Fuel, Refractory and Furnaces

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Lecture No. # 25

Macroscopic Energy Balance

Applications to Design Head Meters

Stack and Blowers, Types of Flames

We continue our lecture on transport phenomena and furnaces, fluid flow that is where we were discussing, we have derived mechanical energy balance and we had applied this mechanical energy balance to design the head meters. The head meters with which we have considered they were orifice, Venturi and nozzle the respective energy balance equation we have already derived. Now, today I will illustrated by solving two problems so that you understand the various parameters and their substitution.

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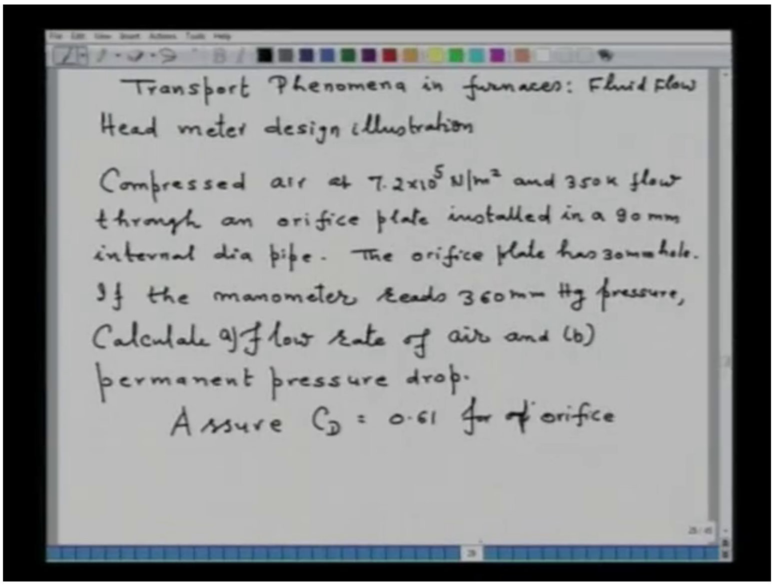

So, let us consider first of all, say compressed air at 7.2 into 10 to the power 5 Newton per meter square pressure and 350 Kelvin flow through an orifice plate through an orifice plate installed in a 90 millimeter internal dia pipe. The orifice plate has 30 millimeter hole. Now, if the manometer reads say if the manometer reads 360 millimeter mercury pressure, calculate flow rate of air and calculate a for example, flow rate of air and b permanent pressure drop.

Now, as you recall here the orifice dimensions is given that is a 30 millimeter hole but from the manometer or from the consideration of the fluid flow lines through an orifice. All of you are aware that the minimum cross sectional area is not the diameter of the hole but some distance downstream the hole and hence the diameter is somewhat lower. Accordingly, in this particular problem, if we know their coefficient of discharge value, then we can proceed with the problem.

So, as such assume, C D rate of coefficient of discharge for this particular orifice that is equal to 0.61 this is for orifice.

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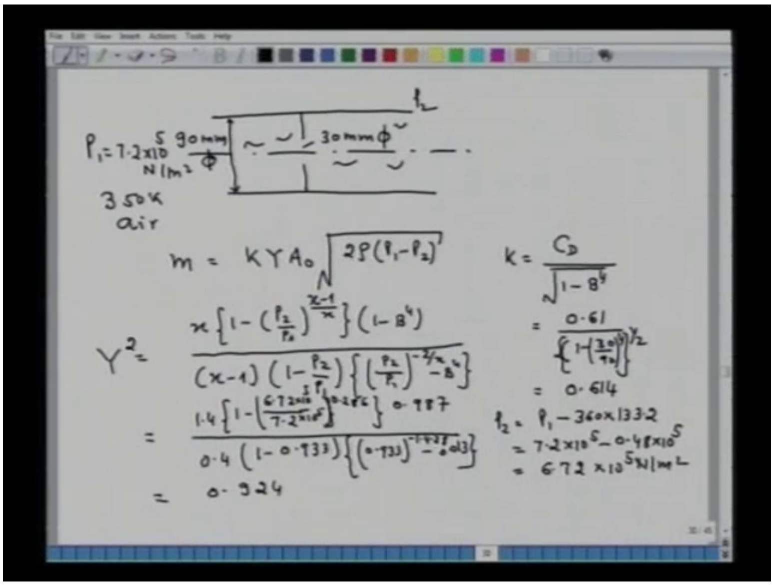

So, let us proceed to solve this particular problem. Now, what is given is said this is the pipe, this is for example, a center line and somewhere here a plate of a 30 millimeter hole. That is 30 millimeter phi and the diameter of the duct is 90 m m phi and p 1 that is equal to 7.2 into 10 to the power 5 Newton per meter square pressure 350 Kelvin and air is flowing through this pipe and we have to find out the flow rate of air and permanent pressure drop.

Now, straight away we can use the expression which we obtain from mechanical energy balance the mass flow rate through the orifice. So, we got the equation for example, mass flow rate through the orifice that was equal to K Y A 0 2 rho p 1 minus p 2, where p 1 minus p 2 is the pressure differential, A is the flow coefficient, Y is the expansion factor and A 0 is the cross sectional area of the orifice. So, now we proceed to calculate the different parameter as we know, that K that is equal to C D upon square root of 1 minus B to the power 4 and B is the ratio of the diameters. So, C D is 0.61 upon 1 minus 30 upon 90 raise to the power 4 this is square root that so if we solve, we will get K that is equal to 0.614. So, we got one variable K.

