Fuels, Refractory and Furnaces

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Lecture No. # 39

Furnace efficiency, Fuel saving, Carbon Offset: Concepts and Exercises.

In this lecture and the next lecture I will be talking on furnace efficiency, fuel saving and carbon credit. The concept of carbon credit is also known as carbon offset and also carbon trading. Whatever, I have covered in the last lectures on fuel furnace and refractory I will be using all the contents of the lectures to illustrate the concepts over here. So, let us first of all consider the furnace efficiency. Now, for that let us consider a fuel fired furnace.

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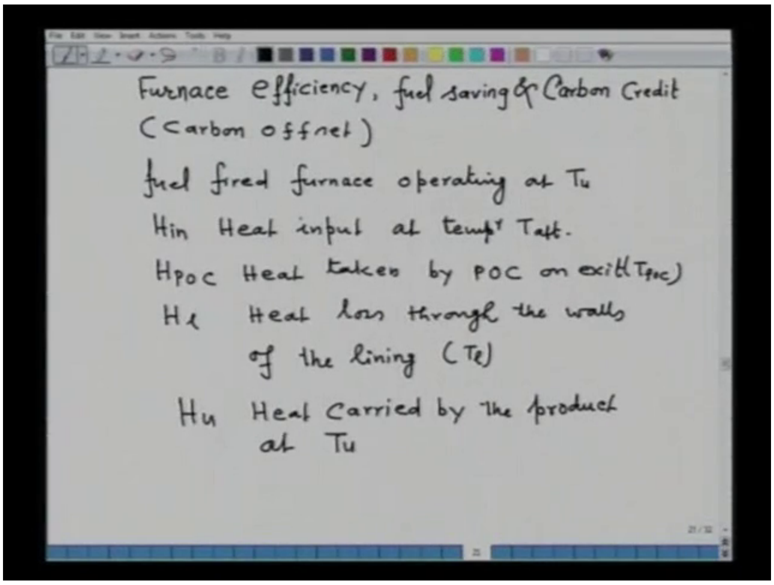

Let us consider a fuel fired furnace which is operating at temperature T u. We will also consider T u is the furnace temperature as well as the product temperature and this temperature is attained by combustion of fossil fuel. As we all know on combustion, potential energy of the fuel is converted into sensible heat of the products of combustion, at adiabatic flame temperature. Now, this heat is transferred to the walls of the furnace and to the product which are which is used for heating and after completion of the heat transfer the products of combustion exit the furnace.

So, let us take the H in is the heat input at temperature T aft which is the adiabatic flame temperature. Let us take H P O C is the heat taken by products of combustion on exit, a fraction of the heat is also lost through the walls of the lining. So, let us consider, H l is the heat loss through the walls of the lining. Now, it is also important to tell the quality of the heat which depends on temperature and let us see, that H P O C heat taken by P O C on exit is at temperature T P O C and the heat loss through the walls of the lining is at T l. So, the product also carries with them heat and let us take H u is the heat carried by the product at temperature T u.

So, the same thing now we can represent in the form of a diagram that will clear,

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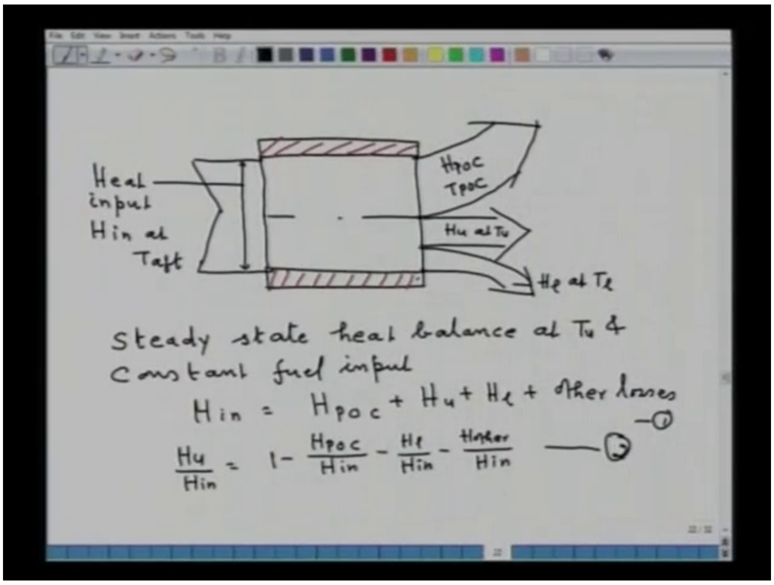

say this is the furnace chamber, this is somewhere here the lining. So, this one from here to here this scale let us consider, this is heat input this one is the heat input we are nomenclaturing H i n at temperature T a f t, which is the adiabatic flame temperature. Now, as you have done in problems on combustion and heat utilization and heat transfer so on, you have seen that a fraction of the heat is lost with the products of combustion and this is a major fraction. So, this heat which is the H P O C which is lost at temperature T P O C. Now, a sum of the heat is taken by products of combustion by product which is H u at T u, and this is the amount of heat, which is lost through the walls of the lining H l at temperature T l.

