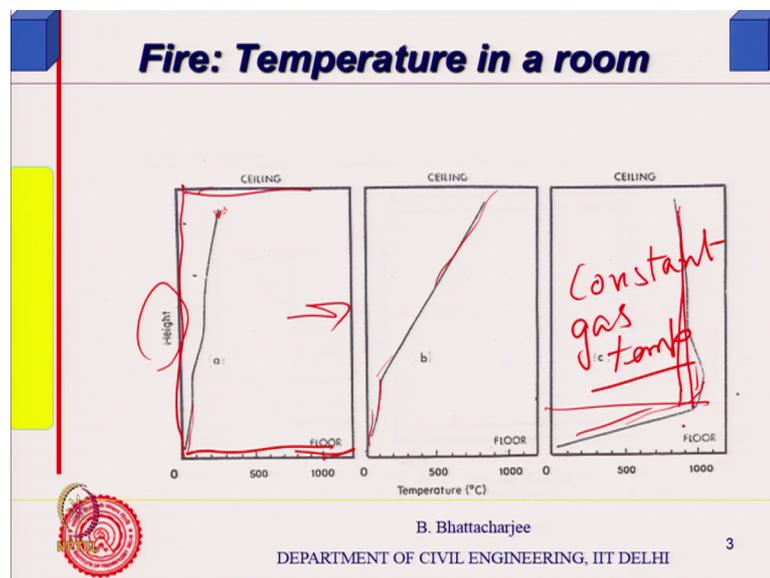**Fire Protection, Services and Maintenance Management of Building**
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Lecture - 04
Process of Combustion: Introduction

So will you know like now; we look into fire resistance, you have looked into severity effect of fire on structures we look into.

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But, first let us see; how does the temperature in a room varies and get some idea if I want to find out theoretically while you know, I said a ventilation factor a w into h w to the power half why it is so, that is we look into. So, what people have seen is in case of a fire or fully grown fire beyond the flashover, beyond the flashover point, beyond flashover point with time, you find that in the beginning, if I look at the height; height of the building, this is the floor, this is a ceiling. So, this is a compartment again experimental work.

So, in the beginning, in the initially, you will find the temperature at the top is and bottom is average, we are talking of average gas temperature or air temperature gas because it will have product of combustion also the gases; gas temperature within the room average, if I take it its somewhat higher at the top and as the time passes, this goes

further something like this and when it is fully grown. In fact, you have very little you know it is almost more or less a constant temperature you can think of.

So, temperature of this compartment or the room remains by and large constant with height except for a small portion close to the floor where it is somewhat varying. So, I can assume a constant gas temperature; constant gas temperature as we call it constant gas temperature within the room, constant gas temperature within the room. So, you can talk in terms of constant gas temperature within the room and you can see typically this can go up to 1000, etcetera etcetera depending upon the fire load and so on.

So, we assume gas temperature is constant within the room, all right, from post flashover temperature in a room can be assumed to be uniform, it remain; it is become same because everything has caught fire now everything is burning. So, temperature would be more or less constant.

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Now, this is in a simple compartment as I talked about this is what the scenario would be, this is the room this is the room, this is the room compartment, let us say and this is a you know, this is a opening and hot gases will go out from the top hot gases, hot gases go out from the top; you know the it; hot gases goes out from the top hot gases goes out from the top and fresh air enters from the bottom fresh air enters from the bottom.

And there is something somewhere; there is something called neutral plane somewhere something called neutral plane where actually you know it is a boundary between hot gases going out and cold.

Student: Cold.

Fresh air entering; so, the pressure difference should be 0 there, here the pressure should be higher, pressure on this side should be lower and here, the pressure should be higher here pressure should be lower there, pressure should be lower there. Now, you can understand this; of course, we can understand this; why because the density of the pressure is given by rho gh. So, it is depends upon density. Now if the hot gases will have lower density, right hot gases will have lower density and air will have higher density.

