Fuels, Refractory and Furnaces
Prof. S. C. Koria
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture No. # 26
Macroscopic Energy Balance: Applications to Design Head Meters
Staci and Blowers, Types of Flames

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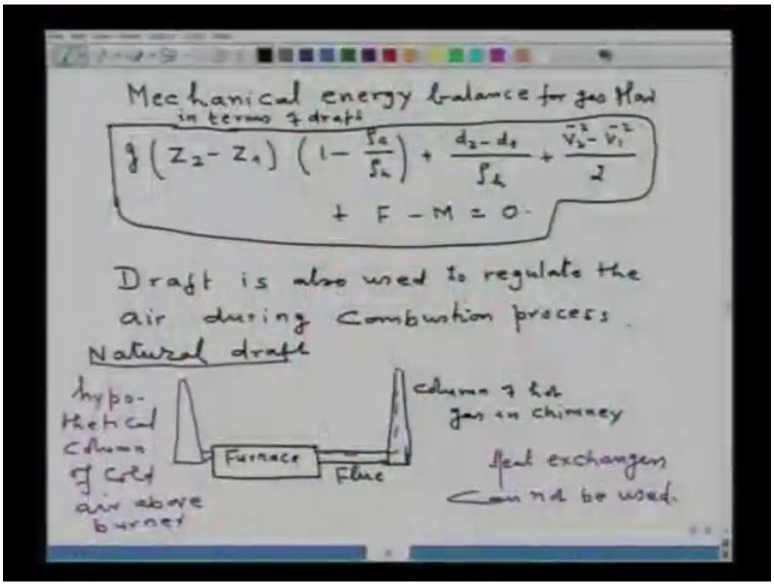

So, in the last lecture, you derived mechanical energy balance for gas flow which is g z 2 minus z 1, 1 minus rho a upon rho h plus d 2 minus d 1 upon rho h plus v 2 bar square minus v 1 bar square by 2 plus M minus M, that is equal to 0. Now, we will use this equation to illustrate some of the problems.

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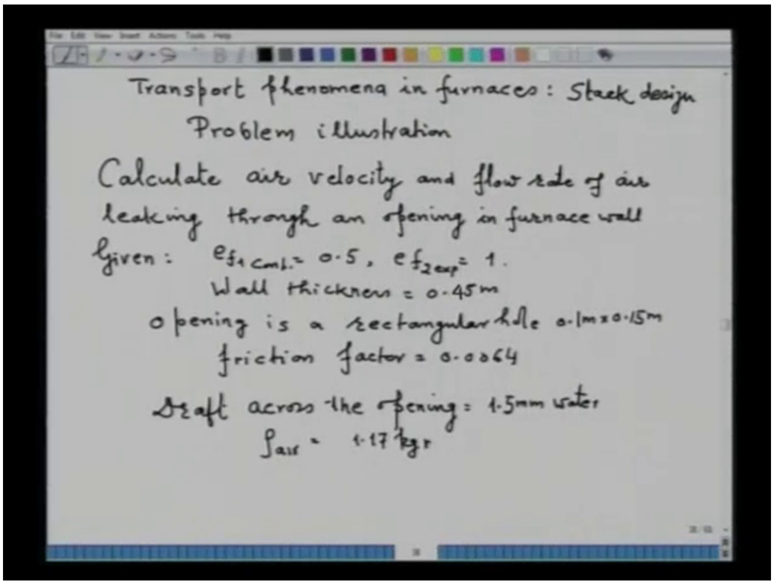

So, let me write down the first problem say, calculate calculate air velocity and flow rate of air leaking through an opening in a furnace wall. Given the following data are given ef 1 for contraction that is equal to 0.5, ef 2 for expansion that is equal to 1, wall thickness that is equal to 0.45, opening is a rectangular whole of cross section 0.1 meter into 0.15 meter.

Now, for easiness, the friction factor that is equal to 0.0064 and draft across the opening that is equal to 1.5 millimeter of water, density of air that is equal to 1.17 kilogram per meter cube. So, normally furnace opening all of your no and let us calculate their velocity enhance flow data of here.

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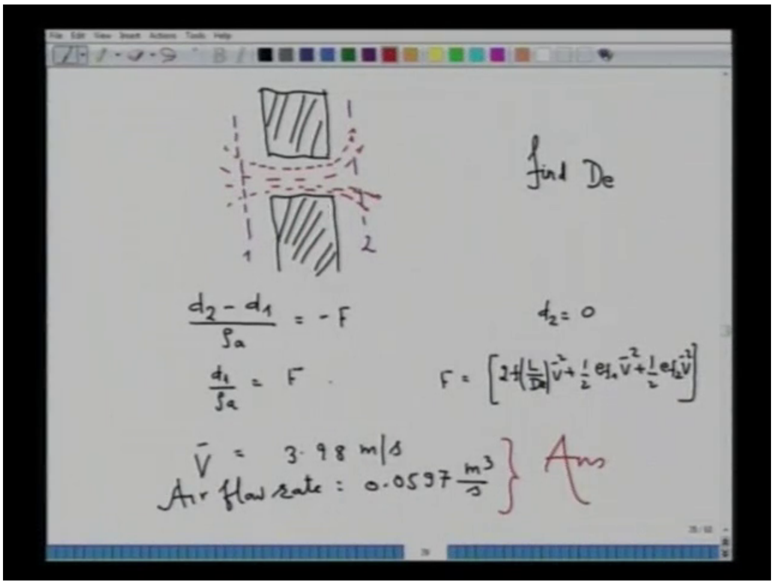

So, for the sake of doing the problem, you have to represent first of all in the pictorial form. For example, this is all of furnace. This is the one and this is the opening and through the opening say air is design. So, this opening is rectangular cross section 0.1 into 0.15 meter and we have to calculate their velocity the s sets. What you have to take? This is our plain 1, this is our plain 2. Now, applied mechanical energy balance, since it is horizontal delta z is equal to 0. Then, there is no mechanical pump.