Now, this is typical a sankey diagram or a energy flow diagram, which is used to illustrate the flow of energy in a system. So, you are seeing here a constant amount of energy is in and it is utilized to heat the product. The product carries the heat equal to H u at temperature T u, fraction of the heat is lost which is H l and another fraction is carried by the products of combustion. So now, if we write down steady state heat balance at temperature t u and constant fuel input and it is here the mentioning of the temperature is important because once the furnace attains a steady state the furnace operates at temperature T u, which is attained by the heat transfer from the products of combustion at T a f t that is adiabatic flame temperature.

A fraction of the heat is lost through the products of combustion and so on as shown in the figure. So, that means if we alter the adiabatic flame temperature by altering the fuel input then, this balance will be disturbed. So, that is where it is important to say that this steady state heat balance is done at constant temperature of the furnace. So, by mentioning constant temperature of the furnace it is automatically meant that the temperature or the adiabatic flame temperature is also a constant, that is fuel input is constant and so on so forth. So, that is where this is important to say that the steady state heat balance at constant temperature of the furnace. So, if you do that then H in that is equal to H P O C plus H u plus H l plus other losses, which at the moment we are ignoring. Other losses could be say, from the hearth bottom of the hearth through the cooling water, through the opening door, these are all the say the additional losses which are there.

Now, we define say for example, if we divide by H in let us take this is equation one we divide the whole equation by H in and rearrange the equation then we will get H u upon H in that is equal to 1 minus H P O C upon H in minus H l upon H in minus H other losses upon H in, let us say this is our equation number two.

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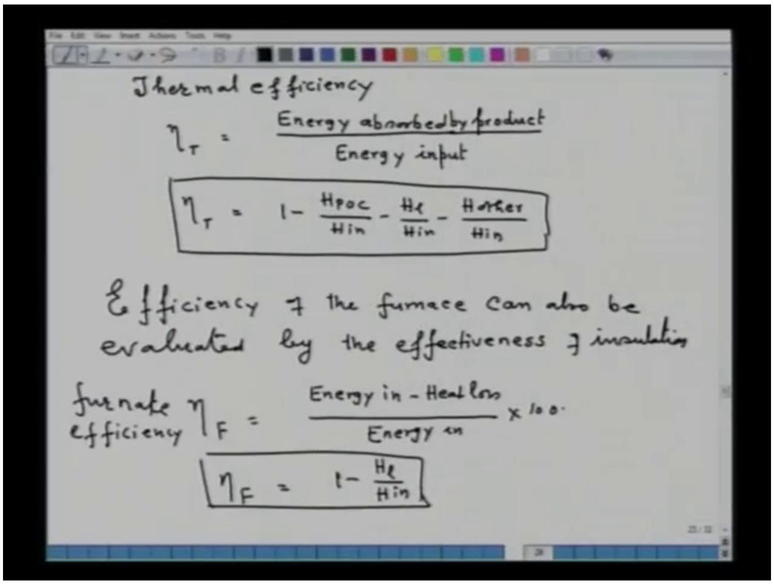

Now, if we define say let us define the thermal efficiency of the furnace. Now, thermal efficiency of the furnace is defined in terms of the ability of the furnace to heat the product or to do the useful work.

So, the thermal efficiency we define say, this thermal efficiency we define, that is equal to energy absorbed by the product divide by energy input. In this definition, we are evaluating the performance of the furnace in terms of its function for example, in this particular heat balance the function of the furnace was to heat the bloom billet or slab or whatever the case may be. So the thermal efficiency that is equal to 1 minus H P O C upon H in minus H l upon H in minus H others upon H in, this is the thermal efficiency of the furnace. So you note from this equation, that thermal efficiency of the furnace can be increased by reducing the heat lost through the walls of the lining that is H l upon H in and by reducing the losses say H others upon H in, for example: reducing the opening losses or through the hearth or through the cooling water and so on. Once the temperature of the furnace is T u, then H P O C upon H in has become a constant value.

So, the increase in thermal efficiency can be achieved only by decreasing, either the wall losses or other losses, so that is the one thermal efficiency. Now, in some cases sometimes the efficiency of insulation can also be assessed, that is you have made a furnace chamber by a lining of certain thickness, of certain thermal conductivity. So, here efficiency of a furnace efficiency of the furnace can also be evaluated by the effectiveness of insulation. So, here this efficiency this is called as furnace efficiency or you can also call at this particular parameter evaluates how effective the insulation needs to retain the heat in the furnace.

So, that is equal to energy in minus heat loss. Now, remember when I say heat loss that means heat through the lining of the furnace. The heat taken by P O C is not considered to be loss because it is the inherent feature of the energy achieved by combustion of fuel. So, that is so that is not the heat loss which is carried by the H P O C that has to be there, so when you say heat loss that means heat loss through the lining upon energy in into 100 so ultimately this becomes 1 minus H l upon H in, so this is the furnace efficiency.