Now, we can calculate also Y. now, as we recall, Y was the expansion factor and this equation is that kappa 1 minus p 2 upon p 1 raise to the power kappa minus kappa 1 minus b to the power 4 upon kappa minus 1 1 minus p 2 upon p 1 p 2 upon p 1 raise to the power minus 2 upon kappa minus b 4. So, all that we have to substitute the values, but we have to find out p 2 and p 1. Now, p 1 we have to find out this way say p 1 is given 2 into 10 to the power 5 per Newton square and p 2 is somewhere at the exit. So, p 2 will be equal to p 1 minus the pressure differential which is 360 millimeter mercury, when multiplied by conversion factor into Newton per meter square so that is equal to 7.2 into 10 to the power 5 minus 0.48 into 10 to the power 5. So, p 2 is equal to 6.72 into 10 to the power 5 Newton per meter square.

Now, since p 1 is 7.2 into 10 to the power 5 Newton per meter square, the manometer refers 360 millimeter of mercury as the reading of the that is a pressure differential. So, hence p 2 will be accordingly less than p 1 that is how the gas will flow that means, that fraction of the p 1 is converted into the velocity. So, now we know the value of Y, we know the value of K, we know the value of A 0 which is phi by 4 d square and so on.

So, now we can calculate first we evaluate the value of Y so, I do not think I need to substitute well you can do well, let the substitute for you. We know kappa is exponent which is 1.4 for all diatomic gases so I substitute 1.4 1 minus 6.72 upon 7.2 into 10 to the power 5 into 10 to the power 5 that is equal raise to the power this is this one 0. 286 0.987 that is a value of 1 minus v to the power 4 that is equal to 0.41 minus 0.933, 0.933 raise to the power minus 1.428 minus 0.013. So, if you solve this Y value is equal to 0.924.

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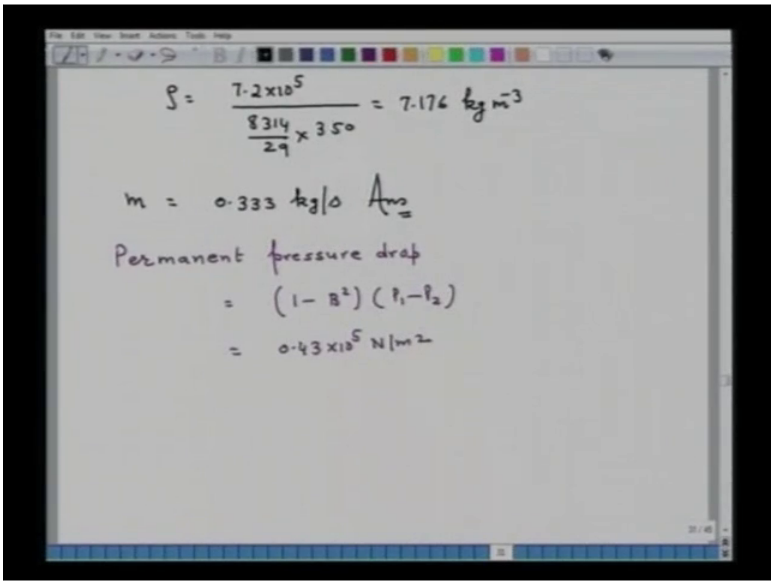

Now, we know this thing now, we can proceed to calculate say, we have to calculate also rho. Rho will be equal to say 7.2 into 10 to the power 5 is our pressure, we divide by a gas constant and the temperature of 350. So, this value is 7.176 kilogram meter cube. Now, we know all the value now, I can substitute into the expression so this m will come out to substitute, will come out to be equal to 0.33 kilogram per second and this is the answer for the flow rate of air. This is all you can see by installing a manometer and orifice in a pipe one can calculate the flow rate of air.

Now, since I have already said that, because of the formation of vena-contracta there is a heavy loss of pressure when air flow through the orifice. So, let us calculate and this pressure drop is permanent in nature that means, we can recover this pressure once it is loss, because of flow through an orifice that is I recall permanent pressure drop. An permanent pressure drop that is equal to you recall formula 1 minus B square into p 1 minus p 2. So, we already knows the value and if I substitute I will be getting the permanent pressure drop is 0.43 into 10 to the power 5 Newton per meter square, so that is what a typical of the orifice meter which shows substantial amount of loss of pressure when for that matter any fluid air or water which flows through an orifice. Now, let take an example of an Venturi meter.

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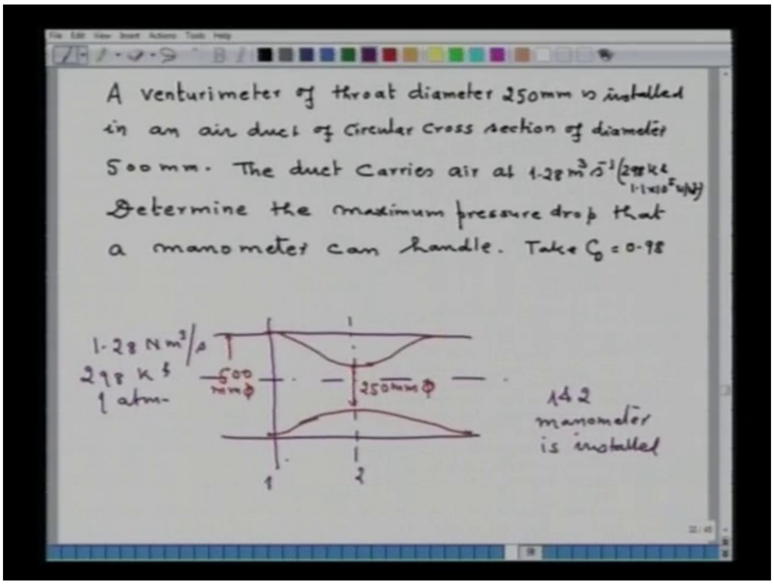