So, M will be equal to 0, v 1 that is at the outlet to v 1 equal to v 2, since gases are being exhausted in an environment. So, if we substitute all these things into a mechanical energy balance, then the equation that result is d 2 minus d 1 upon rho air, that is equal to s. That is what the equation result. So, what we have to calculate now? We know the draft across the opening d 2 minus d 1 is given to us.

Now, this is minus F. Since, the other range is to atmosphere, so d 2 is equal to 0. So, we have d 1 upon 0 that is equal to f. So, we substitute the values in the proper dimension and I will request you to do yourself and replace F and replace F by no is 2 F l upon d e v bar square plus half e f 1 v bar square plus half e f 2 v bar square.

So, since it is a rectangular cross section, so you have to find out d equivalent. So, find d equivalent. The formula is already given and then, if you substitute all these values, then the answer v bar that will come out to equal to 3.98 meter per second and air flow rate you can calculate and air flow rate that will come out to be 0.0597 meter cube per second.

So, these are the answers for this particular problem. Now, here some of the steps I omitted. So, I request to solve this problem. Now, d 1 is d 1 in millimeter walker. So, you have to convert into Newton per meter square and this conversion you do yourself and see that you come to this particular answer which I have given. Now, let us say as the problem with respect to the design of the chimney and flue.

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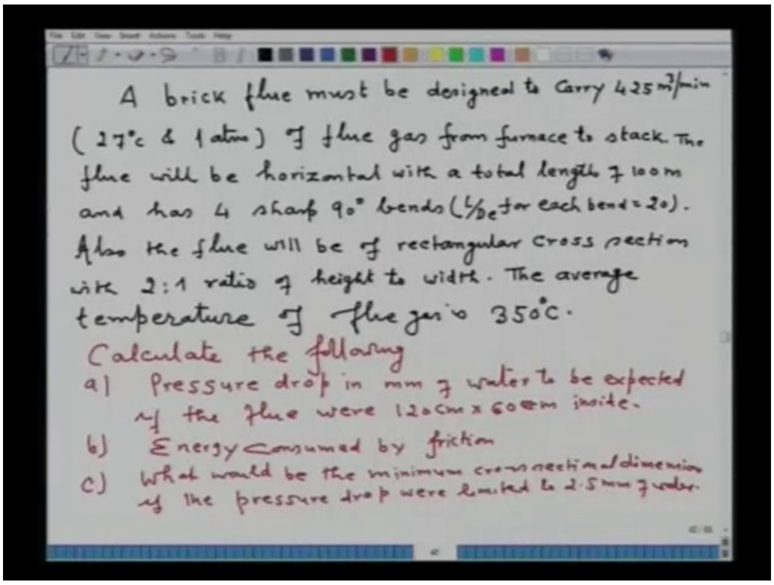

Let us take a brick flue. A brick flue must be design to carry 425 meter cube per minute. A gas is given at 27 degree Celsius and one atmospheric pressure of flue gas from furnace to the stack. The flue will be horizontal with a total length of 100 meter and has 4 sharp 90 degree bends. Here, l by d e for each bend is equal to 20. Also, the flue will be of rectangular cross section with 2 is to 1 ratio of heights to width. The average temperature of flue gas is 350 degree Celsius.

Now, what you have to calculate? Calculate the following. Pressure drop in millimeter of water to be expected if the flue were 120 centimeter into 6 meter 60 centimeter cross section inside. B: Energy consume by friction energy. That is also you have to calculate. C: You have to calculate say what would be the minimum cross section area, the minimum cross sectional dimension if the pressure draft were limited to 2.5 millimeter of order.

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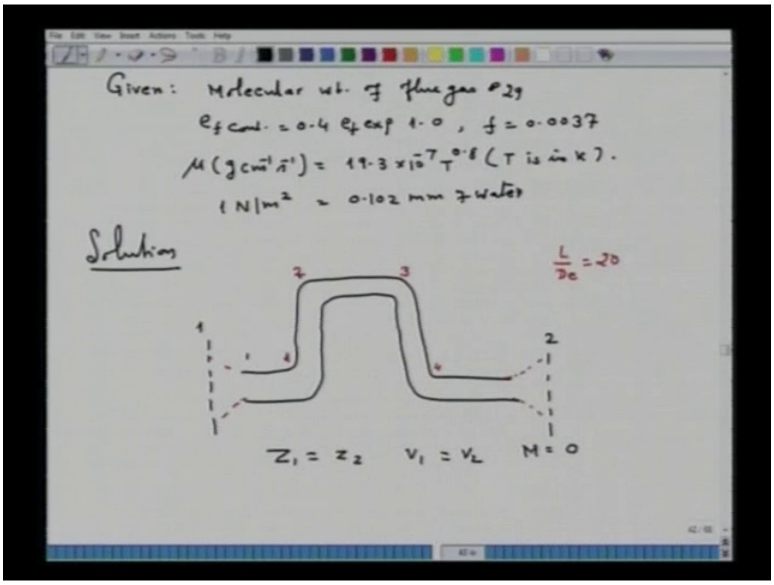

So, this is a typical problem for design of the flue and stack and so on. Now, there is something which is also given. What is given is as follows say, given molecular weight of flue gas is 29, then e f contraction 0.4, e f expansion 1.0, f is given 0.0037 this viscosity in gram, but centimeter per second can be calculated. Sum this relation 19.3 into 10 to the power minus 7 t raise to the power 0.8, where t is in kelvin and 1 Newton per meter square, that is equal to 0.02 millimeter of water.