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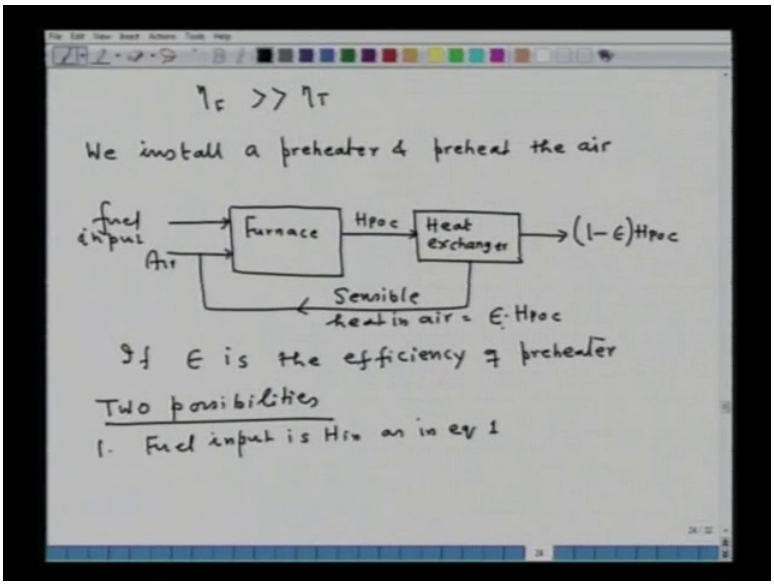

Now, note that the furnace efficiency is very much greater than thermal efficiency as I will show in a problem which I will be taking immediately after this particular lecture. Now, say let us consider that we install a preheater say we install a preheater we install a preheater and preheat the air and preheat the air. So now, what we are doing, for example, this is a furnace here, H P O C is out, it is taken into the heat exchanger, this is heat exchanger, this is again out and from here say we are having here fuel input and this is the sensible heat in air sensible heat in air and if say epsilon is the efficiency of preheater if epsilon is the efficiency of preheater then, sensible heat in air will be corresponding to epsilon into H P O C and 1 minus epsilon, H P O C will be exiting this is our furnace, this is the fuel input, this is the air. So this is how now the balance looks like.

Now, in this situation when we are when we are say recouping the heat and transferring into the furnace then two possibilities arise, then we have two possibilities you can think of two possibilities. Say in one we keep say fuel input, we keep fuel input is H in as in equation one.

That is, we are not changing the fuel input in other way we are not changing the heat input. If epsilon is the preheater efficiency then epsilon into H P O C is the heat recouped and sent back to the furnace.

So if we write down again the steady state heat balance…

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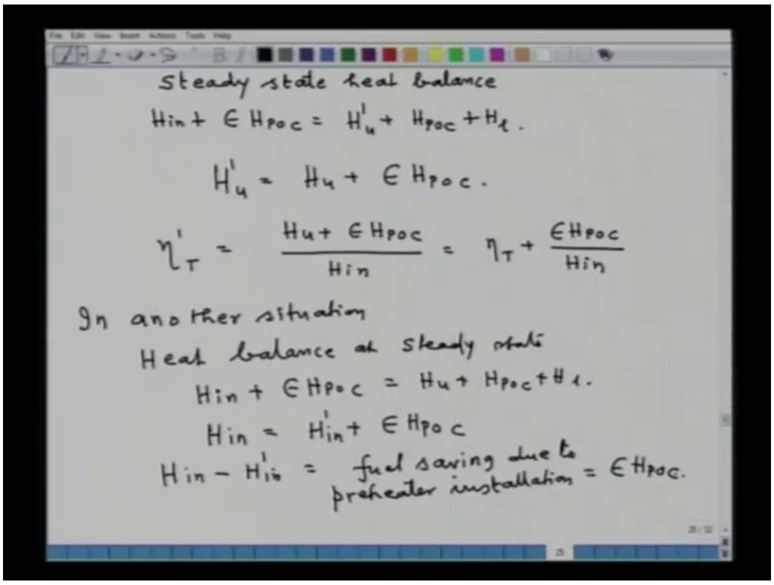

Then write down the steady state heat balance is H in plus epsilon H P O C that is equal to H dash u plus H P O C plus H l. Now, since T u is to be kept constant when we supply addition amount of heat into the furnace, the temperature of the furnace enhance the temperature of the product is not, should not change it that is the first condition. When this happens, then T P O C will not change, could you get me? What I am trying to tell you is that, by supplying extra amount of heat into the furnace the temperature should not change because that is our requirement the product should be heated at temperature t u on which we have made the balance in equation one. So, if the temperature does not change then T P O C will also not change, T l will also not change, then what will happen to the additional amount of heat which you have supplied into the furnace? Then all the additional amount of heat will be used to heat the extra amount of product. So, that means here H dash u that will be equal to H u plus epsilon H P O C.

So, now we define, redefine thermal efficiency that will be equal to H u plus epsilon H P O C upon H in that will be equal to thermal efficiency original that we have defined plus epsilon H P O C upon H in. So, the addition of extra amount of heat, when fuel input is not changing temperature should not change then it will lead to increase in the thermal efficiency of the furnace. In another possibility, let us take another situation. In another situation, what another situation could be? We are using the same amount of load, we are not increasing the amount of load, in that case what will happen the extra amount of heat that you have supplied into the furnace that will increase the temperature.