Let us consider a Venturi meter of throat diameter throat diameter 250 millimeter is installed in an air duct of circular cross-section of circular cross section of diameter of diameter 500 millimeter. The duct carries air at 1.28 meter cube per second which is given at 298 Kelvin and at pressure 1.18 into 10 to the power 5 Newton per meter square. Now, determine the maximum pressure drop that a manometer can handle. Now, as I have said that Venturi meter they are designed such that, there is insignificant loss of pressure and hence, their coefficient discharge will be for calculation purposes. So, take C D that is equal to 0.98.

So, now we have to calculate, what is the pressure coefficient discharge. So, in fact the problem can be illustrated, this way that this the duct of circular cross-section, well somewhere here is a center line and there we are installing a sort of Venturi meter, this is a Venturi meter installed in a duct. And this Venturi meter this is it is cross section area that that is equal to 250 millimeter pi and the duct has 500 millimeter diameter. So, for this particular case the manometer is installed at position 1 and here, since there is no mean of contracta formation the flow is very straight forward and so the manometer tube lagged here so in between 1 and 2 manometer is installed.

So, we have to; for this condition when say air is flowing say 1.28 Normal meter cube per second air is flowing at 298 Kelvin and 1 atmosphere that is given to us so, we have to calculate the so called the maximum pressure drop. So, now let us proceed so we know the equation, because there is no difference in the equation that we obtain from mechanical energy balance though, we have said it is for the orifice. In fact it relates the diameters that is the pipe diameter and the diameter through which the pressure passes. So, same equation will be valid.

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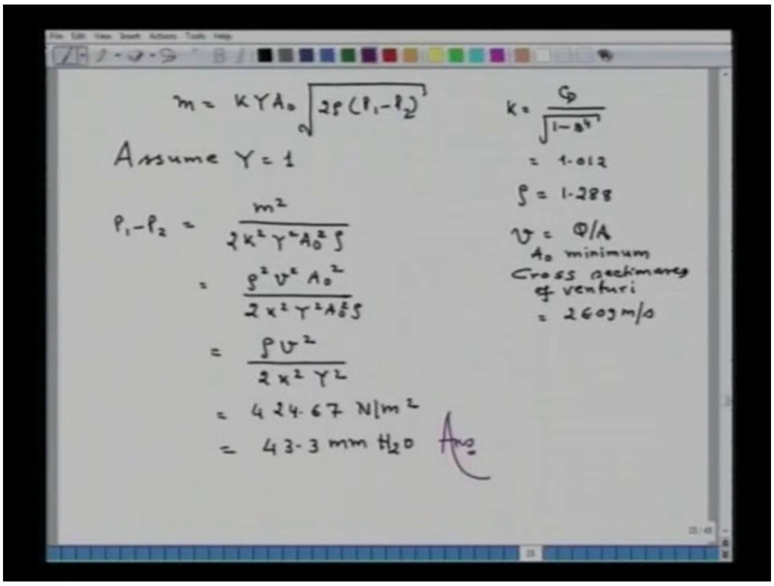

So, m we is equal to K Y A 0 2 rho p 1 minus p 2 that is our equation. Now, first of all we have to calculate the value of K. So, K straight away we can calculate, we know this formula C D 1 minus B to the power 4 square root substitute the values K will be equal to 1.012. Similarly, I can calculate the density also, it will come 1.288 you calculate yourself. Similarly, I can calculate the velocity v that will be equal to Q upon A so, A rather A 0, where A 0 is the minimum cross-section area of Venturi that is given 250 millimeter. So, if we calculate V that will coming out to be equal to 26.09 meter per second so, we know all the values.

Now, here Y is not known to us so, we can let us say assume say Y is equal to 1, but this assumption has to be verified once, we calculate the pressure differential. So, if we assume Y is equal to 1 then, we can calculate now. So, we can just re-write the expression say p 1 minus p 2 that is equal to m square upon k square y square a 0 square into rho 2. So, all the variables are known so if I substitute the values I mean I you can substitute value of m, m will be equal to what, m square that will be equal to rho square V square A 0 square. So, we can further simplify if you wish 2 K square Y square A 0 square into rho so that will be equal to rho V square upon 2 K square into Y square. So, if is substitute the value I will be getting 424.67

Newton per meter square that translate into 43.3 millimeter H 2 O. So, in fact that is my answer that is a manometer can handle 43.3 millimeter of water as a maximum pressure difference.

Now, this answer is subject to the validation that Y is equal to 1 that means, the answer or the solution of the problem is incomplete at the this state, because we have made assumption Y is equal to 1. So, we have to; now, since we know the pressure difference now, we can calculate the value of Y, we know the formula for Y.