So, we can actually look into the scenario; for example, let me consider this diagram again at the bottom. P 1 is here, 1 is here, 2 is here, 3 is a point here and 4 is a point there; 3 and 4 you know or let me use black colour; that would be better. This is 3, this is 4, this is 2, this is 1. Pressure at 1 must be more, pressure must you know pressure; I mean basically the direction of the flow is like this. So, pressure should be somewhat from this; you know outside, just outside point 2 should be because here there are hot gases. So, pressure should be there should be flow along this direction. So, pressure should be higher somewhere here.

And in this case, pressure should be how somewhat higher. So, this will be the actually pressure diagram or even you know related pressure or velocity is this pressure is 0 here. So, pressure diagram is somewhat there. So, let me call this height is h 0 and this is called as h f. Now h 0 or h oxygen, you might call it where fresh air is coming in and here the you know flume the fire basically. So, h f; so, h F and h 0; so, P 3 is the pressure here, P 4 is the pressure here, pressure must be here more; you know and pressure here actually is more negative. So, let us see; how I can express this pressure; let us see how do I express. So, for points 1, 2, 3, 4, point 1 and 4 are inside the compartment 1 is inside, the compartment 4 is inside, the compartment 2 and 3 are just outside, 3 is outside and 2 is just outside. So, we can actually find out the pressure difference between these 2.

Now, this pressure is a function of y because if this is my y this I define as y; any point from this point, I call it as y, this is y at any point here is y. So, this is my cluster, this is my data origin, I call it 0 and this pressure. So, I can write get an expression for pressure at 1 and 2 first and then 3 and 4 first. Now pressure at 1 will be lower than the pressure here, right. So, it will be P 0, if it is outside, pressure is P 0 minus rho g h rho g h minus rho g h or h is actually y. So, at any point y, it will be written like this rho 1, the density here minus g into y. So, y any distance y, I am considering from here rho 1 and P 0 is outside pressure and P 0 rho g rho 0, rho 0 is outside density 1 is that density here and rho 0 g y. So, that is what it is.

Now, this value is smaller than this value because this is at higher temperature and there is a negative sign here, there is a negative sign here. So, the pressure difference would be P 1 minus P 2 because P 0 minus rho 1 g rho 1 is rho 1 is.

Student: Inside.

Yeah in rho 1 is inside and rho 1 is actually less. So, I am separating less quantity, here, I am subtracting more quantity.

Student: More quantity.

So, come so, therefore, this is what is happening. So, P 1 and P 2; I can express like this. Similarly P 3 and P 4; I can express like this.

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So, rho 1 and rho 0 are densities of gas inside and outside, they are respectively gas on going out would expand as soon as it gas out, it will expand because the space is now full and it will attain the same density as the.

Student: Outside.

Outside density; right and attain nearly same density as outside as well as the concept that we are trying to deal with.

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Then let us look at 3 and 4, let us look at 3 and 4. Now at 3 and 4, again it would be P 0 rho 0 g y and P 0 rho 4 g y. Now, rho 4 would be again less because we said that nearly constant temperature prevails into the room. So, temperature of gases inside will be higher. So, their densities are lower. So, rho 4 is less than rho 0. So, therefore, you know the I mean you know the, but the y height here that y will y the height there, h is positive and this is what will actually see this is somewhat higher rho 0 plus actually this should be rho 0 plus because rho 0 is here plus the excess pressure would be rho 0 g y because there is a minus sign this.

See the my datum is here. So, this is negative y; y is negative, right. So, this effectively becomes plus.

Student: Plus.

This effectively become plus; therefore, this is plus difference would be this because this is larger value this is smaller value, this you know rho 4 is less than rho 3 y is negative here, from this datum, P 0 is the outside air pressure which is datum. So, y is now pressure here will be less than the pressure here and this y is actually that I can take by taking y as minus sign. So, that is how the flow occurs in this position. So, this is how we can express both this you know y have to while we minus.

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So, for negative values of y, P 3 and P 3, 4 go to greater than P 0 actually, they are both greater one is still more another is slightly less more slightly less more. So, flow takes place in this manner right this is understandable now.

So, that is why; you can see that this you know these are this diagram P 0 is here, P 3 is more, P 4 is there, P 1 is here, P 2 is there; you know. So, correspondingly because this was y is positive here, y is negative there and that is why you know these are. So, y positive neutral plane while positive that is what it. So, that is how the pressure difference would be, right.

