Fire Protection, Services and Maintenance Management of Building
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Lecture – 05
Process of Combustion: ventilation and fuel controlled fire

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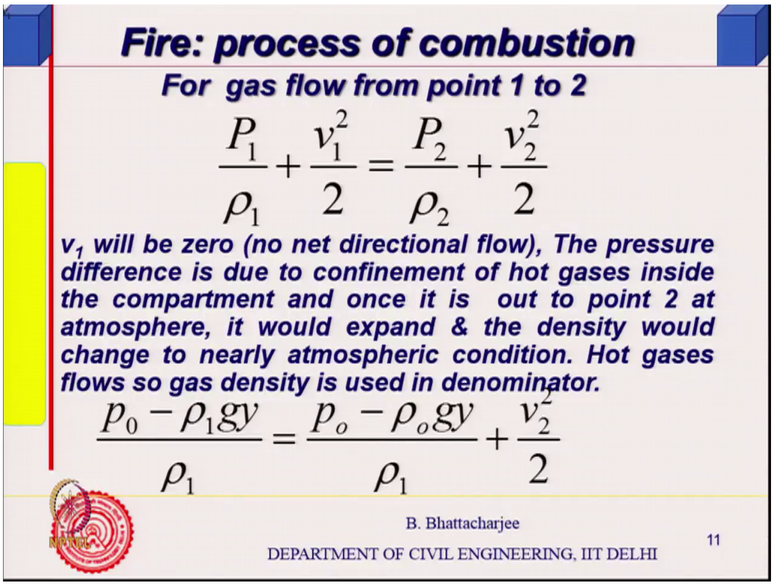

So, we look at the Process of combustion; repeat some of the portions what we have done last time. We have seen that we can apply Bernoullis equation to point 1, 2 and 3, 4. And since there is no no bulk movement, you know there is there is no streamline flow at 1, so we take v 1 equals to 0, and v 2 because that was at the top v 1 is inside, and v 2 is just outside at the hot gases. And v 2 is what we are interested in finding, so that we can quantify the quantity of volume of flow.

So, we take v 1 equals to 0. And the gas hot gases is moving out, so we take density of hot gases throughout right, density of hot gases throughout and write that equation. So, if you write this equation P 1, P 2 expressions we had earlier in terms of y at any distance y from the neutral plane.

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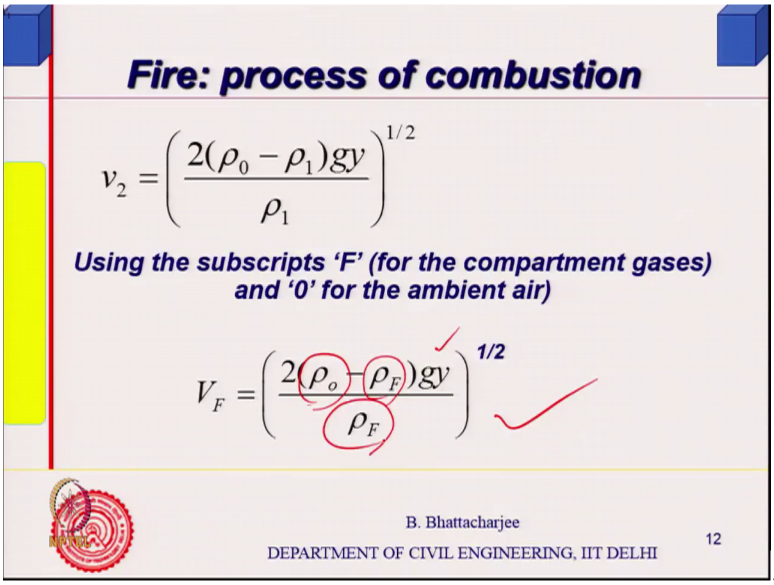

And then we can then just simple algebra gives us v 2 is equals to 2 rho 0 minus rho 1 divided by rho 1 g y etcetera, etcetera to the power half. Now, rho 1 is nothing but we call it rho F that is density of hot gases; rho 0 is that of ambient air or you know similar because everything whatever comes out will expand. So, we write this V F, because this is a velocity v 2 corresponds to velocity of hot gases. So, V F at any point y hot gases velocity of hot gases is this given by this kind of an expression that is you know that is it is a function of y. So, this would be for the ambient air, this is for the hot gas and at a distance y. So, we can find out.

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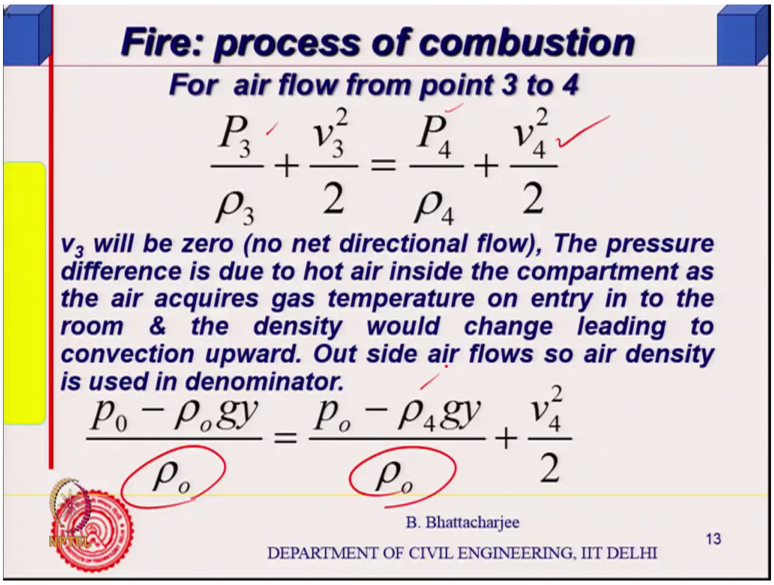

Similarly, we can do an exercise for 3 and 4, points 3 and 4. And here we assume the velocity v three is equals to 0, because that is outside; 4 is inside, and you know like outside air.

Student: (Refer Time: 02:29).

Right, right, right, and here just inside the inside the inside the compartment, where fresh air is just entering, this is the velocity of the fresh air coming in. And P 4 and P 3 was already available to us. So, therefore, we just put it. And since air is what is begin we take density of air throughout, and replace this by rho you know.

Student: (Refer Time: 02:57).

rho f.