That should not happen because our condition is that the furnace should operate at constant T u which was attained by constant T a f t adiabatic flame temperature due to the products of combustion. So, when the product amount is not changing and if we add the extra amount of heat that will lead to increase in temperature which should not be there so in that case we have to cut down the fuel input. When we cut down the fuel input, then again the entire situation of the furnace the entire temperature will again remain the constant. So, in this case heat balance that is in situation when product or the amount of product is not increasing, also top of the condition is the furnace temperature should not increase.

So, in that case the heat balance at a steady state for this situation would be, say H in plus epsilon H P O C that is equal to H u plus H P O C plus H l. Now since, T u and T P O C is to be kept same so fuel input must decrease. So therefore, H in that will be equal to H dash in plus epsilon H into P O C and H in minus H dash in that is equal to fuel saving due to preheater installation and that will be equal to epsilon H p o c. So, that is what the concept of the thermal efficiency and as affected by the installation of preheater so that is how this quantification of thermal efficiency can be done this way.

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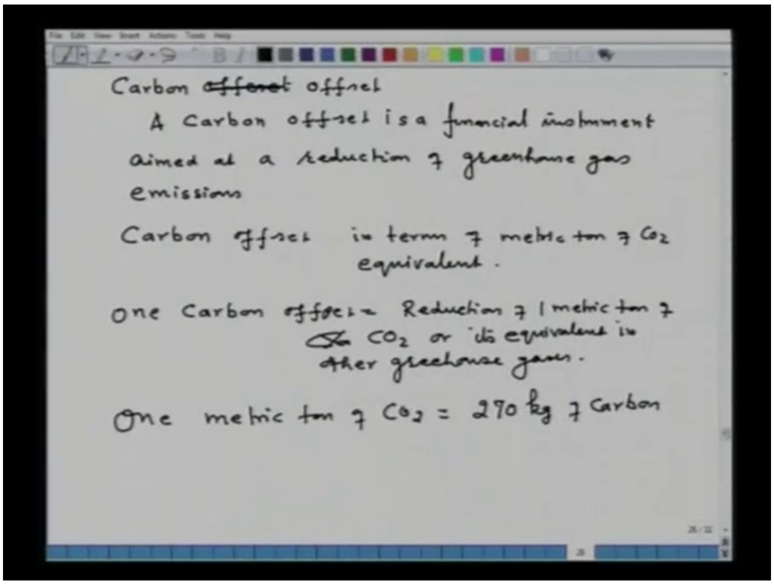

Now, another thing is that the carbon credit or carbon offset and its inter relation with energy efficiency. Now, let me define what carbon offset means a carbon offset is a financial instrument aimed at a reduction of green house gas emissions, that is what a carbon offset means. Now, carbon offset is measured in terms of Metric ton of C O 2 equivalents that means one carbon offset that is equal to reduction of 1 Metric ton of C O or its equivalent in other green house gases. Now, again one Metric ton of C O 2 reduction is equivalent to reduction of 270 k g of Carbon that means if we want to generate one carbon offset we have to reduce 270 k g of Carbon in our process by making the furnace more energy efficient. Now, reduction in Carbon it depends upon how efficient the furnace is one of the example.

There are several ways to generate the carbon offset say ways to generate carbon offset.

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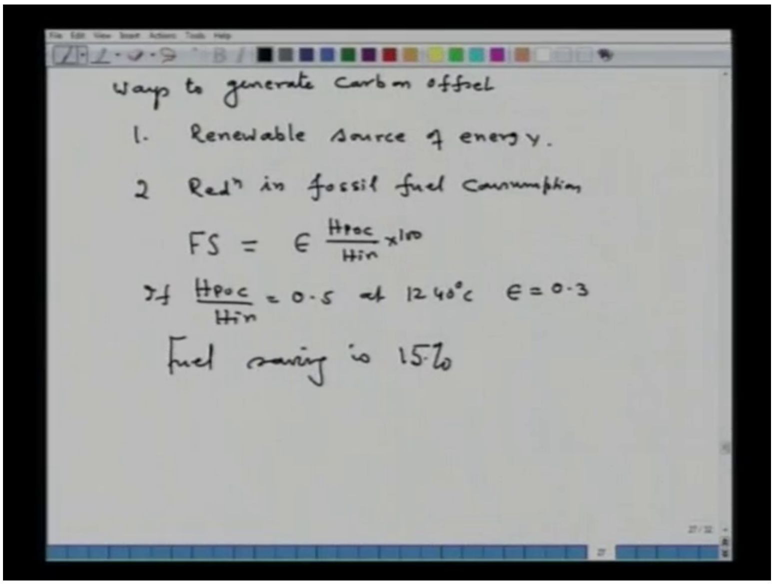

All that you have to reduce, the amount of Carbon that is going into furnace. So, one way is that renewable using renewable source of energy, one way is to use renewable source of energy and another is reduction in fossil fuel consumption and it is in this connection the energy efficiency is a very important one way is to recuperate the heat.