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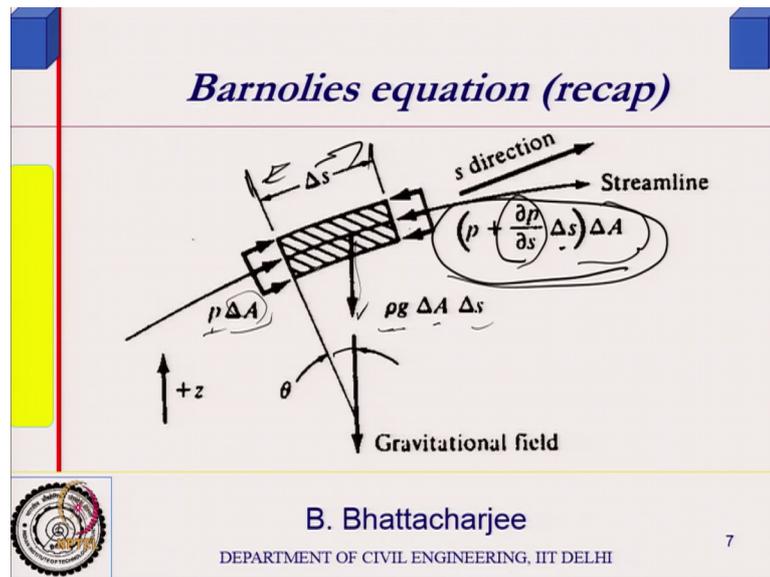
And then we can use Bernoulli's equation now anybody's an architect here; no. So, normally this Bernoulli's I also derive Bernoulli's equation quickly in its quick manner to recollect it. So, that you know and those people who are in architecture, they may not have studied a fluid mechanics. So, I is normally been deriving this.

So, if somebody is an architect they can look into Bernoulli's equation, otherwise, but it is fairly simple to derive this kind of an equation because if you consider the flow through an element like this stream flow, there is a stream line, right and it is its incline in this manner this length is delta s, this length is delta s direction of flow is like this pressure here and the area delta A. So, p into delta A is a force acting here and p plus rate of change of pressure with s multiplied by d s. So, that is the pressure acting here multiplied by the d A. So, that will be the force here right in addition to this the mass of this is acting density is rho g, delta A, delta s, there is a volume element, delta s is the length, delta A is the area.

So, all the forces; we can equate right, we can actually equate this angle is theta; let us say. So, this angle is theta.

So, if we equate these angles; just for your recollection, one can write velocity also as a function of one can write velocity. So, this forces we can equate will do that, but just let us do one thing more, let us write velocity; velocity will be varying with distance. So, rate of change of velocity with s multiplied by ds plus; it might vary with time dt, V is a function of tns, let us assume that V is a function of t and s, but if we assume steady, then t part will go; let us generalize it little bit.

So, acceleration is dV dt it will be written like dV ds, ds dt and dV dt because acceleration will be simply dV dt. So, this could be written as because when I am trying to equate the forces, I need the acceleration also, since the fluid is flowing mass into acceleration must be equals to all the resultant forces acting along the direction of the flow. So, acceleration is given by dV ds V plus dV dt that is how it is a simple derivation, there is no complication involved in it, right.

So, that is same one, I am writing again applying force balance p minus delta A minus this part minus rho g delta, there is the mass into ds sin theta. Now this force along this direction, I am interested in and this is you know this should be this component of this one, along this direction, I am interested in whichever way. So, it will have one component there, one component there. Now this is, if this is theta this will be and this is you know this is rho g ds, sin theta will be this distance ds sin theta will be this distance.

So, I am multiplying rho g da ds sin theta that is that is a force that is acting that must be equals to the mass rho delta a delta s into acceleration that is all causing the flow.

I am simply writing the force balance the one force is a pressure difference pressure here and minus the pressure here and then the component of the force acting here component the force acting here. So, this must be the total force that is acting and you know must be equals to mass into acceleration mass into acceleration. So, if I do a little bit of further, now sin theta can be simply written as dz you know, if this is the height difference dz, dz by dz by dz by ds sin theta will be written by dz by ds. So, I write sin theta here again and replace sin theta by dz by ds.