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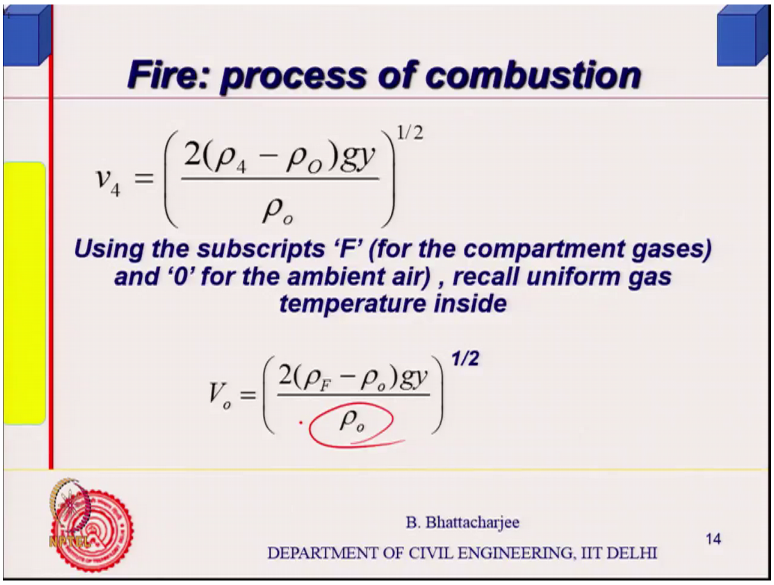

So, so that is how we do it. So, rho 4 is rho F right. So, putting F and 0 subscript that is what we get overall it is rho 0 because hot cold air, air is coming in and that is how we get the velocity at a distance y below the neutral axis of fresh air right.

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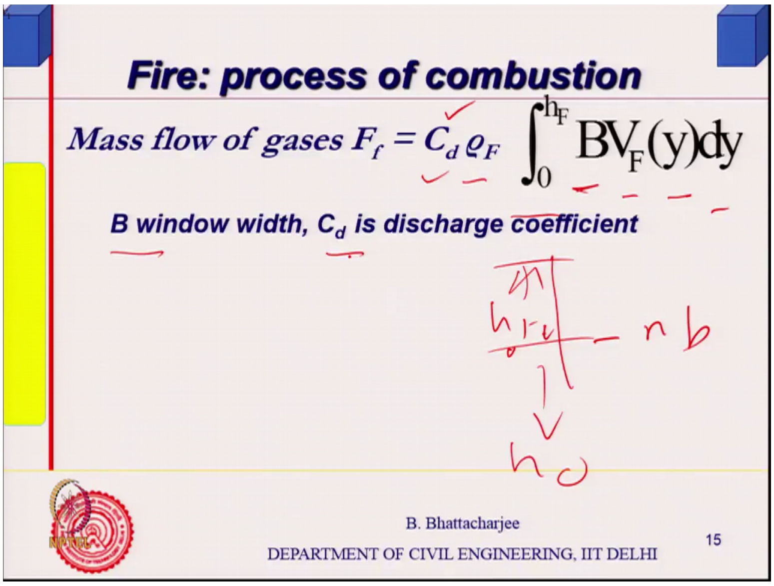

So, mass flow of gases, therefore one can find out by multiplying this velocity and integrating over 0 to h F because it was something like this. This is I am calling as h F there is neutral plane and that is I am calling as.

Student: H naught (Refer Time: 03:40).

H naught to 0, so that is the I can integrate B is the width of the window or opening velocity as a function of y dy. C d is a discharge coefficient because in you know we are assuming so many things we are assuming it is a stream flow and applying Bernoulli's equation and all that, so there has to be a discharge coefficient there and this is a hot gases so density of hot gas. So, there is a mass flow of hot gases. So, B is the window width; C d is the discharge coefficient so that is what it is.

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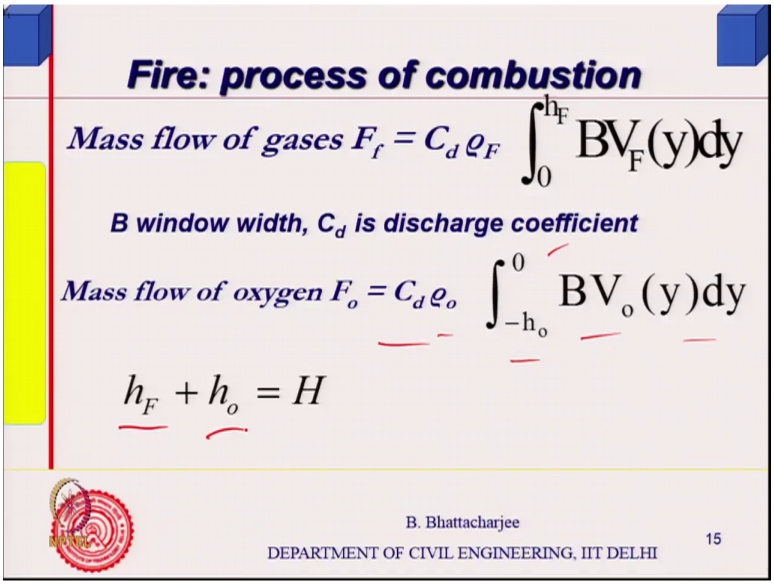

Now, similarly I can find out the mass flow of oxygen. Similarly, I can find out the mass flow of oxygen C d rho 0 minus h 0 to 0 v 0 y d y etcetera, etcetera. So, now this mass flow whatever hot air comes in, it must be reacting with the product of pyrolysis and producing the hot gases; their ratio of this mass, I can actually ratio of this mass I can obtain in terms of the you know say unit mass of product of pyrolysis reacts with r unit of oxygen then 1 plus r would be the product. So, if r comes in, 1 plus r will go out that is what we are assuming. And second thing is another expression is h F plus h 0 must be equal to capital H.