Just now, we have seen and used to pre heat the air. So, in this case we have seen that fuel saving if you recuperate the heat of the waste gases and use to preheat the air then, just now we have said that is fuel saving that is equal to epsilon H P O C upon H in into 100 that is in percent. Now, let us say if H P O C upon H in let us, say equal to 0.5 at 1240 degree Celsius and epsilon is equal to 0.3. Then, fuel saving is 15 percent and from there depending upon the data on the available fuel consumption one can calculate the carbon off set and so on. Now, this whole concept I will be illustrating by solving a problem.

So, let me illustrate whatever I have said in this particular lecture through a problem.

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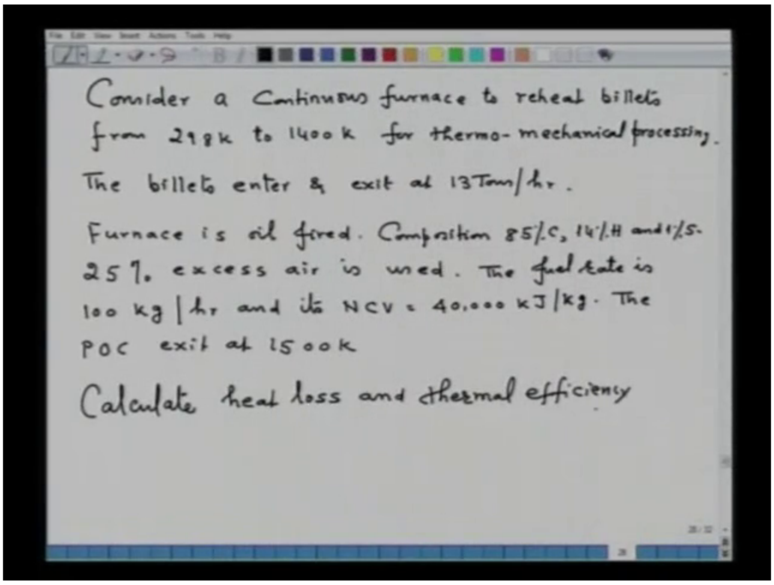

So, let us consider a continuous furnace to reheat billets from 298 Kelvin to 1400 Kelvin for thermo mechanical processing, the billets enter and exit at 13 tons per hour. Now, the furnace is oil fired, the composition of oil composition is 85 percent Carbon 14 percent Hydrogen and 1 percent Sulphur, 25 percent excess air is used. The fuel rate is 100 k g per hour and its net calorific value that is equal to 40000 Kilojoule per k g the P O C exit at 1500 Kelvin.

Now, this is the problem that I have selected to illustrate thermal efficiency, furnace efficiency and so on. Now, say calculate heat loss and thermal efficiency. So, now let us proceed to solve the problem:

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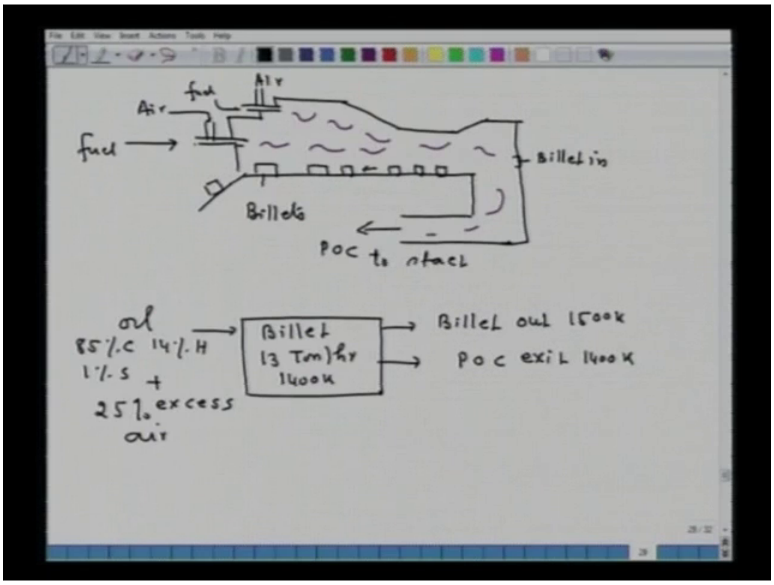

Now, for example, the furnace looks something like this is a belt on which there is a continuous discharge of the billet enters and exits. This is the burner, this is another burner it is somewhere here, there is a billet in, here P O C to stack, here you have billet, they are moving continuously and here billet is out, here supply is fuel and here supply air same thing here fuel and top is supply air.

So, the products of combustion they move and ultimately they are out so it is a counter current process and if the billet and products of combustion they move opposite to each other. Well, we have nothing to do with the process but, since this is a continuous process and you know and these are the so called billets. This is the exit of the billet and this is the exit of p o c. So, let me represent this problem by a block diagram which is like this, here say billet out, here P O C exit, here say billet in a furnace which is at 13 ton per hour and heated to 1400 Kelvin so billet out and P O C exits at 1500 Kelvin at 1400 Kelvin. Now, this is supplying oil of composition: 85 percent Carbon 14 percent Hydrogen and 1 percent Sulphur. Combustion condition: 25 percent excess air. That means, total amount of air is 125 percent. Now, this is a steady state block diagram to solve the problem. Now, this is the way I solve you can generate your own style of solving that is up to you.