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Barnolies equation

Applying force balance

$$-\frac{\delta p}{\delta s} \Delta s \Delta A + \rho g \Delta A \Delta s \sin\theta = \rho \Delta A \Delta s \left(\frac{\delta V}{\delta s} V + \frac{\delta V}{\delta t} \right);$$

$$-\frac{\delta p}{\rho \delta s} - \rho g \frac{\delta z}{\delta s} = \rho \left(\frac{\delta V}{\delta s} V + \frac{\delta V}{\delta t} \right)$$

$$-\frac{\delta V}{\delta t} = V\frac{\delta V}{\delta s} + \frac{1}{\rho}\frac{\delta p}{\delta s} + g\frac{\delta z}{\delta s}$$

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So, sin theta is this one; rest all will cancel out as we can see from here, this will cancel out P delta a terms, this will cancel out leaving del p del s del s minus you know, I can just put that rho g. So, this is what will be remaining minus with a minus sign and this is rho g del A del s sin theta will be replacing by del z by del s and then is the right is right side. This cancels out from everywhere pA pA p delta rho delta A will cancel out from everywhere rho delta A and also delta s will cancel out from everywhere next.

So, I will be left with minus del rho del s g del s is canceled out, d z by rho g rho should also go out no rho remains rho g remains actually rho remains here because this did not have rho; this term did not have rho. So, rho g remains actually. So, rho g remains delta s cancels out, finally, it comes out to be this and if I assume steady flow; what I get is

minus del V del t, etcetera, etcetera, just divide everything by rho. So, this will get divided by del V del t is equals to V del V by ds V del V by ds divided everything and this will be divided this rho will cancel out; only this part divided. So, there is something like this.

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So, in a steady situation, this term can be put equals to 0 dV dt is acceleration x terms can be written like this and for steady flow this is equals to 0, then I can integrate this whole thing. So, in steady flow this is equals to 0. So, therefore, integrating V del V right V del V plus 1 by rho del P plus t g del z integrate all of them because del s, since right hand side is equals to 0 del s will not be there anywhere and you get V square by 2 plus P by rho plus z equals to a constant because I am integrating it right hand side is 0, if I integrate, I get a constant that is simple derivation of Bernoulli's equation, you would have studied in much more details.

Since, we are most of your engineers there is not a problem. So, Bernoulli's theorem is velocity head, pressure head and datum head sum total must be constant in a steady stream line flow steady stream flow right. So, in our fire case also you can assume that the stream flow is occurring at the top as well as the bottom and we can apply Bernoulli's equation, we can apply Bernoulli's equation and it is steady because we are assuming the fully developed fire constant its going.

Barnolies equation

$$-\frac{\delta V}{\delta t} = V\frac{\delta V}{\delta s} + \frac{1}{\rho}\frac{\delta p}{\delta s} + g\frac{\delta z}{\delta s}$$

For stead flow $\frac{\delta V}{\delta t} = 0$; integration result in

$$\frac{V^2}{2} + \frac{p}{\rho} + gz = \text{constant}$$

$$\frac{\rho V^2}{2} + p + \rho gz = \text{total pressure is constant}$$

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You know; we are not varying time variant scenario you are not taking account here right. So, that is what it is. So, total pressure or you can say you know total pressure; total pressure is constant; total pressure is constant you can write it like this in this manner.

So, rho V square by 2 pressure; you know pressure is rho V square by 2 in pressure unit will be like this and head unit it will be something like this, right.

Fire: process of combustion
For gas flow from point 1 to 2

$$\frac{P_1}{\rho_1} + \frac{v_1^2}{2} = \frac{P_2}{\rho_2} + \frac{v_2^2}{2}$$
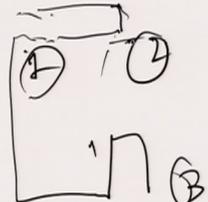
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So, for gas flow from one to now I can apply this to point 1 and 2. So, at point 1 pressure was P 1 and divided by rho 1 pressure one you know divided by rho 1 and if the velocity is there that will be V square by 2 and since they are at the same height. So, z I need not take one and 2 are at the same height it one the same height in the compartment if you recollect it was in the same height in the compartment if you recollect what we said was it something like this you know this is the window this my this is the window.