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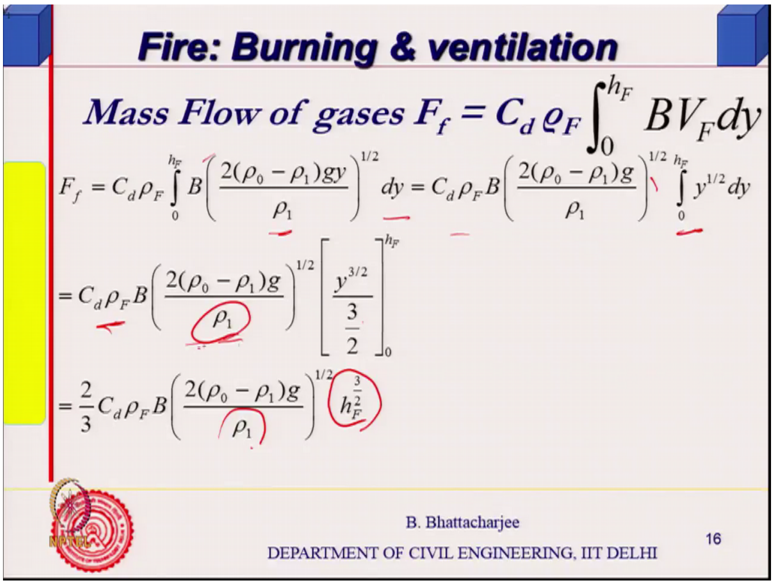

So, these two ratios if I look at it, integrate it from 0 to h F, then if I integrate it I get it y to the power half. So, this y to the power half integration would give us you know y to the power 3 by 2 by 3 by 2 and rest all is outside the integral sign. So, I just put them there, there. And simply you know simply find out the you know do a little bit of algebra. So, it is h to the power 3 by 2 h F to the power 3 by 2 and this, this one is there is there is you know this is rho F available here, this is actually rho, rho this should be rho F actually. So, rho F to the power half and this is actually rho F this is rho f. So, rho F and this rho F, it will it will come here you know.

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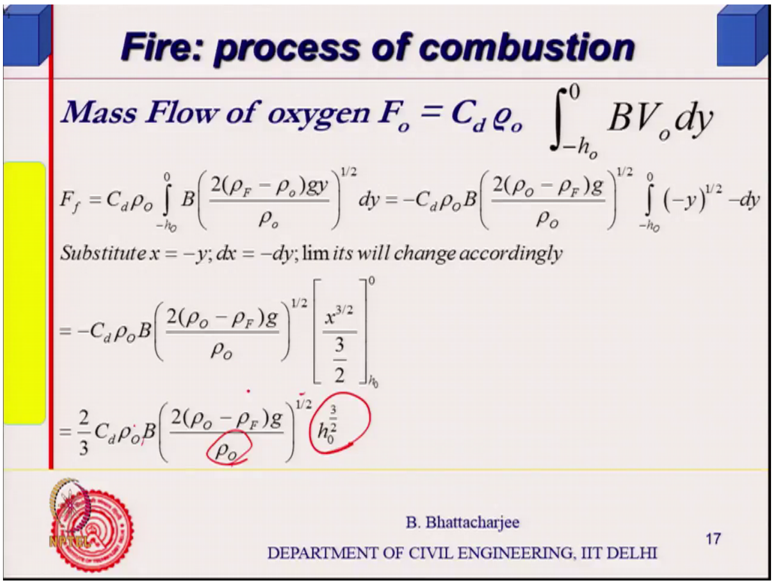

Final expression turns out to be something like this. Both these cases h 0 to the power 3 by 2, and there it was h to the power h F to the power 3 by 2. And rho 0 is here rho 0 to the power half and rho 0. So, what will get it this all of.

Student: (Refer Time: 06:26).

Yeah, actually this will you know this ratio of course, when I take ratio many of these things will cancel out. So, if I take ratio, this is how it is actually this is fine this there is no problem, but that should have been that should have been actually rho F, this should have been rho F, this should have been rho F, this should have been rho F because we are using that notation rho F notation we are using. So, now, I can find out that ratio as I am saying.

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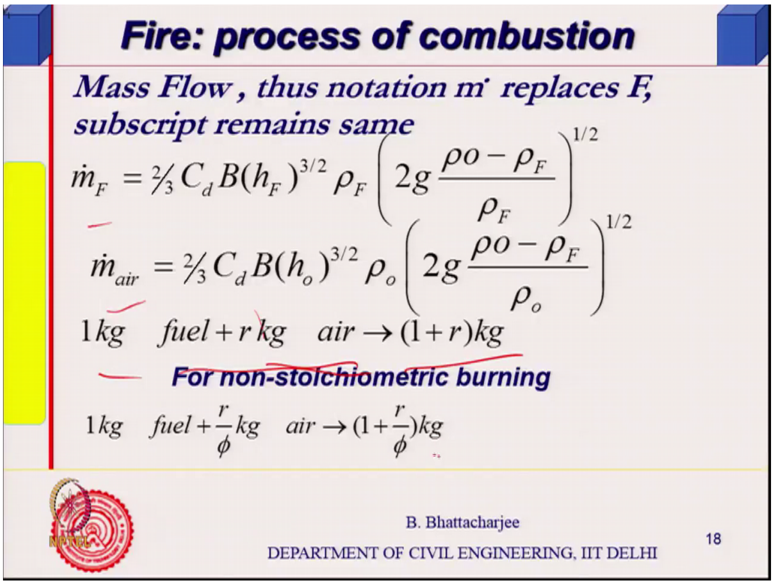

Ratio of ratio of you know m dot F the hot gases coming out; and the air coming in. And this if I divide this ratio if stoichiometric relationship is something like this; 1 kg of fuel reacts with r kg of water producing 1 plus r kg of. And for non-stoichiometric burning I can use a factor that not all r is reacting, r divided by something is reacting that is phi could be more than 1. In that case, it will be 1 plus r by phi k g, so that is what that is what it is.