Now, you also require certain values so I am giving you also certain values, say for example, you require the heat content of the billet because when you do the heat balance. So, I am giving you certain heat values:

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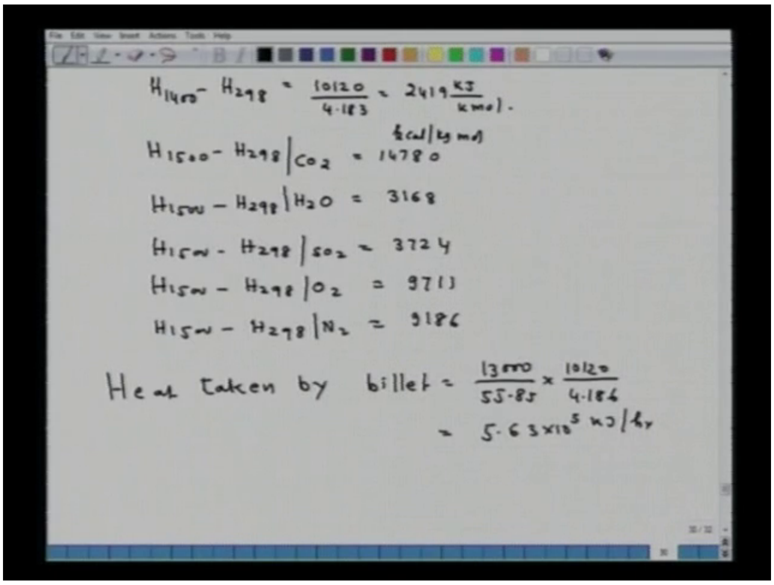

H 1400 minus H 298 that is equal to: 10120 upon 4.183 that is equal to 2419 Kilo joule per kg mole. Then H 1500 minus H 298 for C O 2 that is equal to 14780 this is in Kilo calorie per kg mole, for H 2 O that is equal to 3168 this is H 1500 minus H 298 then H 1500 minus H 298 for S O 2 that is equal to 3724 and H 1500 minus H 298 for O 2 9711 and H 1500 minus H 298 for Nitrogen that is equal to 9186.

Now, in fact these values you should be able to calculate by c p d t by integrating for example, if you want to know the heat content in steel if you integrate c p d t from 298 to 1400 Kelvin use the value of c p a plus d t and so on, similarly, the products of combustion you have to calculate from c p, but here I am giving you the calculated values but, for solving the problem you have to calculate so on.

So, once these values are before you, now we can proceed to calculate for example, first of all we have to calculate heat taken by billet that is straight away calculation that will be equal to 13000 upon 55.85 this is in moles into 10120 upon 4.186. So, that is equal to 5.63 into 10 to the power 5 Kilo joule per hour. So, that is what the heat taken out by the billet, now next we have to calculate the composition of the fuel oil is given 25 percent excess air is being used, so you have to calculate the composition of the products of combustion that exercise that you do it and the fundamentals I had already covered in my lectures on combustion so I have calculated straight away.

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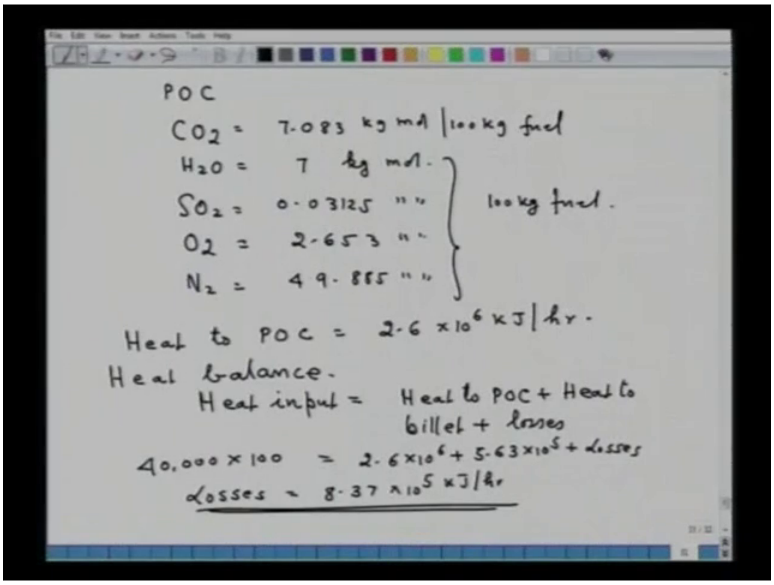

So, P O C now do not forget since we are using excess air so the P O C will also contain oxygen now that is an important thing. So, P O C C O 2 that will be equal to 7.083 k g mole per 100 k g of fuel, then H 2 O that will be equal to 7 k g mole S O 2: 0.03125 k g mole O 2: 2.653 k g mole and Nitrogen that is equal to 49.885 k g mole. I mind you all these are based on 100 k g fuel. So, what we have to do now you have to multiply now this k g mole with the heat content that I had already given you earlier H 1500 minus H 298 for C O 2 was 14780. So, I multiply each values and I sum total then I get heat to P O C that is equal to 2.6 into 10 to the power 6 Kilo joule per hour.