So, this is also given to us. Now, we have to find out first of all, the special drop in millimeter of water to be expected if the flue where 120 centimeter into 60 meter inside. So, let us now state, since the design of the flue is not given by its set, it has four sharp bends. So, this solution of the problem will have to first of all things how the flue is. So, problem if the flue looks, this could be the probable design of the flue air one bend, two bend, three bend and four bend. Somewhere here is the entry, somewhere here is the exit, this is the mighty flame one, this is mighty flame two and this is air expansion and this is air contraction.

So, e f 1 contraction is given and e f 1 expansion is given. So, I will apply now. So, this is the bend one, this is the bend two, this is the bend three, this is the bend four and l by d e for each bend is given to be equal to like g. So, state where we have to apply the mechanical energy balance friction one a two. What we note say, since the flue is horizontal, so z 1 is equal to z 2, v 1 equal to v 2. Since, the velocity is extremely small, there is no pump. So, M is equal to 0.

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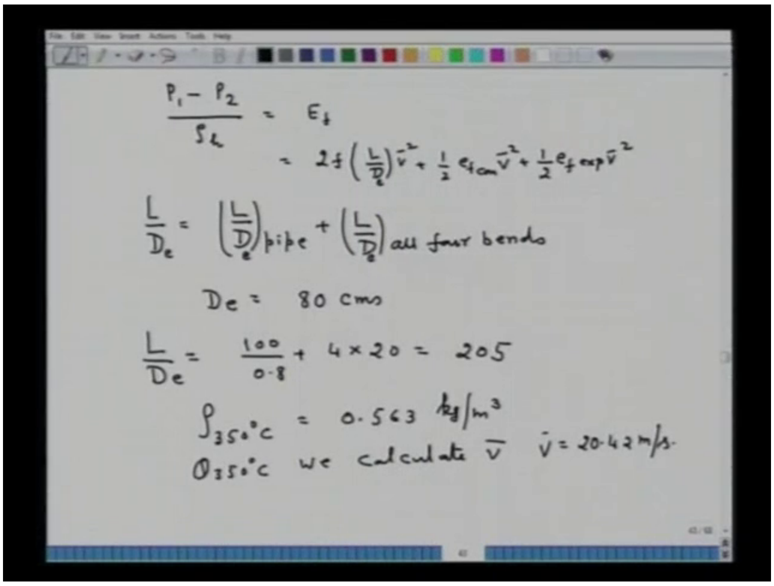

So, if we substitute all this simplification into a mechanical energy balance. Then, we will be getting p 1 minus p 2 upon rho h. That will be equal to e f and since, we can substitute at e f 2 F l by d v bar is square plus half e f contraction v bar is square plus half e F expansion v bar square. Now, remember here l by d l by d that will be equal to l by d of pipe plus l by d of all four bends.

So, first of all, we have to calculate because it's rectangular cross section how we will do it. So, first you have to calculate. So, here initiate b we will put b e, here also d, here also d e, so here also d e. So, that is two a do it and this is also here d e. So, we will calculate first of all d e. You know already. So, I am leaving some calculation for you. I am straight away wrapping d e will be equal to a p centimeter. You know how to calculate. I believe you know how to calculate.

So, now we can calculate l upon d e that is to be substituted at that will be equal to 100 upon 100 meter upon 0.8 meter plus 4 into 20. So, l by d h becomes equal to g 205. Now, we have to calculate density at 350 degree Celsius. I leave on you. You have to calculate the density. I am straight away writing down that will be 0.563 kilogram for meter cube. That is the density at 350. Similarly, they have to express q. They have to express this 350 degree Celsius because it is given a 27 degree Celsius and from q we have to calculate say, we have to calculate v bar along q. We calculate v bar and I request to calculate v bar and this value of v bar that will come out to be equal to 20.42 meter per second.

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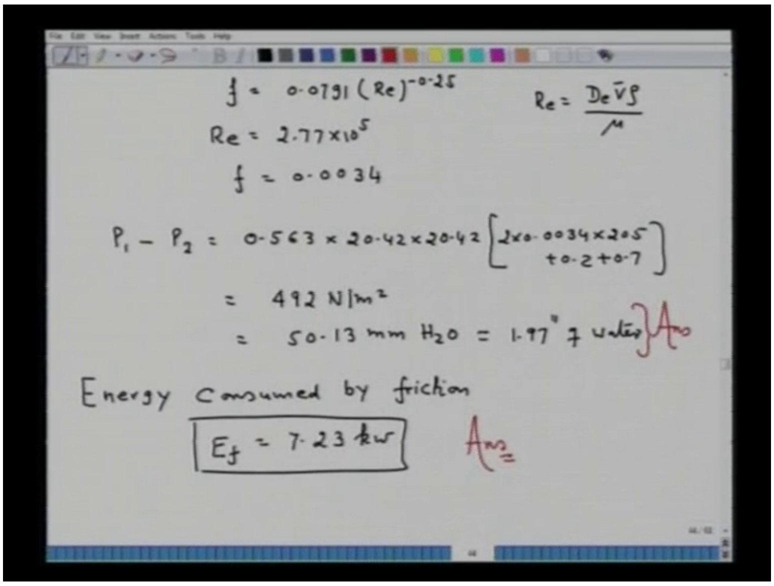