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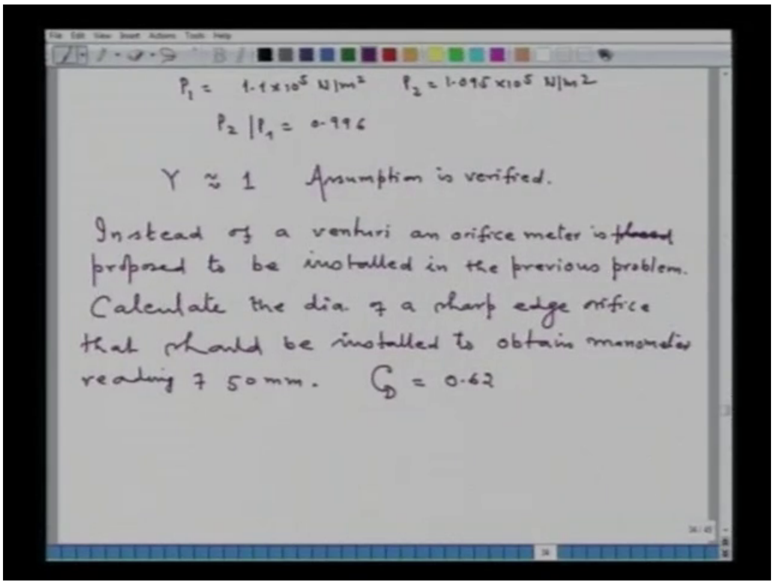

Say p 1 now, is given to us 1.1 into 10 to the power 5 Newton per meter square. So, p 1 minus p 2 that is equal to pressure difference so, p 2 that comes out 1.095 into 10 to the power 5 Newton per meter square. What I can do? I can substitute so, p 2 upon p 1 that is equal to 0.996 well, I left this exercise of substitution. The various parameters that are involves in the calculation of Y and I straight away write down the value of Y that, we are getting is approximately equal to 1 and hence, assumption is verified.

Now, if you do not want to make any assumption then you can substitute the value of Y that is the formula into the expression. Now, in the expression p 2 upon p 1 that is the only variable that is all known so by the method of iteration you can also find out the value of p 2 upon p 1 or the pressure differential that is also one of the technique to find out. So, now with this we have verified the assumption hence our answer is okay, there is no problem at all.

Now, let us see another problem from this, say what we are doing now, say what say instead of Venturi an orifice meter is placed or rather is proposed to be installed in the previous problem, all the things are same that is duct of diameter 500 millimeter and so on. Now, what is required? Calculate the diameter of a sharp edge orifice, orifice that should be installed to obtain manometer reading manometer reading of 50 millimeter. Take C D for this problem of orifice is equal to 0.62. Now, note that the C D is different for Venturi 0.98, for orifice we had taken 0.62 so, the flow rate pressure everything is the same.

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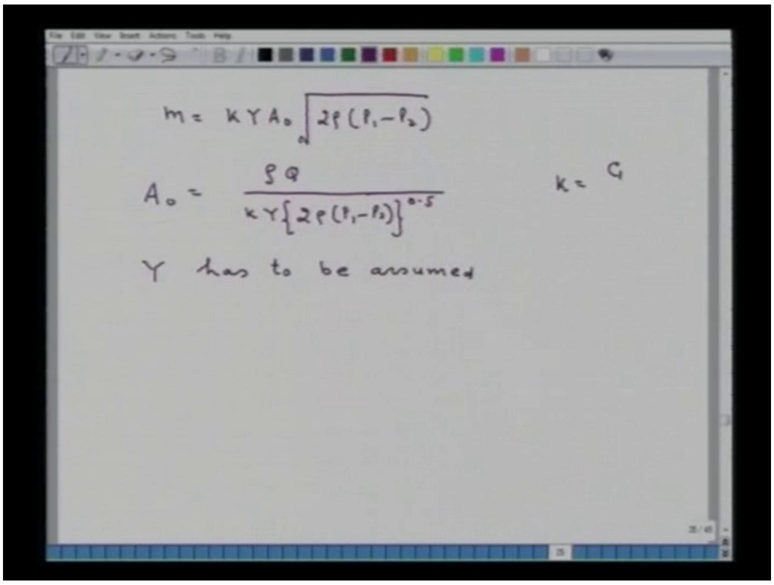

Now, we have to calculate an alternative proposal that well Venturi is not a variable let us see if I can work with the orifice so I have to calculate now. So, if I do that I straight away write down the formula m that is equal to K Y A 0 2 rho p 1 minus p 2 that is what we know. Now, from here we can say that A 0 that is what we have to find out, that will be equal to rho Q, you can derive this equation K into Y 2 rho p 1 minus p 2 raise to the power 0.5. So, now here, again the value is not known. So, here again Y has to be assumed, rest all parameter you can calculate we have done already. So, if I substitute all variables over here then I will be getting. Now, note here the B is also known not know, because K, K is equal to C D so, we have to calculate the value of B.