Now, we know now if we see this particular block diagram and if you do the heat balance then heat input that is equal to heat output by the billet and heat taken by the p o c. So, what we will have to do now? We have to do now the heat balance, we have to perform now the heat balance and in the heat balance heat input that will be equal to heat to P O C plus heat to billet plus losses. Now, we have to determine the losses so heat input the 40000 per k g multiply by 100 k g, 40000 is the net calorific value.

And we are burning at a rate of 100 k g per hour. So, heat to P O C we have calculated: 2.6 into 10 to the power 6 plus heat to billet we have calculated: 5.63 into 10 to the power 5 and plus losses. So, easily we can determine the losses so the losses would be from here that will be equal to 8.37 into 10 to the power 5 Kilojoule per hour. So, this is the answer for one particular problem now I will suggest you please calculate yourself without seeing the solution that will help you more. Now, we can calculate the thermal efficiency see thermal efficiency.

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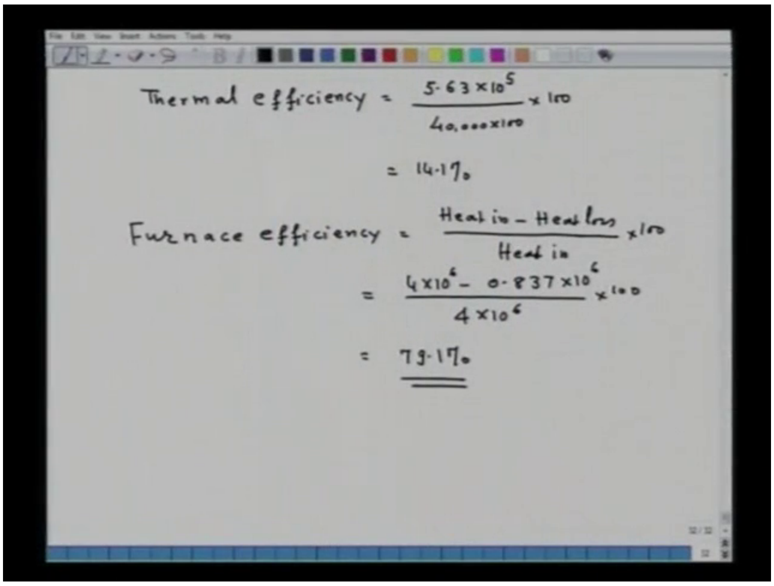

That will be equal to 5.63 into 10 to the power 5, that is heat taken by the product heat in that is: 4 into 40000 into 100 multiply by 100, so that will be coming around 14.1 percent. So, you can see now from here that only 14 percent of the heat which is supplied by the fuel, is used to heat the product and that is important and as in the initial lecture I have said, that for the fossil fuel fired furnaces a large fraction of the energy is taken by the products of combustion. So, you are seeing in this particular solution of the problem that thermal efficiency is only 14 percent in many in if you calculate for other cases also the thermal efficiency of the furnace without pre heating it hardly exceeds 15 to 15 or 20 percent, it remains more or less between 14 to 20 percent because major amount of heat is carried away by the products of combustion.

So, it suggest as I have said in my initial lectures that the recouping of the heat from the products of combustion is a very very important part of the fossil fuel fired furnaces. In this case in general wherever, fossil fuel is used and the temperature involved are high, then the products of combustion will leave at high temperature and heat recovery becomes a very crucial in order to optimize the fuel consumption. Now, in these connections for example, if you calculate the furnace efficiency you can also calculate furnace efficiency.

So, furnace efficiency is that is equal to heat in minus heat loss again I emphasize this heat loss is through the lining and other losses it has nothing to do with the heat taken by P O C divided by heat in into 100 of course, for percentage then it will be heat in: 4 into 10 to the power 6 minus 0.837 into 10 to the power 6 upon 4 into 10 to the power 6 into 100, so this is equal to 79.1 percent. So, you can see now as I have said in the lecture that furnace efficiency is much higher than the thermal efficiency you are seeing here the furnace efficiency is of the order of 4 to 5 times higher than the thermal efficiency.

Now, the whole whatever, calculated we can represent in the form of a diagram which is known as energy flow diagram or you can also call as a Sankey diagram.