Now, though I have given the friction factor, but then we can make use of the formula as all of you know that friction factor that is equal to 0.0791 left to the power Reynolds number to the power minus 0.25. So, we can calculate the Reynolds number. You please do this exercise. Calculate Reynolds number that will be equal to b e v bar rho upon mu at 350. Calculate by the expression which I have given to you. I am leaving this exercise to you. Please do it to Reynolds number that will come out to be equal to 2.77 into 10 to the power 5 and F. I substitute, then I get F is equal to 0.0034 since all the values are known to me.

Now, what I require are to substitute all the values into the equation p 1 minus p 2 upon rho that is equal to e f. So, if I do that, then p 1 minus p 2 that if the pressure differential 0.563 into 20.42 into 20.422 into 0.0034 into 200 and 5 plus 0.2 plus 0.7. Solve it. We will be getting 492 mu per meter square and that will be equal to 50.13 millimeter quarter and that is also equal to 1.97 inches of water to this is answered as required. Now, some of the places where I told to calculate, please do the calculation and field for the solution of the problem.

Now, the second we have to calculate energy consume by friction. This you can calculate yourself because in the mechanical energy balance, F is per unit of mass. So, if you multiplied the value of F is per unit of mass, we will directly get the energy consumed by the friction and if I do that, then e F that will be equal to 7.23 kilowatt. We have to appreciate that there are considerable amount of energy is loosed also in the overcome friction. It is very simple to calculate. All that you have to calculate is e F is e F occur unit mass multiplied by the total mass and you will get the energy which is last by the friction.

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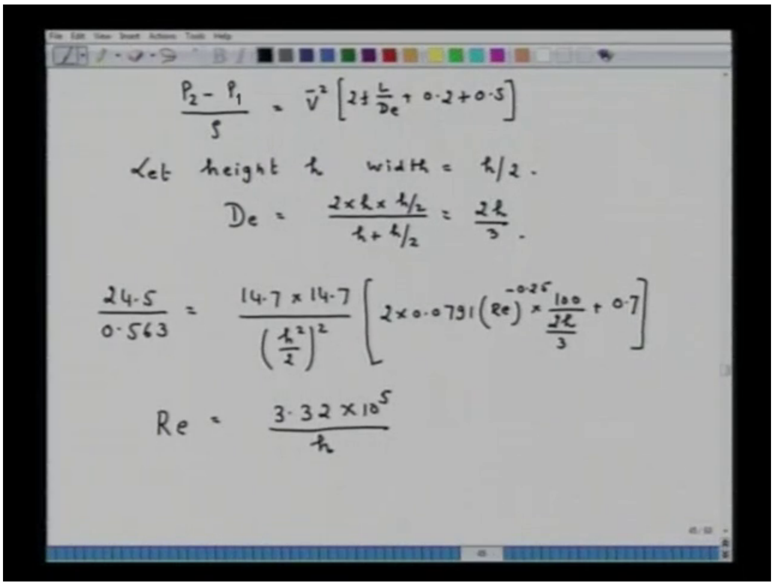

Now, next we have to calculate the certain pressure difference is given throughout to find out what is the minimum cross sectional dimension of the flue. Now, the same equation will be valid say, we have p 2 minus p 1 upon through that is equal to v bar square 2 F l upon d e plus 0.2 plus 0.5. Now, since here d is not known to us, since the cross section dimension is noncore not known core, it is unknown variable and hence, we cannot calculate v bar. Also, d e s we are able to calculate a in the previous problem.

So, now let us see let height of the flue is h, then width as given height to width (()) half width will be equal to h by 2. Now, we can calculate equivalent diameter d e that will be equal to 2 into h into h by 2 divided by h plus h by 2. So, that will be equal to 2 h upon 3.

Now, since d e is known, I can also calculate the velocity in terms of h. You please do that I am writing straight away the equation, so I have 24.5 because I have to convert the

2.5 millimeter water into the Newton parameter square divided by 0.563. That will be equal to 14.7 into 14.7. That is the flow rate form. The cross section dimension H square by 2 square 2 into 0.0791 r e to the power minus 0 .25 into 100 upon 2 H by 3 plus 0.7

So, this is my expression. Now, I can calculate Reynolds number also in terms of H. So, Reynolds number will be equal to you can calculate yourself. Reynolds number will come 3.32 into 10 to the power 5 upon h. Now, I know all the values now I substitute into the expression.