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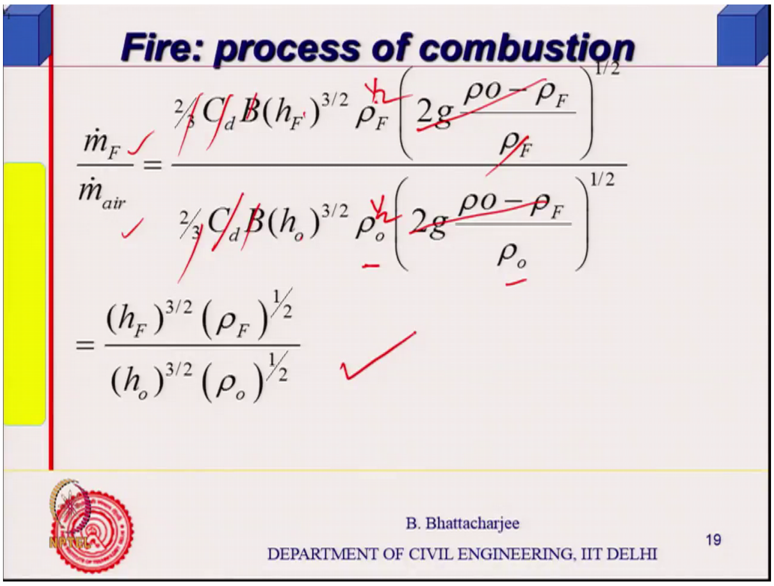

So, this ratio this ratio would be m dot by m air, I can find out this would everything will cancel out because this portion this portion will cancel out; this portion will cancel out. This comes to the power rho to the power half rho 0 to the power half and this becomes rho F to the power half, this is rho you know, so this cancels out h F and h 0 remains, C d cancels out, 2 by 3 cancels out, B cancels out, so I am left with this. So, this is the mass flow rate of hot gases outside by mass flow rate of air inside right air inside ok.

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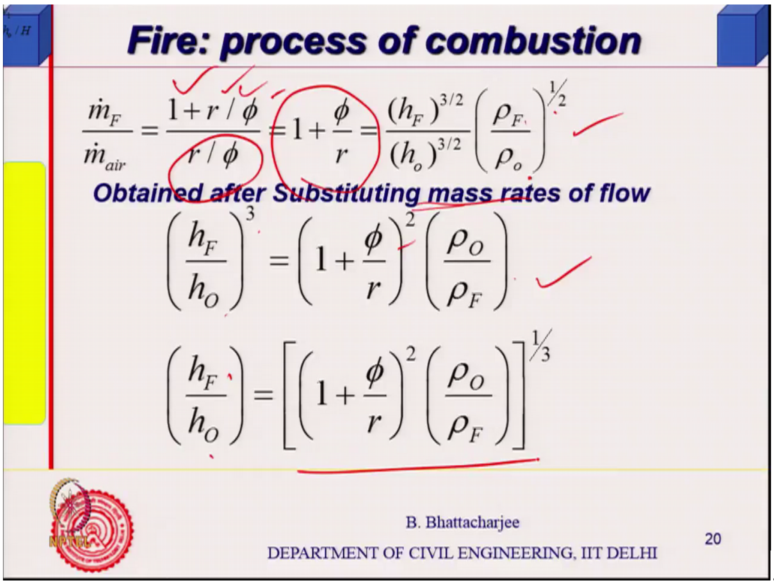

So, this ratio if you must be equals to this, 1 plus r plus phi divided by r by phi, because this is the total product of our gases. 1 kg of combustion or combustible or pyrolysis product of pyrolysis reacts with r kg of air or oxygen. Phi is a factor for incomplete burning, so that much you know they will have some amount remaining as product of pyrolysis itself. So, this ratio if I look at it 1 by phi r this must be equals to quantity of hot gases come going out divided by quantity of hot gases I mean fresh air coming in.

So, this ratio is something like this which you have just calculated. And if phi is equals to 1 putting you know I can I can get expression for h F by h 0 in this manner, because square of both these sides this will become square, rho F by rho 0 I will be left to it. And this will be to the power 3. So, h F by h 0 is given by this formula.

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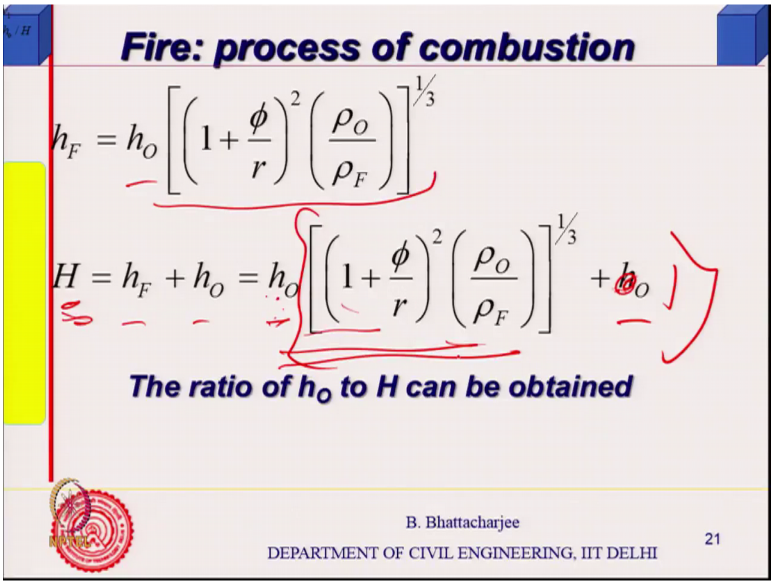

Now, for you know h F can be written in terms of h naught. And we know capital H if h F plus h naught. And therefore h 0 plus h 0, so this is h F, so h F plus h 0, I can write like this. So, this will be h 0 can be taken common, h 0 can be taken common

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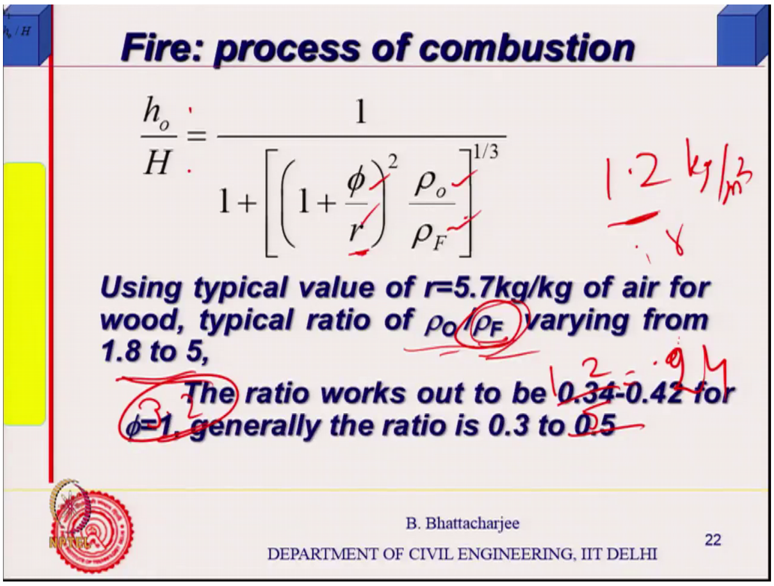

So, I can get h 0 by H a factor like this from this relationship which I told you in the last class. I am just repeating this again, so that this is a little bit of algebra. So, I am repeating it for your better understanding. So, h 0 is 1 plus this, 1 plus this, 1 plus you know h 0 I can take common. If I take h 0 common, then I will get 1 here, this is like this. So, h 0 by H would be 1 over all this term 1 over 1 plus all these terms right. So, 1 plus this term. So, now, as I said typical values of r is 5.7 kg that means, 1 kg of wood or when you burn wood I mean when you heat up product of pyrolysis, when you heat up the product of pyrolysis right, product of pyrolysis, it is consumed 5.7 kg of oxygen product of pyrolysis consumes 5.7 kg of oxygen.