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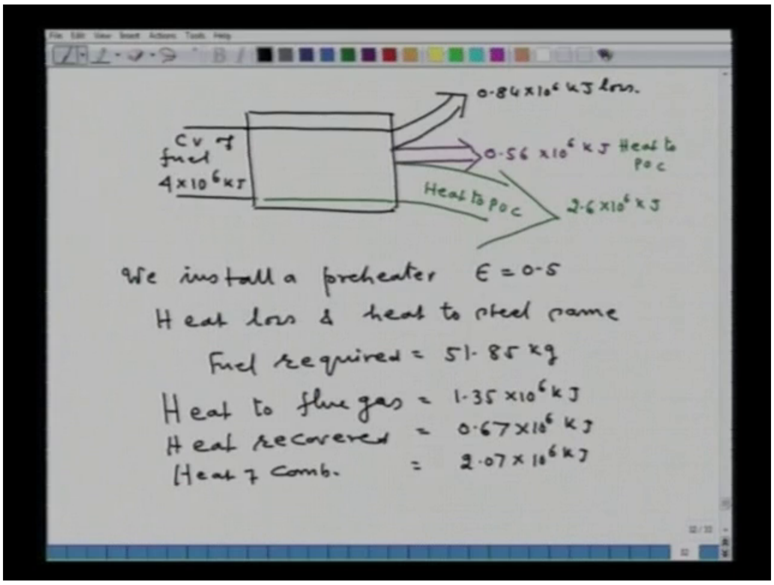

Now, say if i take now say this is the reheating furnace and this one is a calorific value of fuel that is equal to 4 into 10 to the power 6 Kilo joule that is in. Now, out of which say this is how the energy is flowing, now say part of the energy is lost this is the one: 0.84 into 10 to the power 6 Kilo joule loss, say heat taken by steel again a very small fraction that is 0.56 into 10 to the power 6 Kilo joule and the major fraction that is this is the 2.6 into 10 to the power 6 Kilo joule is taken by heat to P O C and that is heat to steel. So, this is how it represents how the energy is flowing into the system.

Now, suppose we install a preheater say we install a preheater and we recoup the thermal energy there will be fuel saving, because we are keeping heat loss and we are keeping now heat loss and heat to steel same and heat to steel we are keeping same. So, there will be naturally, fuel saving, so first we have to calculate the fuel saving so you please calculate by performing the heat balance so the fuel. Now, you require the fuel when we recoup the heat and let us consider the preheating efficiency epsilon that is equal to 0.5. So, now the fuel required would be only now 51.85 k g you can see you are saving at least 49 kg of the fuel by recouping the heat.

So, heat to flue gas we can now calculate heat to flue gas, we can also calculate heat recovered and heat of combustion. So, heat to flue gas: 1.35 into 10 to the power 6 all these values you have to calculate I am simply writing the calculated value that will be 0.67 into 10 to the power 6 Kilo joule and heat of combustion since, you are now combusting less amount of fuel that will be 2.07 into 10 to the power 6 Kilo joule. Now, the entire this furnace is the preheated system can be represented by an energy flow diagram in this particular way now for example, if you consider this is a furnace.

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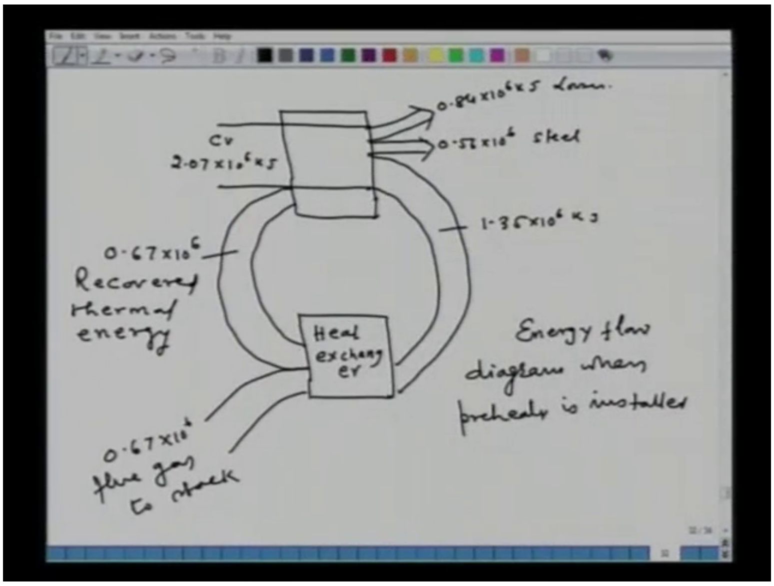

And this is where, here we have the heat exchanger, this is the heat exchanger. So now, this is the calorific value of the fuel which is now 2.07 into 10 to the power 6 Kilo joule. Now, out of which here the heat losses 0.84 into 10 to the power 6 Kilo joule steel is taking 0.56 into 10 to the power 6 this is to steel this is through losses and now what we are doing is that we are now, taking this to a heat exchanger and this amount of heat is 1.35 into 10 to the power 6 Kilo joule. This is our heat exchanger, we are taking this heat to the heat exchanger and from the heat exchanger we are recouping the heat that this heat is 0.67 into 10 to the power 6, this is the recovered thermal energy and the rest that is 0.67 into 10 to the power 6 this is the flue gas to stack.

Now, this is the energy flow diagram when preheater is installed. So, this particular diagram indicates very clearly how the energy is flowing and what part, heat exchanger is playing, so you see significant amount of energy is recovered and the amount of fuel that you are saving around 49 to 50 k g and that is the considerable value.