So, 1 was somewhere there, 2 was somewhere there; therefore, 1 and 2 are the same height. So, z can be z is ignored and this is a velocity at that location at distance y by 2 and P 1 by rho 1 P 2 by rho, etcetera, etcetera. Similarly for 3 4 also, I can apply, but let us do for 1 and 2 first let us do for 1 and 2 first.

So, V 1 will be 0 why V 1 will be 0 because it is a bulk, it is inside the room, actual velocity is just close to the wind only and V 1 can assume V 1 is equals to 0 because it is bulk in the room from where it is coming. So, I am comparing inside the room; if you recollect, it was in this corner. Similarly 3 is here, 4 is just inside the room. So, 2 is just outside the window just outside the window. So, that is what I am interested in that velocity actually.

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So, V one can be considered to be 0 assume to be 0 no net directional flow the pressure difference is due to confinement of hot gases because hot gases are confined there

therefore, that is why there is a pressure, you know the volume is fixed here and outside it goes in the expand and the pressure is reduces down.

And once it is out at point 2 at atmosphere it will expand and the density would change to nearly atmospheric condition. So, hot gases flows so, gas density is used in the denominator. So, velocity is 0 and outside density will be rho 0 inside density will be gas density, right. So, that is what it is. So, this was the pressure in one if you recollect rho is 1 that was the gas and gy divided by rho 1 and here rho 0 g 1, well, this will this will take it as rho 0 gas temperature, I mean this should be 2 rho; you know this should be rho 2 this should be 2 V 2 square by 2.

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Now, this I can write further; get an expression for now yeah at you know this, get an expression for; get an expression for get an expression for yeah, since, the volume I am not considering the volume, sorry, this is there is a problem little bit of problem since the volume of the gas, I am considering this you know this density rho 2 also, I am taking as same gas because hot air is going out; so, hot gases flows. So, gas density in both the cases, we are using as rho 1 only where pressure we are using rho 0 and rho 1 there.

So, if you now find out the V 2 get an expression for V 2, you will get an expression for V 2 from this one simply V 2, I can separate out and I will have P 0 cancelled out from both the sides and this side if it goes it will be rho 0 minus rho 1 gy would be there divided by rho 1. So, v 2 square to the power half twice will come here rho 0 minus rho 1

g 1 by rho 1 that is how it will come the velocity there would come like this velocity will. So, it is A at any point y above the data the velocity will be given by this formula and if I am interested in flow, then what I should do? I should take a small element dy.

Student: D y.

Because it will vary velocity will pressure varies in this manner pressure varies in this manner, velocity will also vary correspondingly velocity will also vary pressure varying in this manner you know in this parabolic manner and this side, it was varying in this manner pressure is changing velocity will vary accordingly.

So, at any distance y, I find out the velocity given by this formula above I find out supposing I consider a small dy element, then the flow will be simply area of the window I mean the width of the window multiplied by dy into the velocity as a function of y integrate this from 0 to h w by 2, height of the because we are assuming approximately this will be you know. So, one can do that way, but we will see how we are doing how we are doing slightly physically I am trying to explain you.

So, I can find out the flow of quantity of flow of hot gases outside and also find out the quantity of fresh air inside the volume ok.

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Fire: process of combustion

$$v_2 = \left(\frac{2(\rho_0 - \rho_1)gy}{\rho_1} \right)^{1/2}$$

Using the subscripts 'F' (for the compartment gases) and '0' for the ambient air)

$$V_F = \left(\frac{2(\rho_o - \rho_F)gy}{\rho_F} \right)^{1/2}$$

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So, that is what it is. So, supposing we use a nomenclature or subscript F for compartment gas and 0 for or o for ambient one 0 for ambient one. So, this will be rho 0

rho F because rho 1 is rho F and this also rho F you know hot gases and velocity of hot gas is given by this gy to the power half at any distance y from the neutral plane at y distance above the neutral plane. So, this is what we tried to arrive at and this is what we get this is what we get. So, velocity of flue gases; that is why F at a distance y from the neutral plane is given by this formula; given by this formula.