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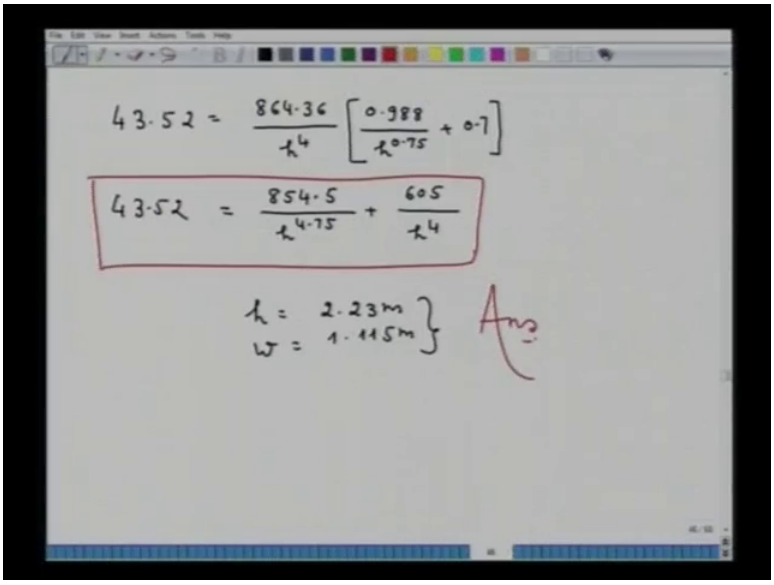

So, I will be getting 43.52 and that will be equal to 864.36 upon h to the power 4 and simplifying, then I am writing I requested to do the remaining exercise at 0.988 upon h to the power 0.75 plus 0.7. So, I get an equation which is to be solved that is equal to 854.5 upon h to the power 4.75 plus 605 upon h to the power 4 and that is equal to 43.52.

Now, this equation you have one variable h which is unknown. So, it can be solved by, this equation can be solved by method of iteration or also try a graphical solution. Now, one of the important thing in case of solution of the problems pertaining to mechanical balance, one should also have little bit mathematical graph because the solution of the equation to end up either in the iteration or a graphical solution. So, we should be able to also perform those types of methods to get the solution.

Now, in this particular case, you have to put several values of h or some gas value of h and see that right hand side equal to the left hand side. So, I did something. So, the value of h that will be equal to 2.23 meter and that of w that is half of it, that is 1.115 meter. That is the answer for the particular problem which we have given through you.

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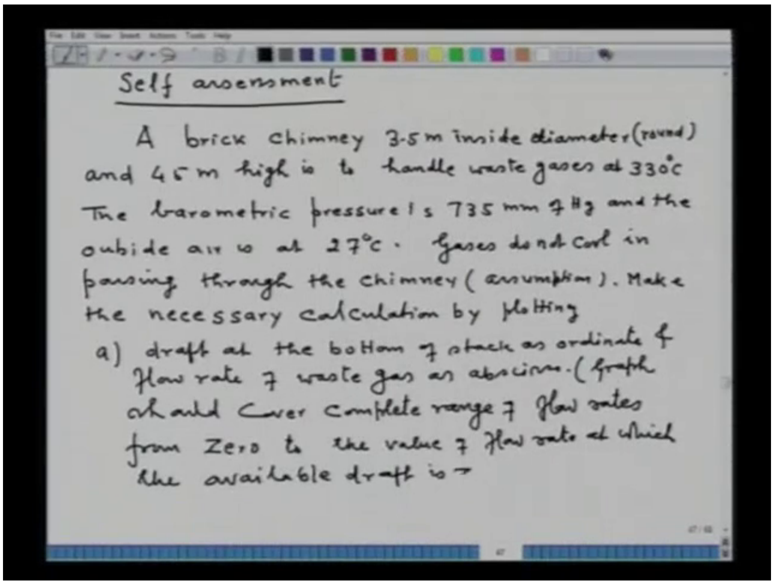

So, I give you one problem for self-assessment and see that you can do. The problem is a brick chimney 3.5 meter inside diameter of say it is round and 45 meter high is to handle waste gases at 330 degree Celsius. The barometric pressure is 735 millimeter of mercury and the outside air is at 27 degree Celsius. Gases do not cool in passing through the chimney. I will say this is the assumption.

Now, make the necessary calculation plotting a draft at the bottom of the stack as ordinate and flow rate of waste gas as (()). Now, graph should cover complete range of flow rates from 0 to the value of flow rate at which the available draft is 0, that is you have to cover the entire range.

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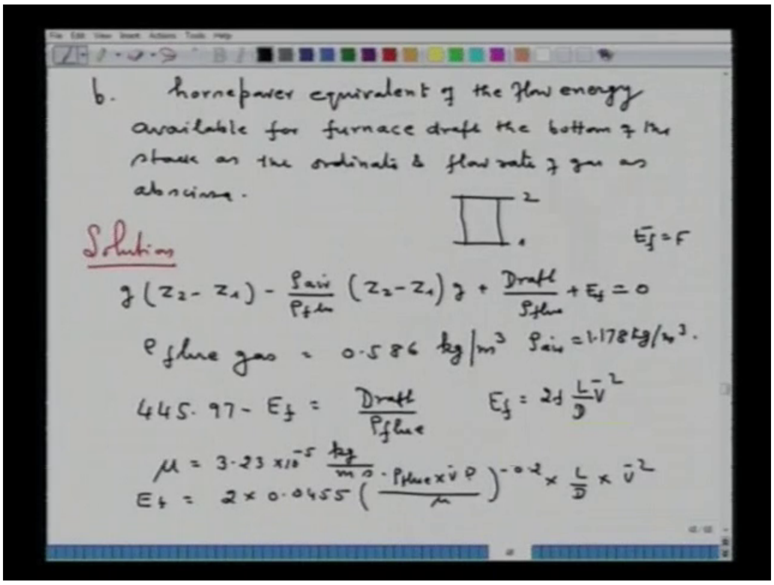

B. You have to calculate horsepower equivalent of the flow energy available for furnace draft at the bottom of this step as the coordinate and flow rate of gas as abscissa.

So, this particular problem will tell you how much of the mechanical energy balance application you have understood. This is straight away application of the mechanical energy balance and to plot the result to see a thousand to draft is effected by the flow rate. So, I will just give you the little bit hint to solve this particular problem. I will give you the answer and rest of the solution you attain to yourself.

