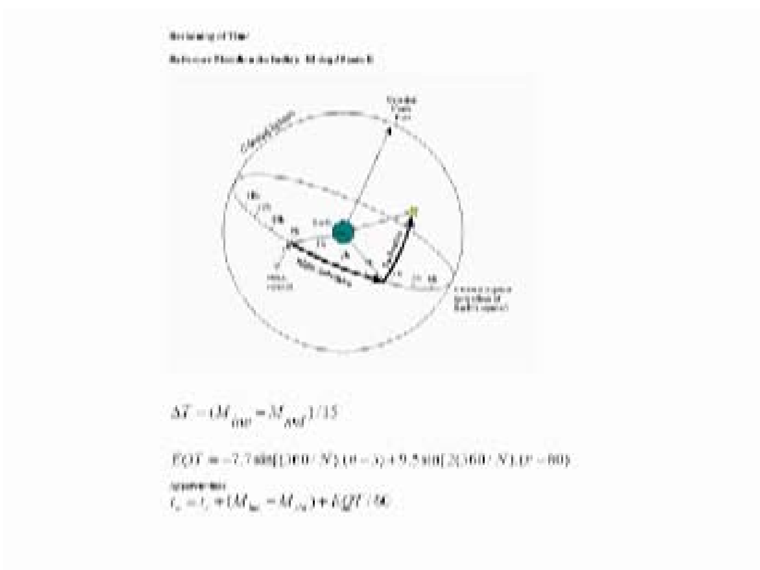

To make things slightly more clear, you see another other picture here. Now you see the inclined plane. The earlier plane with my horizon was the horizontal plane. This is the earth, this is your celestial equator plane, then this is moving, this declination is fixed but this hour angle changes with respect to time and that is what I want to do. I will pass on this information to you. We do not need to spend a lot of time, but I will start using the H and deltas and sigmas but you should have some idea and then you will agree with me that these have importance with regard to the solar radiation that will reach us. How that is done – that we will do in the next class; in the next class, we will discuss it further. Meanwhile, I will pass on this information to you have a look. We will stop here. Thank you very much.