So, 1 kg of wood in a way consumes around 5.7 kg of oxygen. So, this value of r is 5.7 approximately, typical ratio of rho 0 by rho F vary from 1.8 to 5. You know rho 0 is 1.2 kg per meter cube. Fuel would be much less, so this ratio is you know. So, fuel would be something of like this ratio rho F is smaller say one-eighth of this; one a 1.8th divided by nearly. So, this ratio or one-fifth of this, so which means that hot gases will have a density of 1.2 divided by 5 is how much, point 0.24 and if it is 1.8 roughly nearly about 0.6 something like this, so that is the density of the hot gas that goes out right.

So, this ratio is taken. Now, if I take average of this, this comes out to be 3.2. So, I can take an average value for this ratio average value for this ratio, which is 3.2; put here 3.2 take phi equals to 1 r equals to 5.7. And then I get the ratio of h 0 by f approximately for wood burning scenario. This value seems to vary from you know I am repeating this from last class, so that is why I am going a little bit faster.

So, typically this ratio works out to be 0.34 to 0.42, 34 to point (Refer Time: 12:20) you know for four phi equals to 1, but in real case, phi is not usually 1, it is somewhat higher, it is somewhat higher, because you know burning wood actually not all product of pyrolysis or all product will burn something will go as unburnt product of pyrolysis itself. So, taking general approach you know empirical values has been seen as it is 0.3 to 0.5, 0.3 to 5.

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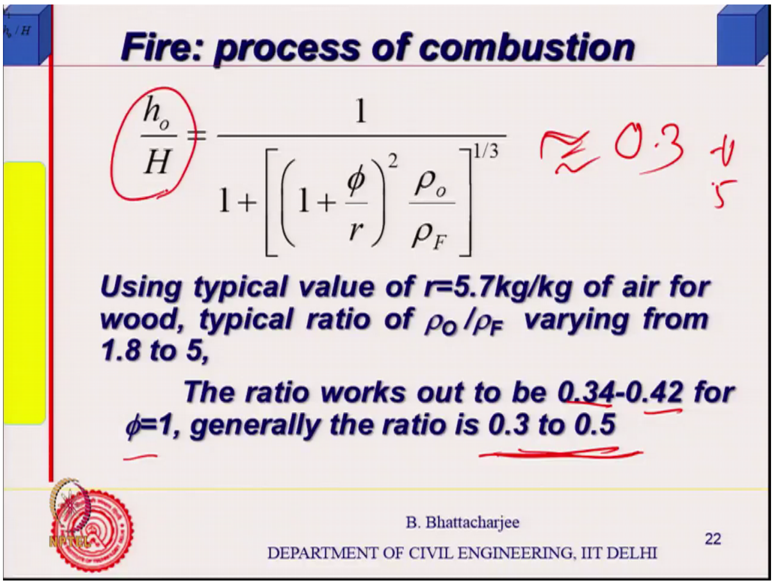

So, h 0 by this is 0.3 to you know 0.3 to 0.5, 0.3 to 0.5, 0.3 to 0.5 all right, so that is that is that is it.

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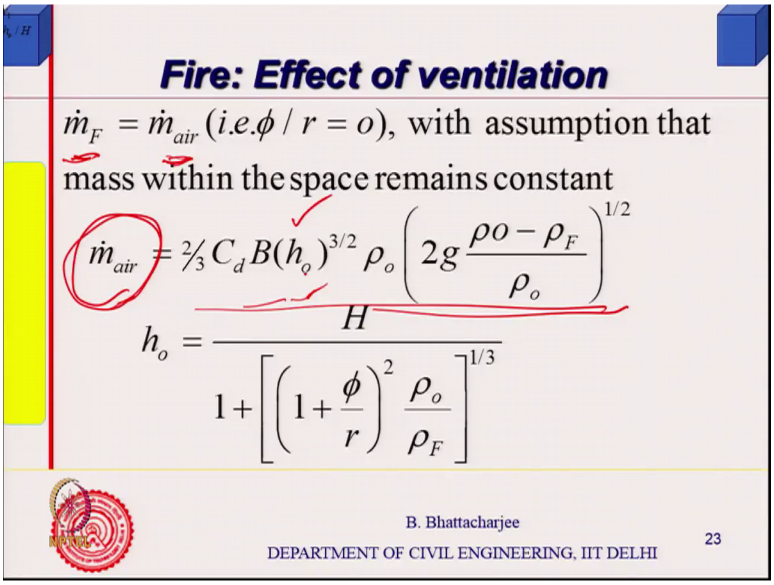

In other words, now I can actually relate everything you know you relate everything in terms of all H in terms of the capital H itself. Now, if we assume m dot is m m F dot rate of material coming in is equals to rate of hot air you know hot hot hot air going out is equal to rate of fresh air coming in. Because mass within the space remains constant then I can you know m dot air I can calculate out, I can calculate out m dot air. So, rate of oxygen coming in I can calculate out which is which was given in terms of h 0 which I have already you know this expression was available to us. Now, I put h 0 in terms of capital H, h 0 in terms of capital H, because h 0 was available in terms of capital H. So, I put it in terms of capital H.