So, in non-attentive solution, first as usual by the vertical column nothing to draw. 3.5 meter height is given, temperature is given and 45 meter is high of the draft is given. So, you have to apply the burner equation. So, burner equation is g z 2 minus z 1 minus rho air upon rho flue into z 2 minus z 1 into g plus draft upon rho flue plus e F x. It is equal to 0 r e x can also write e F, that is equal to 2F are the frictional force does not matter.

So, all that now in the expression, everything is zone. It is put in proper units. So, rho flue gets you have to calculate rho air. You have to calculate at the appropriate. Then, for example, you calculate rho flue gets that will come out 0.586 kilogram per meter cube calculate rho air 1.178 kilogram per meter cube.

Now, apply write down into this balance equation. So, I am writing straight away the equation that will be 445.97 minus e F that is equal to draft upon rho flue. Now, e f wave to the 2 f l by d v bar square since we are taking the section one and section two, write at the inlet and write at the bottom. It is in way what we are. This is our flue, this is my section one and this is my section two.

So, that is where a physical 2 f l by d v bar square. So, I can solve now for e f f you have to calculate F e is already given, that is equal to that is also can take 3.233 into 10 to the power minus 5 kilogram meter upon second. So, you can calculate now e F that will be equal to 2 into 0.0455 rho flue into v bar into d upon mu power minus 0.2 into l by d into v bar square.

So, let us calculate F by the expression 0.0455 Reynolds number to the power minus 0.25.

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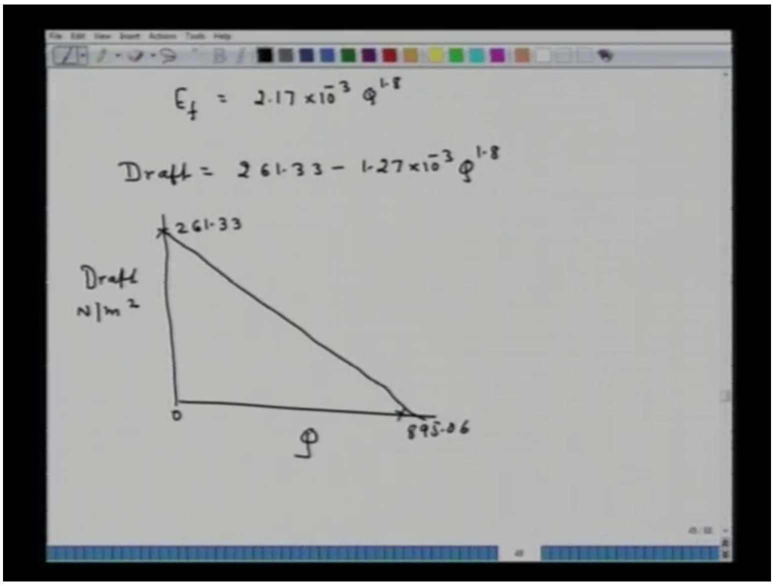

So, if you substitute all these values, then the E f that will come out to be equal to 2.17 into 10 to the power minus 3 q raise to the power 1.8 to the mind you the values of q v cannot calculate because q is not known to q for a naught number has to express in terms of q that is 5.

So, if I write now expression, then drafts that will be equal to 261.33 minus 1.27 into 10 to the power minus 3, Q to the power 11.8. So, now, I have to plot this value. I put here draft say a Newton per meter square and put here q. So, a q is equal to 0. The draft is 261.33. Now, I have to take when q when the draft is equal to 0 through to put draft is equal to 0 and find out the value of q. So, q will come out to be equal to 895.06 Q in meter per second. So, something like this. So, you have to see that how this curve runs here.

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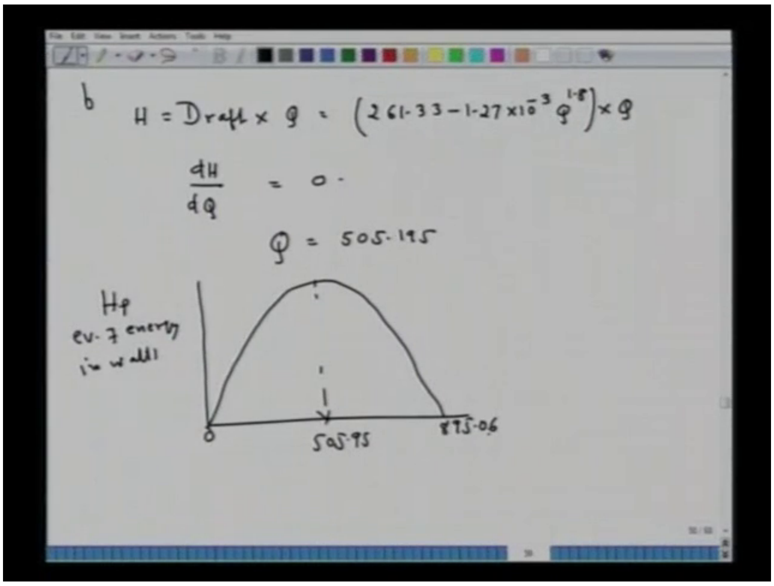

So, in the b part, you have to find out H power equivalent. So, all that you have to multiply drafts into q is the flow rate, that is equal to 261.33 minus 1.27 into 10 to the power minus 3 q raise to the power 1.8 into q. So, we have to find out the god this equation shows there is a maximum.