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Now, for 3 and 4, I will do the same thing and if I do the same thing V 3 will be 0 V 3 will be 0. The no net flow because it is away from the room, V 3 will be 0, no net flow it will be away from the room and the pressure difference is due to the hot air inside which has got a lower density and you know it acquires temperature on entry at the room and the density would change. So, again density would change inside once it enters its get compressed the fresh air we get compressed and then of course, the combustion process will continue and change to the hot gas which will move.

So, outside air flows. So, air density is taken in the denominator in both the cases here. So, you see this is likes previous one this is what is done. So, at a at a distance y from the neutral plane, this will be the formula at V 3 we are assuming it to be 0 because there is no net flow directional flow away from the room and in the same manner I derive a formula v 4 p 4 rho 4 minus rho 0 by rho 0.
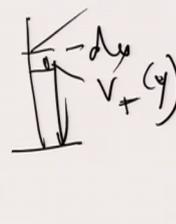
Now, rho 4 would be what rho 4 would be rho F rho 4 would be taken as rho F and 0 remains same. So, this is how we get my expression. So, V air oxygen flow V 0 which denotes the oxygen for V o whatever you call it; it denotes the oxygen velocity of oxygen or air at a distance y below the neutral plane is given by this.

Now, I can calculate out the flow. So, mass flow rate I can calculate out for flow gases it would be V F y into dy integral as I said small you assume now consider a small dy element above the neutral plane, velocity here is V F y. So, the flow is area into velocity.

So, what is the area B is the width of the window, let us say B is the width of the window. So, B dy is a area into velocity and 0 to h F where h F is the height of the.

Student: Height of the window.

Yeah height of the; height of the window above the neutral plane height of the window above the neutral plane, right, usually; we assume to be half, but even if it is not half; does not matter; it can be depending upon the if there is a outside air velocity, there is a wind flowing, then the whole thing gets distorted wind can change the whole thing. So, it need not be also depending upon the you know we will see that later on sometimes some cases neutral plane need not be half, but everything is strength cool no air velocity outside, then it will be something like this.

So, that is what it is. So, B into so, this is a flow this is the density of the gas multiplied by a coefficient C d because you can you know we are assuming streamline flow in almost all in even we when you calculate out wind load you will find there is a coefficient which is utilized because lot of assumptions are used C d is what is called discharge coefficient; it is called a discharge coefficient. It is called a discharge coefficient because physically, we understand these are the factors which will actually affect the density, this is a volume flow multiplied by density is the mass flow multiplied by discharge coefficient. So, this should be the flow, but there is a discharge coefficient which takes care of all unknown factors and all that. So, be window width is it is discharge coefficient, all right.

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So, mass flow of oxygen is similarly one can obtain mass flow of oxygen one can similarly obtain as V 0 y dy and minus h 0 to 0 now because y is h; yeah, right.

Student: (Refer Time: 28:50).

So, negative and rho 0 is a and yeah. So, this 2; we can find out right and actually this H h F plus h 0 must be equals to h because h F is the.

Student: Height.

Height; above the height of the window above the neutral plane h 0 is the height of the window. So, I can change this, I can integrate this anyway because this expression for V F is known to me in terms of y and expression for B in terms of y is also known to me. So, continuing with the same mass flow of gases that is what we have seen.

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Now, if I can express this further a little bit because put the value of V F as a function of y which was coming like this and there is hardly any complex integration here, this velocity was y to the power half. So, only thing that will come out is y to the power half dy and rest all are constant. So, B comes out, C d discharge coefficient density of the gases B comes out and this part also comes outside to the power half and this what it is.

Now, if I integrate this I get what y 3 2 3 by 2 to the by 3 by 2, you know, y to the power half you integrate y to the power half you get y 3 by 2 divided by 3 by 2 which would become 2 by 3 and h F to the power if I put the limits of integration I will get h F to the power 3 by 2 h F to the power 3 by 2 now B into h F is what? B into h; F B into h F well is the total area of the window above the.

Student: Neutral Place.

Neutral plane similarly B into h 0 is the total area under the window so; that means, then h F and multiplied by h to the power half still remains. So, we can see that right now you can see that.