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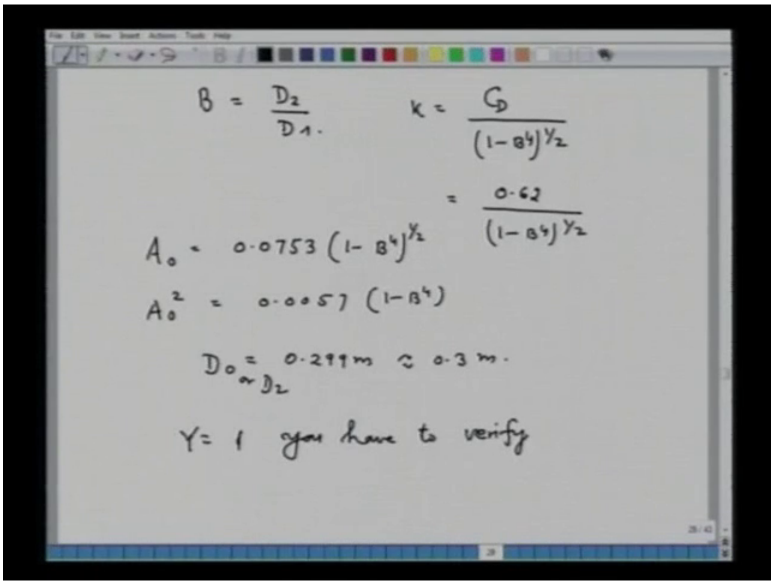

B that is equal to D 2 upon D 1 hence K that will be equal to C D upon 1 minus B to the power 4 square root, B we cannot calculate since D 2 is not known to us. So, K will simply be come out to 0.62 upon 1 minus B to the power 4 square root of that term. Now, we can substitute all the variables so, I calculate now, A 0 that will be equal to 0.0753 1 minus B 4 that is what we get it. Now, we have to solve it. So, we can do that now square say A 0 square that will be equal to 0.0057 1 minus b 4. Now, I can calculate I can put A 0 phi by 4 D 0 square I can calculate now, simple expression. So, D 0 that will be equal to 0.299 meter D 0 or D 2 whatever you want to call that is equal to 0.299 meter or approximately 0.3 meter.

Now, here we assume Y is equal to 1 so, you have to verify, we use the appropriate expression for Y for orifice and verify it whether you get i is equal; Y is equal to 1 or not. Now, I give you further for you to calculate.

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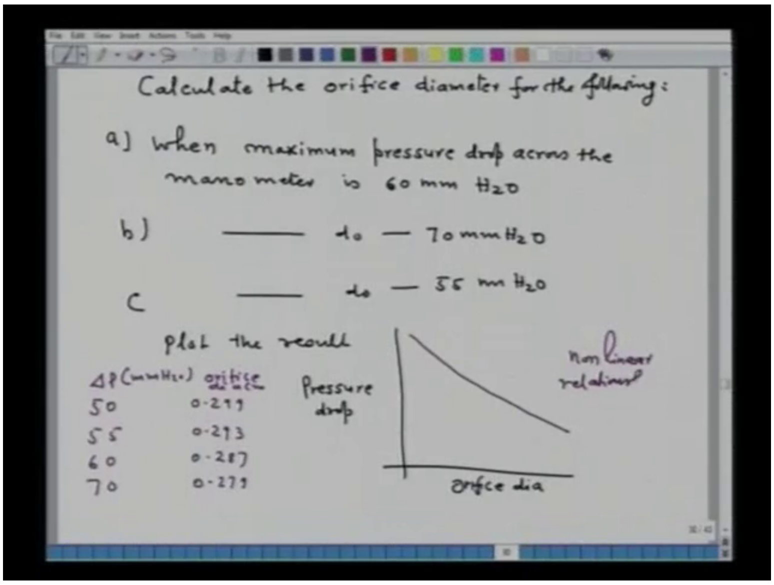

So, for the same flow condition, calculate the orifice diameter for the following conditions for the following condition. Now, a when maximum pressure drop across the manometer is 60 millimeter water, b same when pressure drop is 70 millimeter water, c same when pressure drop is 55 millimeter water, the idea is that to know how the pressure drop varies with the orifice diameter. So, I expect this to be a sort of non-linear and then I ask you to plot also. So, plot the result as for example, take on the Y axis say pressure drop and here, you take the orifice diameter orifice diameter, my calculation yielded me say delta p here 50 millimeter, 55 millimeter, 60 millimeter and 70 millimeter, millimeter water, orifice diameter in meter that 50 millimeter we already calculated 0.299 for 50, 50.293 please get calculated and 0.287 and 0.279 I expect a some sort of a non-linear relationship.

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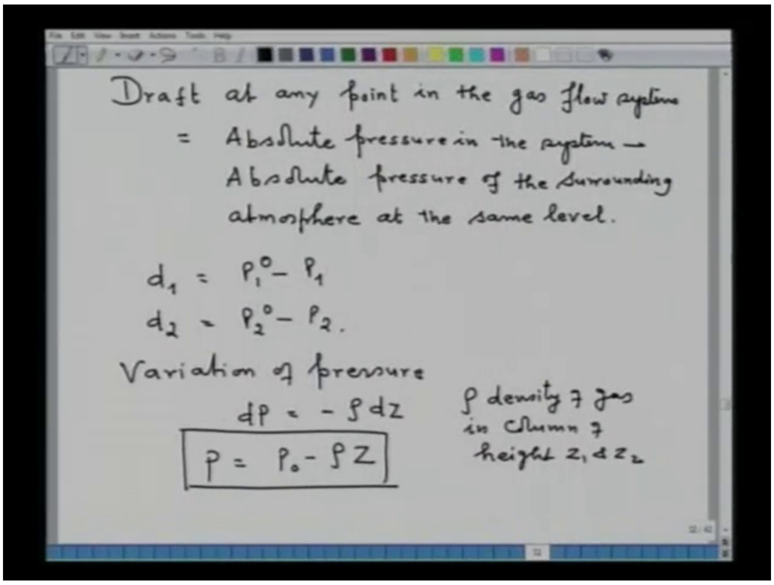