So, I have to take the partial differentiation that is d H. If this wave is equal to H of power d H upon d Q, I do this differential in (( )) 0. There I will be getting q that is equal to 505.95. That means, if I block here say horsepower equivalent of energy in what? Right, then this will be 0. That I have to calculate dot from you have and will go this way and we again come to equal to 0. So, this value is q that is equal to 505.95 and this value e is 895.06. So, I mean this particular problem you have to solve yourself and see that you arrive at this particular solution

Now, having done the application of mechanical energy balance, also we have seen the design of this stack chimney flue century.

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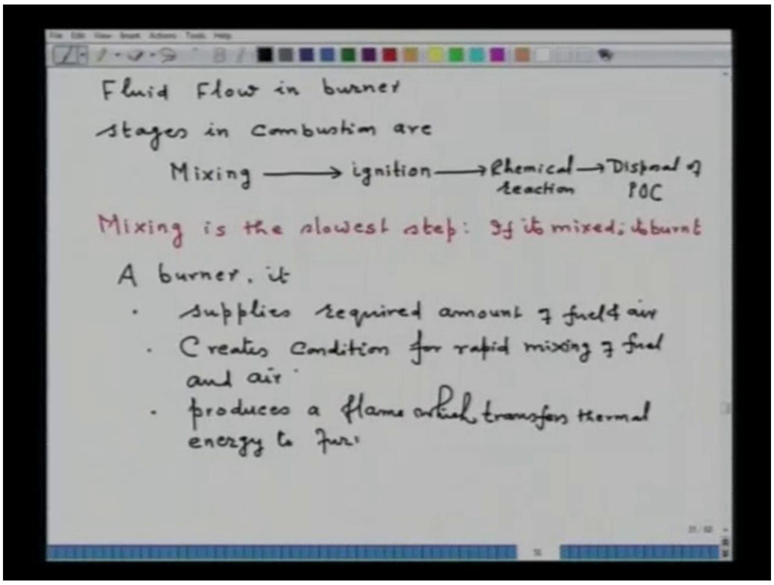

Now, next important thing. Concept the fluid part in burner that is the fluid flue in burner. Now, in combustion the stages are first is the mixing, say mixing of flue and here after mixing, then you have ignition. You have to ignite the fuel and then, ignition allowed by chemical reaction and the last stage is exposal of product of combustion.

Now, in these stages, ignition chemical reaction in exposal, there are very fast steps and this flow a system in case of combustion is the mixing. So, we can know that mixing is the slowest step in combustion that is mixing of fuel and air in combustion. So, it is said if x mixed x bar, so mixing is very very important. So, it is in this perspective a burner is an important part of the furnace. So, a burner is a very important part of furnace and it rather supplies required amount of air supplies, required amount of fuel and air fuel and air. It creates condition for rapid mixing of fuel and air and third, it produces a flame which transfers thermal energy to furnace public charge to a see a burner is a very important component of the furnace it us several job.

So, direct the flame where eight is required. So, direct meant up burner is also an important.

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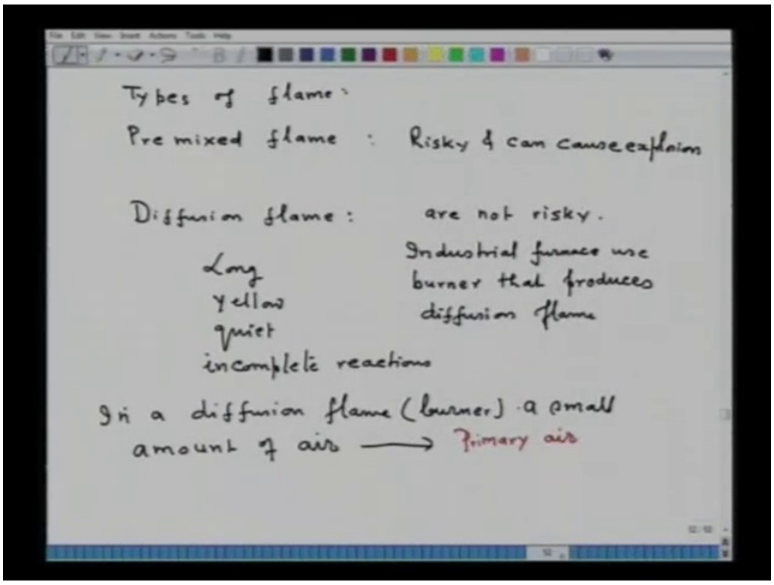

Now, will explain types of flame. One is the premix flame. Now, in the premix flame air and fuel, they are mixed in the burner in the mixture of fuel and there it discharges into the furnace. So, this type of premixed burner of that produces premix flame. That is very risky because anytime an initial happens during the mixing, the chances of explosion is very well there.

So, premix flame, they are infected risky and can cause explosion because already required amount of where we mixed. So, all that ignition is required and once the mixture it will combustion and it may be to explosion also.

So, once again the premix flame or the premix burner, all amount of air is mixed before the fuel in air picture is charge farness the diffusion flame. Another is the diffusion flame. In the diffusion flame, not all air is mixed. The fuel a fraction of air is mixed with the fuel and it is discharged into the furnace and raise amount of air is supplied into the furnace.

So, in a diffusion burner based on producing the diffusion flame, a fraction of the air is supplied with the fuel and raised here is supplied in the furnace. So, this diffusion flame, they are not risky or not and most of the industrial furnaces, all industrial furnaces uses burner that produces diffusion flame produces diffusion flame.