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Fire: process of combustion

Mass Flow of oxygen $F_o = C_d \varrho_o \int_{-h_o}^{0} BV_o dy$

$F_f = C_d \rho_o \int_{-h_o}^{0} B\left(\dfrac{2(\rho_F - \rho_o)gy}{\rho_o}\right)^{1/2} dy = -C_d \rho_o B\left(\dfrac{2(\rho_o - \rho_F)g}{\rho_o}\right)^{1/2} \int_{-h_o}^{0} (-y)^{1/2} -dy$

Substitute $x = -y; dx = -dy;$ *lim its will change accordingly*

$= -C_d \rho_o B\left(\dfrac{2(\rho_o - \rho_F)g}{\rho_o}\right)^{1/2} \left[\dfrac{x^{3/2}}{\frac{3}{2}}\right]_{h_o}^{0}$

$= \dfrac{2}{3} C_d \rho_o B\left(\dfrac{2(\rho_o - \rho_F)g}{\rho_o}\right)^{1/2} h_o^{\frac{3}{2}}$

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Mass flow of oxygen similarly same integration now it is minus y to the power half and dy minus dy. So, I just put it in the perspective negative perspective, etcetera, etcetera because x equals to y dx is equals to dy. So, limits will change accordingly. So, you know because this was dy. So, they call you know because it is negative. So, accordingly every limits will change and I will get again h 0 minus h because 0 to minus h F, there is a minus sign involved and it finally, comes out to be in the same manner as C d rho 0 B h to the h 0 to the power 3 by 2. This simple you can look into it there is no complexity, really involved.

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Fire: process of combustion

Mass Flow , thus notation m˙ replaces F, subscript remains same

$\dot{m}_F = \dfrac{2}{3} C_d B(h_F)^{3/2} \rho_F \left(2g \dfrac{\rho o - \rho_F}{\rho_F}\right)^{1/2}$

$\dot{m}_{air.} = \dfrac{2}{3} C_d B(h_o)^{3/2} \rho_o \left(2g \dfrac{\rho o - \rho_F}{\rho_o}\right)^{1/2}$

$1 kg \quad fuel + r \, kg \quad air \rightarrow (1+r) kg$

For non-stoichiometric burning

$1 kg \quad fuel + \dfrac{r}{\phi} kg \quad air \rightarrow (1 + \dfrac{r}{\phi}) kg$

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And mass flow, thus you know we use mass flow this is mass flow rate actually this is flow rate velocity multiplied by area; so, per unit time. So, this is the mass flow rate. So, we might write m dot that is mass flow rate, mass flow rate we can use subscript remains the same. So, we can use m dot F mass flow rate we can denote it by m dot F 2 by third, etcetera, etcetera and similarly, mass of oxygen flow mass of air flow, we write it in this manner, we write it in this manner.

Now, actually sum total you know; I can do a summation in some manner one kg of fuel supposing 1 kg of fuel, 1 kg of fuel reacts with r kg of air fully because this has to be as stoichiometric ratio whatever air comes in all of it will get assume for the first time, let us assume that everything reacts and produces 1 plus r kg of the combustion product. So, the ratio between these 2 must be related to this you know 1 by r plus r because whatever hot gases is generating whatever is coming in same amount is going out. So, hot you know; so, this mass flow rate of air and the hot gases the flue gases it must be are a ratio with the stoichiometric quantity.

So, I can say that 1 since 1 kg of fuel reacts with r kg of air for wood one knows this, but if it is non stoichiometric that everything is not burning everything is not react, you know everything is not burning whatever combustible product is from everything is not really reacting, then I will take a fraction. So, let us say it is 5. So, only r is a combustible you know so phi is a if there is a partial combustion not everything is combined, right. So, 1 kg of fuel reacts not all the product of pyrolysis is burning only a portion of it is burning. So, r should have actually complete burning would have consumed r amount of oxygen since it is partially burning. So, r by 5 amount of it is come you know its oxygen is will be getting consumed and the product that is coming out is 1 by r plus 1 plus r by phi.