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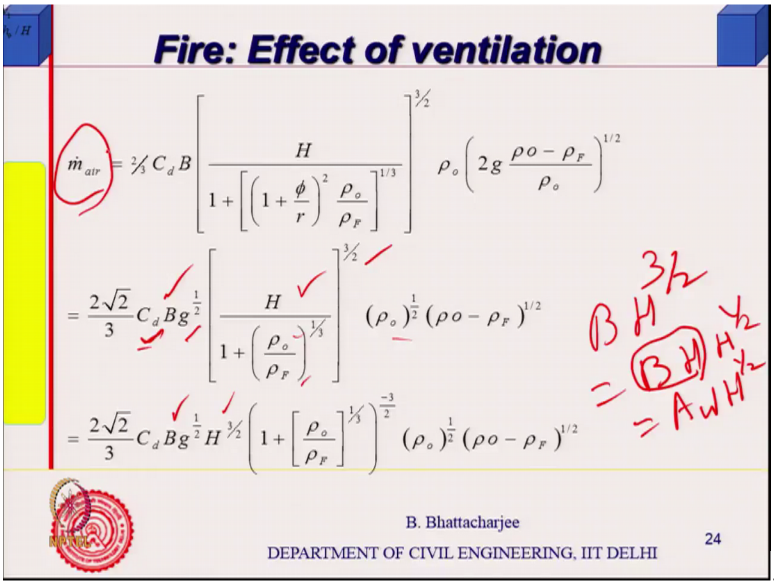

And if I I get an expression for, I get an expression for m dot air in terms of H to the power 3 by 2 and B; rest of the things are constant value. C d is the discharge coefficient; C d is a discharge coefficient which is we know from various studies empirical value, because there is no way you can theoretically derived by and generally not theoretically derive. So, C d is known; g is known; rho 0 rho F we take as same ratio as 3.2 and you know. So, rho F rho 0 values roughly values are known to us. All that are related to the room is B into H to the power 3 by 2. What is B into H or I can write it like this. What is this? That is the area of the window so, area of the window into H of H to the power half.

So, the mass flow rate of oxygen or mass flow rate of hot gases which will be nearly same because mass remains constant that is what we are saying is a function of area of the window and square root of the height of the window. Now, remember ventilation factor I was mentioning earlier empirical studies you know I gave you a formula for calculating the equivalent fire resistance q f. This factor is called ventilation factor. So, the values are not important because lot of them are empirical. But what you I want to understand I want to make you to understand is that the area of the windows or openings, total area of the openings and square root of multiplied by square root of the height which we call as ventilation factor that governs the rate of air flow into the room, rate of air flow into the room right.

So, if you have less, you will have less air flow into the room. If you have this high, high air flow into the room. Now, if it is less, what does it mean, it could be ventilation control. If it is very high, then it is simply controlled by the fuel. Now, the derivation is and you know important to understand this one, but finally, what we are doing is we are taking so many empirical factors, ratio averaging about for hot gases. So, what we take is a constant multiplied by this is a mass flow rate. This constant has been actually calculated out roughly taking all the relevant values like I said take rho 0 by rho F equals to average value 3.2 and take g as the r.

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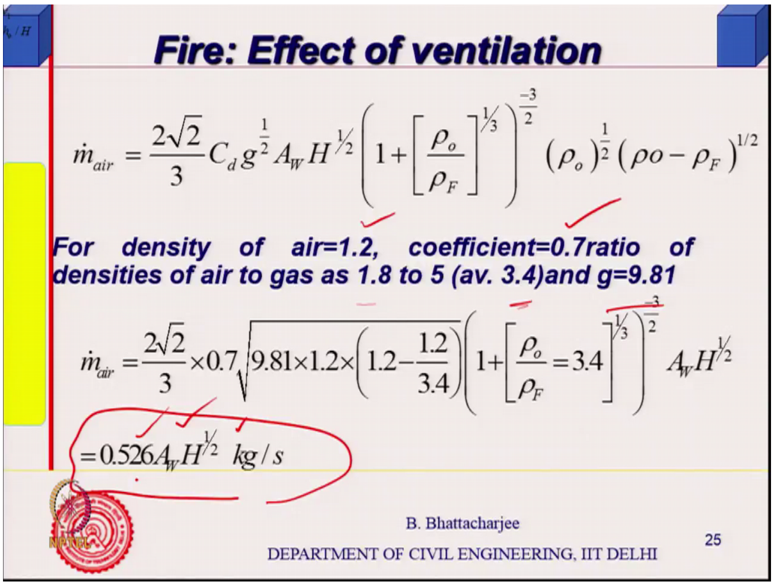

So, so C d appropriate value of C d, so by doing all this you know one can actually find out for density of air to be 1.2; C d is equals to 0.7, ratio of densities so take three point yeah four is averaged; g 9.81. By doing all this, for wood actually one can get a value of 0.526 A W H to the power half. What is important to understand is that it is a function of this factor, ventilation factor a constant multiplied by ventilation factor.

We call this as ventilation factor. We call this as ventilation factor; we call this as ventilation factor all right, we call this as ventilation factor. So, this is important; this is very important that is a fact. And this value is also important this is kg per second everything 9.81 centi you know meter per second we have taken. Now, if I convert this into minute, I will divide by 60 right; convert this into minute, it will be divided by 60. And how much does it come to 60.5 to 6 divided by 62.0.

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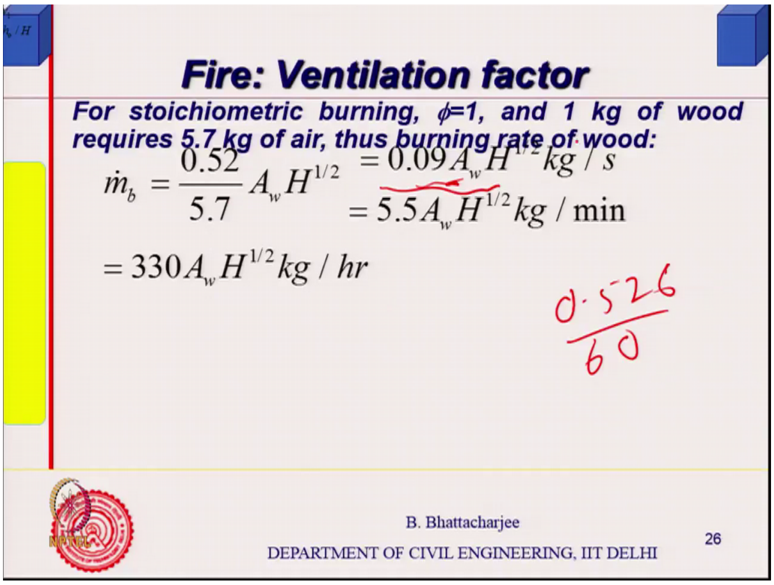

Approximately it will be you know 0.09, 0.526 by 60, so it will be some somewhere close to 0.08 something right. So, it is taken roughly as 0.09 A W sorry ah.