Now, the diffusion flames are long yellow and quiet and some kinds there incomplete reaction as against the premix flame. They are short they are noisy, but the reactions are complete because all fuel and I have been mixed prior to be discharged into the furnace wherein diffusion flame, the air in fuel that mixed in the furnace. So, in a diffusion flame or a burner design for diffusions flame, a small amount of air is mixed with the fuel and this air is called primary air.

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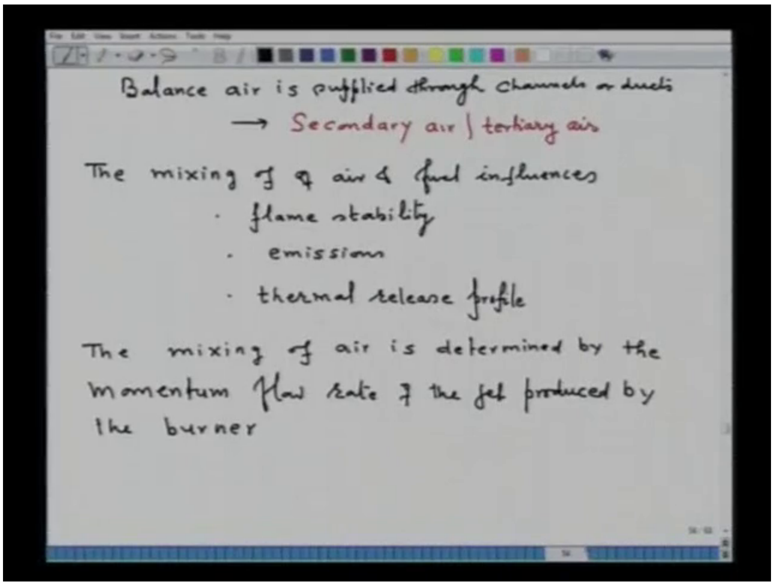

Balanced air is supplied through channels or ducts. They could be at several location and as such this balance air is called secondary air or sometimes called tertiary air. Note the essential difference between premix burner and diffusion burner is set of the amount of air that is fixed. In premix flame all air is mixed. Air is a diffusion burner. Only friction of air is mixed. The fuel (()) is the supply into the furnace.

So, in fact in the diffusions name the mixing of fuel air is very important because this mixing of air in fuel will occur in the furnace because primary at the constitute around 30 to 40 percent of the total air. Rest air you are supplying in the furnace. So, the air which is supplied in the furnace is must value mixed with the mixture of primary at plus 12. Then, the combustion will occur. Therefore, the mixing of air and fuel, it influences flame stability. Emissions, in the sense where the combustion are complete or incomplete. Accordingly, the incomplete combustion products of combustion will also be there and thermal release profile.

So, what I contact to say from here that in diffusion type of flame or the burner based on the diffusion flame, it is the mixing of secondary air with a mixture of primary fuel. Primary air and fuel is very important because you are not supplying or 100 percent air to the burner that supplying only 15 to 30 percent air with the fuel. So, it is the characteristic of the mixture of primary pursues. It starts from burner into the furnace that will create the condition of mixing.

So, in such the mixing of air is determined by the momentum flow rate of the jet produced by the burner by a certain quantity of air and fuel at passes through the burner.

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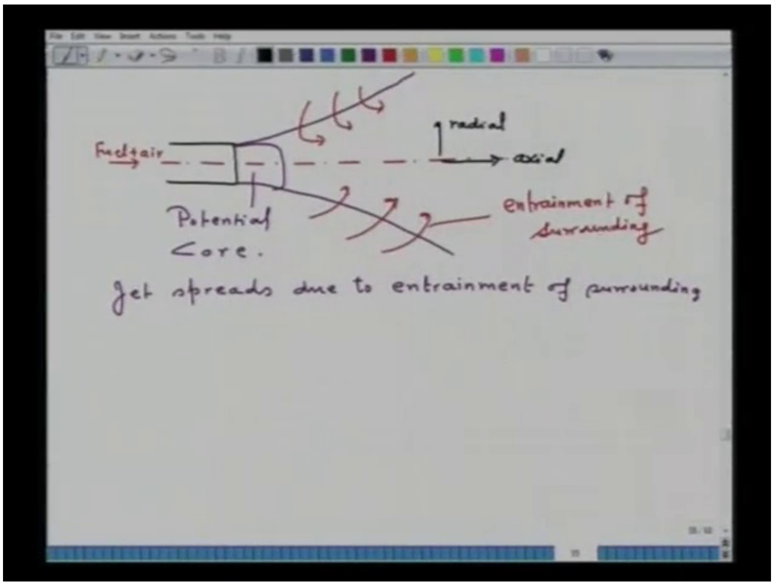

So, if I can represent say this is my burner is a central line. So, here and passing a mixture of fuel plus air and as this fuel and mixture is discharged through the burner, then a free jet is produced. In the free jet, this is called potential core.

So, when this mixture passes, then in fact the jet of air in fuel spreads. So, jet spreads due to encouragement of surrounding that is the diameter of the jet. At any distance down is seeing the nozzle or down, still the burner, it increases. So, here is the encouragement of surrounding. This is the encouragement surrounding.

So, what we see from this that can be mixture of fuel and there is discharge through the burner. A free jet is fixed, the diameter of the jet increases and accordingly, the velocity of the jet actually as well as radically, it decreases that is this is the axial direction and this is the radial direction. So, further details of this mixing process for diffusion burner, we will take them next.