Now, let me go to the next thing that is the draft. Draft at any point in the gas flow system it can be is equal to absolute pressure in the system minus absolute pressure of the surrounding atmosphere at the same level. So, if you take d 1 at one point that will be equal to p 1 not minus p 1 and d 2 at the point two that will be equal to p 2 not minus p 2. Now, it is also important since small pressure differences are controlling factor in the furnace system, variation of the pressure with height in a gas column is important. So, consider a gas column of certain height then accordingly, the pressure exerted on the particular point will be influence by the height.

So, a such it is also important to consider the variation of pressure with the decrease in the height and the variation of pressure with the decrease in height. Say variation of pressure with decreases with height, it can be represented say d p that is equal to minus rho into d Z, where rho is the density of gas in the column of height Z 1 and Z 2, that is z 2 minus Z 1. So, this you can say P that is pressure at any point that is equal to p 0 minus rho into Z. So, this is the equation which tells you the effect of column of the gas on the pressure.

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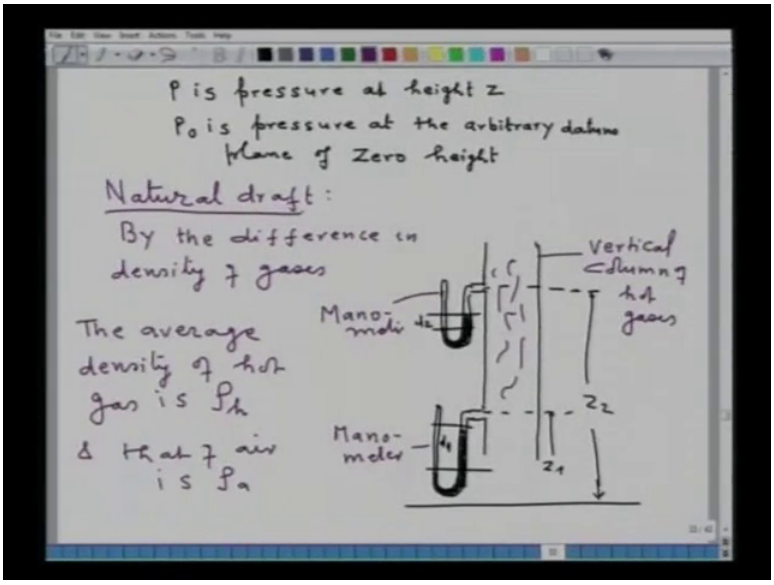

Now, on this expression the P is pressure at height z and p 0, p is pressure at the arbitrary that complain of zero height. So, let us now consider natural draft natural draft. Now, natural draft is created by the difference in density of the gases. Now, let us consider a vertical column so this is a vertical column of hot gases that is this column is filled with hot gas gases are flowing; is filled with hot gas gases are not flowing and this column of hot gas is surrounded by air at ordinary temperature and pressure. Manometer at height Z 1 and Z 2 are installed to measure the relative draft at two levels that means, this is the manometer this is also manometer, they are installed at the location one and two read the relative draft the average density. The average density of hot gas, let us say is rho h and that of air is rho a.

So, what we are considering? Now, in the finding of the expression of natural draft that considering a vertical column of for gas the gases are not moving, we have installed two manometer at two different positions at Z 1 and Z 2 to measure the relative draft. Now, this vertical column is surrounded by air at ordinary temperature and pressure.

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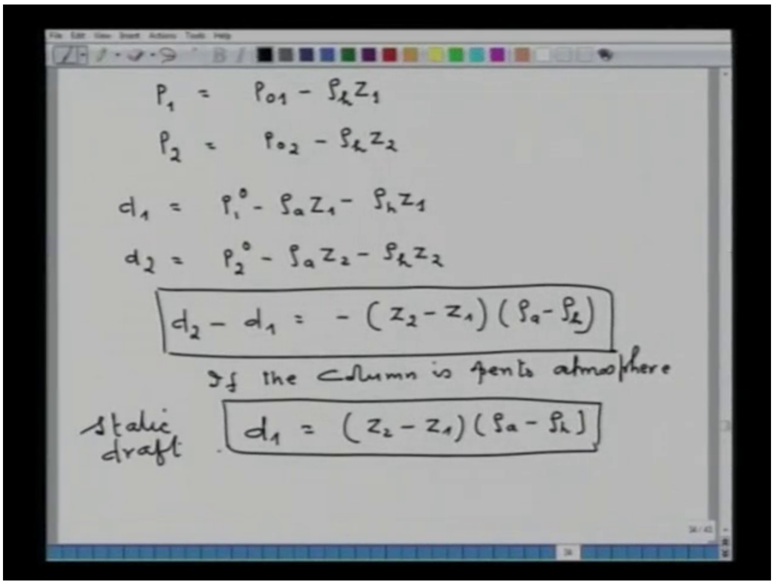

So, we can write down now, p 1 that is equal to as per the definition p 0 1 minus rho h Z 1 that is p n; p 1 that is pressure at the particular point will be absolute pressure at this point plus this pressure of this column that is what I have written p 0 1 minus rho at Z 1. Similarly, pressure at point two that is p 2 that will be equal to p 0 2 minus rho h Z 2. Now, we have to define a draft, draft d 1 that is equal to p 1 not minus rho a Z 1 minus rho h Z 1 and d 2 that is equal to p 2 not minus rho a Z 2 minus rho h Z 2. Whereas, p 1 not know this is the absolute pressure in the system and rho h Z 2 that is the density multiply by the height with reference to that complain at the respective positions.