Student: Multiple.

No, no, no that is this, there is a 5.7 yeah. So, now, taking just a minute taking phi is equals to 1, and a 1 kg of wood and etcetera, the burning rate of the wood will be given by this for wood; oxygen increase this much. Oxygen is 0.526 A w H to the power half. How much will be a quantity of oxygen you know this is a this is a entry of air, how much you divided by 5.7 divided by 5.7 which is the stoichiometric relationship of wood and this.

So, if I divide this by 5.7 we get 0.09 Aw H. So, this is the burning rate of the wood. Burning rate we have defined is the rate of production of product of pyrolysis, rate of production of product of pyrolysis, so that is given by 0.09 A w H to the power half which if I multiplied by 60 how much do I get which you had multiplied by 60 how much do it get? If I multiplied by 60, how much do I get?

Student: 5.5.

Five point yeah something else. So, kg per minute, so therefore, burning rate of wood is given by burning rate of wood is given by 5.5 A w H to the power half and if I in hours then this is 330 A w H to the power half. What is the relevance of this formula? Supposing, I know that total fire load in the room in terms of equivalent kg of wood. So, how long the fire will last? That total kg of wood in the room divided by 330 A w H to the power half.

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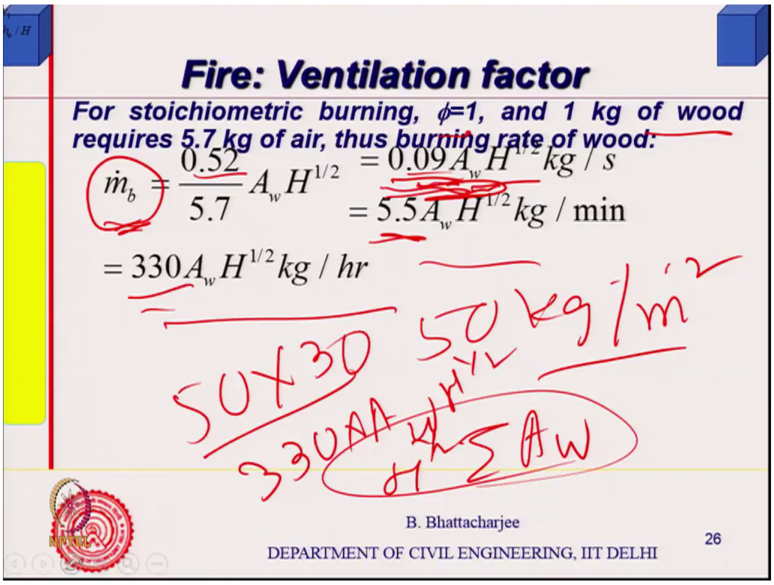

So, if I know like something like 50 kg per meter square floor area equivalent of wood and my room area is let us say 30 meter square. So, total burning time will not exceed 50 into 30 divided by.

Student: 330.

330 into A w H to the power half h to the power right aw h to the power ok. So, what do you do when you have a number of windows will not have single windows. In fact, in case of fire, what happens is glasses breaks down, hot gases even is closed it will break down, glasses you know unless toughened glass takes longer time, but many of the glasses would actually break down easily, unless it is a double glazed there are a lot of other things can be there. But what happens is or even if its window totally window is available. So, what you do you will sum up A w generally h is constant for all of them

and you can assume them in all in series you know all are parallel basically flow path is same the potential gradient across them is same pressure difference is same. So, they are parallel. So, parallel means you sum up all of them.

So, A w sigma A w and H to the power half would be something like that everyone will have H to the power half. So, ventilation factor can be you know summed up, and you can find out. And if you find out this then you can find out how much time it will burn. Now, this is you know it is good these understanding is good if you are doing fire design. But even if you are not doing fire design, in case of you can planning you know how much is the total burning time, what will be the rate of burning. And post fire assessment also this becomes important.

This is what most of the time structural engineers or you know many many people involved with investigation, because there is a fire, there has been a fire, you want to know how long the fire was there. Approximately you can estimate the fire load. And then use this formula to find out well maximum the fire could have been this if it was uninterrupted no even intervention was there. But had there been human intervention obviously, firefighting etcetera, they would have reduced down.

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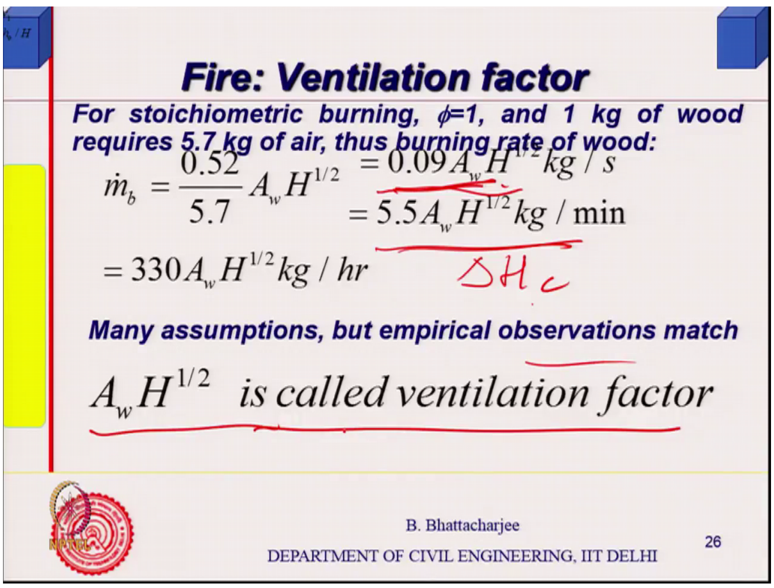

So, this is many assumptions lot of assumptions important formula is this or this is what we will use sometimes we will use them later on also. This is this, the rate of production.

If I multiply this by delta H c of wood, then I will get what this by delta H c, I will get the amount of heat generated per unit time rate of heat generation. So, this formula is important, but what is important is to understand the factors which affect the rate of burning and overall time of burning. So, this is called ventilation factor. So, this I definitely want you to remember that A w H to the power half is ventilation factor ventilation factor right.