So, this ratio should be this ratio I can find out and if I do not assume if I assume phi equals to 1, if I assume phi equals to 1, this ratio must be related to 1 by r by r. This ratio must be related to 1 by r. So, if I take this ratio let us take this ratio this cancels out this cancels out this cancels out this would be there and from here, actually, this will also cancel out from inside the other things would be there. So, rho F by this term will also cancel out because this is same both the places I will be left with rho F it should be other way round m 0 h F is fine by h 0. This should be.

Student: Rho 0.

Rho 0 by rho F; rho F because rho 0 would go up there right rho 0 will n to the power half. So, this is all will be remaining, this is all will be remaining.

So, ratio of these 2 must be equals to ratio of these 2 must be equals to this ratio must be maintained, you know, this ratio must be yeah I think this find this corrected here that is right rho F why its rho F [FL] this rho F cancels out with this rho F all right that is fine that is fine; that is fine that is fine that is fine, I think I did a mistake in algebra this rho F here rho 0, here rho 0 to the power half. So, it remains rho 0 to the power half here rho F to the power half here this correct actually this correct. So, this is how it is this is how it is and this must be maintained now ratio this ratio must be same as the stoichiometric ratio this ratio must be same as the stoichiometric ratio and that is how it is obtaining after substituting mass flow rate this is obtained after mass substitute in mass flow rate.

Therefore I can get an expression for h F by h 0 in terms of rest of the things h F by s you know h 0 because this can be separated out and the half is there the you know. So, this is to the power if I square both sides up this goes away, this goes away I will be left with rho 0 by h F rho 0 by rho F this will come here and h F by h 0 to the power 3 and then put 1 by 3. So, h F by h 0 I can find out right h F by h 0 I can find out.

I have another equation h 0 plus h F is equals to 1 h 0 plus h F is equals to capital H capital H height of the window. So, I can replace everything in that terms I can replace everything in that terms, right.

I can replace. So, h F can be written as h 0 like this and h is equals to h 0. So, I can write it in this manner the other equation the ratio of h 0 is and can be obtained this we can obtain now h by h 0.

If it is half, then you know h F by is h 0. So, if is the one can get this expression using typical value of point r is equals to 0.57.

Now, stoichiometric requirement of air or oxygen or amount of air for 1 kg of wood requires 5.7 kg of air for wood and densities of this 1 point rho 0 and rho F vary from 1.8

to 0.5 rho 0 by rho F vary from; that means, fewer the plume or the fire the gases have got a density, you know ratio of density of air is the air densities around 1.2 kg per meter cube. Air density is 1.2 kg per meter cube value of this typical smoke and gases is known to us at this ratio varies from 1.8 to 5; there is a large variation as you can see and so, the ratio you know for phi is equals to 1, generally this value turns out to be this rho 0 by rho F you know this; this whole thing this ratio turns out to be 0.32, 0.5 for 5 equals to 1.

So, if I take this value is equals to 1 by putting relevant values, for example, this value somewhere average. So, 5 point; 6.8 divided by 2 is 3.2. So, I put this equals to 3.2 this put this equals to 1, this has 5.7, then I can get a value of h 0 by h F which will work out to be about 0.3 to 0.5, 5.3, to 0.5; right. So, point sorry 0.34 to 0.2 generally the ratio is 0.3 to 0.5. So, what is it the bottom area is about 30 percent to 50 percent of the window height, bottom area is about 30 percent to 50 percent of the window height.

In other words you can write everything in terms of h, you can write h 0 you know in terms of h.

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So, I will just so we can write h 0. So, mass flow rate this is h to the power 0; supposing, I write it in terms of H capital H, right because I know h 0 by h is about 0.3 0.4, etcetera, etcetera taking some value some fraction. So, I can write in terms of h and if I rise to the power h some fraction will come out. So, C d B into h to the power 3 by 2 B into h to the power 3 by 2 will come this part.

Rest all of course, values are approximate values you take rho F by rho 0 as I said we take you know rho F rho 0 is 1.2 kg per meter cube and this correspondingly, I can take an average value divided by 3.2. So, g is known all these are known. So, this part if you see, this is a related to the wall area this is related to the 1 area, this is related to 1 area, right. So, B h to the power you know. So, area of the window into h to the power half that is what it comes, I think we will stop here next class we look into we look into next class we look into ok. So, that is what it is.