So, now we can determine very straight forward d 2 minus d 1 that will be equal to minus Z 2 minus Z 1 into rho a minus rho h, this is the equation for determining the draft. Now, if the column is opened to atmosphere, then d 2 will be 0 and d 1 draft that is equal to Z 2 minus Z 1 rho a minus rho h that is what equation for the calculation of the draft. Now, mind you, we have calculated the draft under the static condition that is the when the gases are not flowing. So, this the sort of you can call this is the static draft.

Now, static draft in the particular form for a given height of column and the given temperature of the surrounding where rho h is fixed, the static draft and be increased only by decrease the density of hot gas, that is when the hot gases are discharged at higher and higher temperature. So, increase in temperature will decrease rho h and hence will increase the static draft. But, normally when this chimney is connected to furnace the gases flow and the flow of gases causes frictional losses as you have done in case of mechanical energy balance. So, if we apply again in mechanical energy balance at 0.1 and 0.2. And try to know what will be the say losses or what will be the draft in presence of the frictional forces then, what we have to do? We have to apply mechanical energy balance and as we apply, we already done the mechanical energy balance. So, I would straight away write down, the mechanical energy balance for the flow of gases in a vertical column at 0.1 and 0.2.

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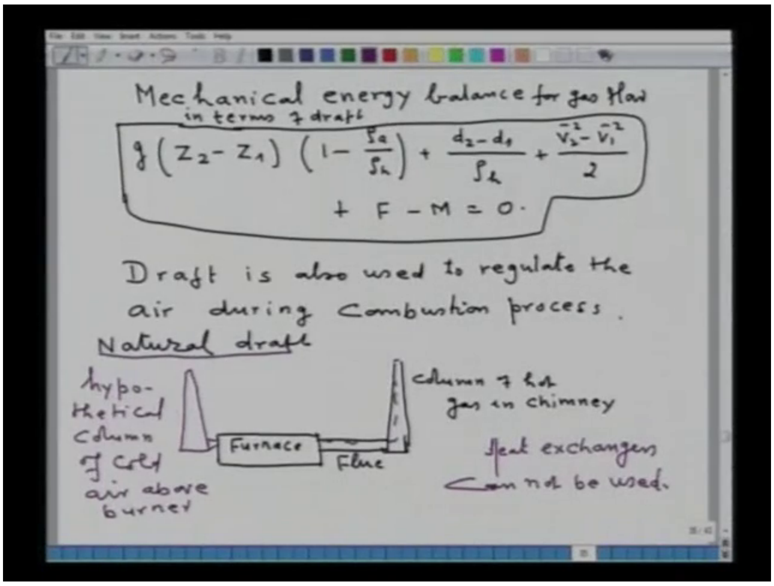

So, this mechanical energy balance mechanical energy balance. So, you have to write I can write down this is g Z 2 minus Z 1 into 1 minus rho a upon rho h plus d 2 minus d 1 upon rho h plus 2 plus F minus M is equal to 0. Now, what you have to do is that is very simple, in order to obtain this form of mechanical energy balance which is in terms of draft. The equation of mechanical energy balance which we obtain in terms of absolute pressure that is p 1 and p 2 that has to be transformed in terms of the draft by the respective equation which I have given to you. That is very simple, you just write down p 1 and p 2 in terms of draft and replace p 1 minus p 2 from the original mechanical energy balance and you will be getting this expression for mechanical energy balance for gas flow system.

For gas flow in terms of draft in terms of draft d 2 and d 1 they are the draft. So, this is the equation which will be using to calculate some of the parameters of the column of gas and so on, F the frictional forces and M if there is a pump or whatever the case may be. So, this equation is applicable to furnace opening ports, design of dampers, because dampers are also the flow control devices in the flue to regulate the flow and so on. Now, also one should consider, that these draft is also used to regulate the air during combustion process.

Now, for example, say the natural draft what happens. Suppose, we have a furnace this is a furnace and from here, the hot gases are flowing and this is the chimney, this is the say column of hot gas in chimney, this is the flue, this is the flow of the p o c flow upward. Now, let us consider a this is the burner from where air is supplied, this is a burner from where air is supplied. And above a burner, we can consider a column, say this is a sort of hypothetical column of cold air above burner of the same height as that of the chimney.

Now, this is a mechanism where the flow of air through the burner and into the furnace can be regulated by way of the natural draft, but with this natural draft the problem is that, if you want to have a very high natural draft then very high temperature of the furnace gases are required. So, the disadvantage for using natural draft as flow regulating device is that heat exchangers cannot be used I say the. So, this natural draft is also used or can be used to regulate the flow of air into the furnace, but then the use of heat exchanger is not possible.