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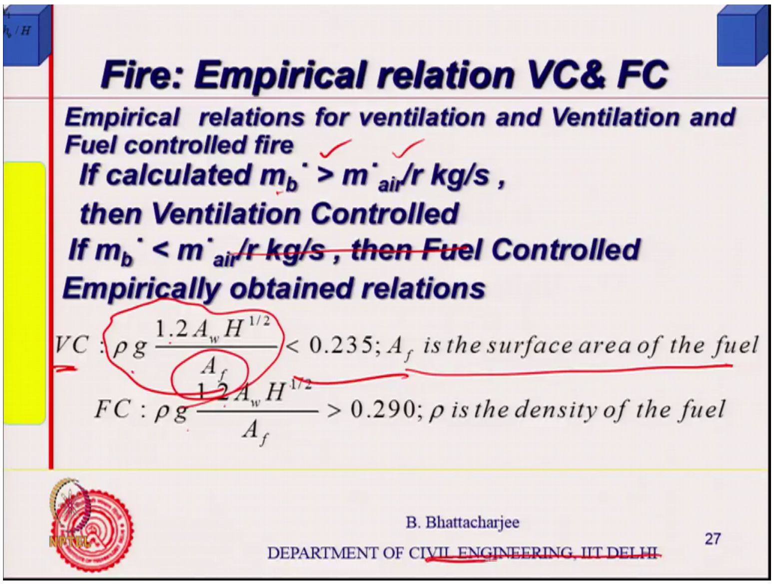

So, empirical relation of ventilation and ventilation factor that is that is people have actually derived. What they have done they have changed A w and H to the power half in furnaces. And they try to find out what was the burning rate, because one can measure this burning rate as well or heat generation or whatever it is. So, if m w burning rate of the fuel is more than m w rate of inflow of air divided by r it is ventilation control. If you know like if the if the burning rate right, if the available you know you can calculate out m b by this formula right, you can calculate out m b and m air you can calculate out again. So, relationship is when the rate of burning is faster than air available air, it will be ventilation control.

If the rate of you know less air, it will be ventilation control whatever is the air that will control the air entry that will control the rate of burning. And when it is other way around, then it is fuel control, lot of oxygen is available. So, you calculate out air rate of air entry using the formula, but people have done experiments actually people have done experiments right, empirically then they have obtained some relationship. So, what they found it that if rho g 1.2 A w H to the power half divided by A f is less than 0.235 235, they they are done experiments in compartment.

A f is a surface area of the fuel; total surface area of the fuel let us say in compartment. So, in our case we can say surface area of the fire load, total fire which could be floor area you know surface area. So, then this is actually ventilation control, this is ventilation control. So, this this you know rho g multiplied you know which is given by this formula. If it is rho g 1.2 A w H to the power half is greater than 0.290, it is density or you know rho is a density of fuel both these cases density of the fuel itself density of the fuel itself. So, this is actually fuel control.

So, if this is greater than this because this is air density of air, this is the density of fuel this is the density of fuel, g obvious is there. So, one can calculate without if this greater than 0.235 in a room, and this is the surface area of the fuel. So, in a compartment, whether it will be ventilation controlled in fully develop state or it will be fuel controlled you can find out from this sort of empirical relationship, this sort of empirical relationship.

Now, this is as I said this is quite important I mean we have used it number of times in post fire assessment also. What would have been the case of fire, although the values there these values are from empirical observation a certain type of furnaces you know in controlled condition. But this some idea is definitely obtained, some idea is definitely obtained from even in case of post fire assessment and prefire scenario as well design training scenario.

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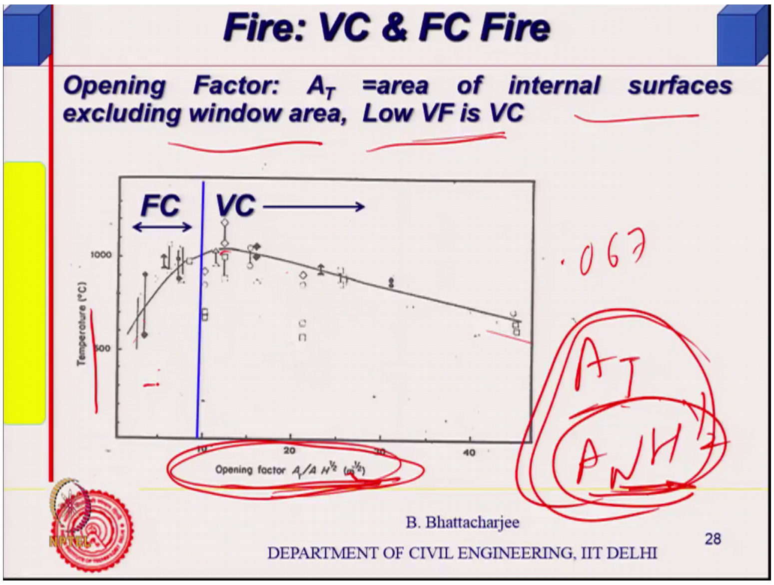

So, this is at the experimental result is. What they have done they have actually find out A T is the area of internal surfaces excluding the window area people have measured. And you know this is the opening they call it opening factor. So, I told you that I gave you that formula 0.067 remember that I gave you Q f the opening factor this comes from this kind of an experimentation.

So, people have done experimentation. So, opening factor is given by this temperature they found the temperature increases peak temperature increases with higher opening factor. And beyond the opening factor, peak temperature tends to decrease. Now, some portion is fuel control, some portion is ventilation control; some portion is fuel control, some portion is ventilation control.

So, this portion or portion beyond left hand side of this line is fuel control fuel control right, because this you can see the ventilation factor is 80 divided by A w H to the power half. So, you know smaller this value is higher this value would be; larger this value is smaller this value would be, that means you have more ventilation when you have small values of this.

So, this zone is said to be beyond this peak is fuel controlled, because you have large value of this, because this value is small, A T is the total internal surface area, A T is the total internal surface area. So, ventilation area is more compared to total surface area, that means, less ventilation area less oxygen flow that is why this is fuel control. And beyond this is actually ventilation control; beyond this is ventilation control alright. So, beyond this is ventilation control ok.

So, this was from experimental compartment fire experimental work. And 0.235 these values comes from those kind of scenarios only similar argument right. So, we will break for a while, and then go into the next aspects (Refer Time: 29:06) answering your questions.