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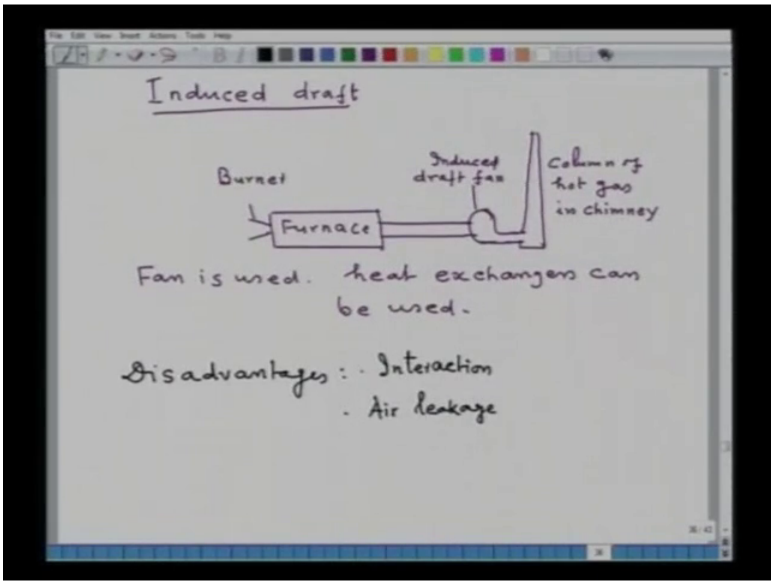

Now, another type of say draft that we have that is the induced draft. Now, induced draft let a second consider a furnace, say this is a furnace here you have a burner for supply of the I mean gaseous mixture and here, this is the fluid and somewhere here, we have a installed a fan, this is a fan and this is a chimney. So, what is done this is the column of hot gas in chimney, this is induced draft fan, this is a burner. So, what you are doing, in the induced draft you are not; you are no more using the density difference of the gases, but you are putting an extra fan. Now, this fan which you have pushed, which you have put downstream the furnace it creates a suction so, in induced draft a fan is used, it may be require to find out the capacity of the fan the problem we have done.

Now, increase in suction is available, because you can run the fan and hence, heat exchanger can be used that is possible. But the only disadvantage in this type of only disadvantage, the disadvantages of using induced fan is first of all interaction. Interaction between hot gases dirty gases with the fan temperature is very high so, the chances of a destruction of the fan is there and second important disadvantage is that the air leakage. Now, since the furnace operates under suction so the chances of air leakage is very very high. So, one is to be careful, because any air leakage will take away the heat of the furnace and such calculation we have done is our lecture from combustion 9 to 13. So, air leakage is very detrimental though, the induced draft is good, but these are the disadvantages. So, another type of is the forced draft system.

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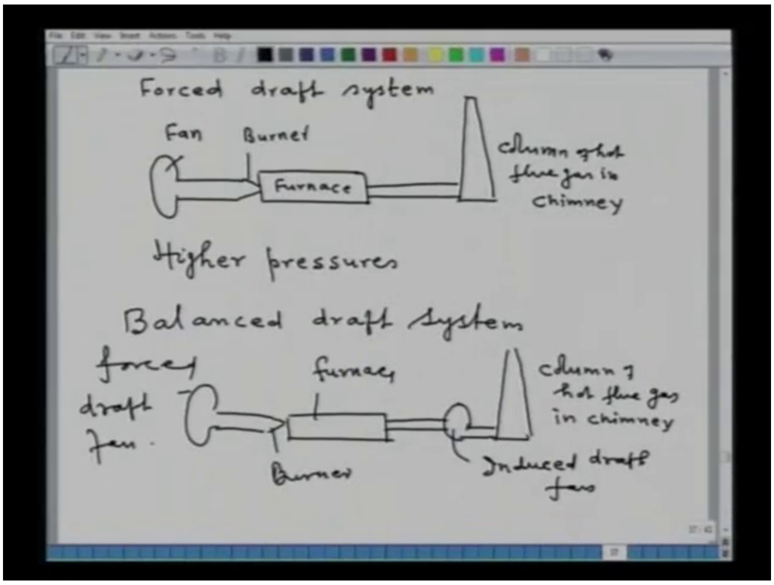

Now, in the forced draft system what you do, this is the furnace again, this is the furnace here you have the fluid and here you have the chimney. Now, what you are doing, say this is your burner and somewhere here, this is now the fan, this is burner, here is again the column, column of hot flue gas in chimney. So, what you are doing here? You are supplying air through burner. So, here higher pressures can be achieved, higher pressures in the furnace can be achieved, high pressure draft from possible. Now, be careful, because in this forced draft system the furnace operates at pressure slightly greater than the atmospheric pressure. So, in that case leakage of product of combustion from the furnace to the environment is very much possible and which is very very detrimental.

Hence, the forced draft system has to be considered in that the furnace, that there should be no leakage in furnace, because any such leakage the products of combustion is c o 2 or c o it will leak and it will destroy the environment.

So, in into counter this there is another draft that is called the balanced draft system. Now, in the balanced draft system say again, we have a furnace over here furnace, this is the flue and here is the fan and this is the chimney and here this is a burner we are putting one fan also over here. So, what we have done, this is the column of hot flue gas in chimney, this one is the induced draft fan, this is the furnace, this is the burner and this is a forced draft fan.

So, the advantage of this is that, the pressure inside the furnace will always be balance. So, the problem is for there is the forced draft system that is the leakage will not be there, but this balanced draft system is a complicated one and it require several control. Well these are the four type of system are available to regulate the flow of air during the combustion process.