Fuels, Refractory and Furnaces

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Lecture No. # 40

Furnace efficiency, Fuel Saving, Carbon Offset: Concepts and Exercises

In the last lecture, I have presented furnace efficiency, fuel saving, carbon offset, concepts and exercises. The concepts behind furnace efficiency, fuel saving were presented in that lecture and I tried to clear the concept by solving some problems over there. In this lecture, I thought of to solve few more problems, so that you understand the concept of furnace efficiency, fuel saving and carbon offset, because particularly when we talk of energy saving in industrial furnaces, so it is the furnace efficiency is very important and the factors contributing to the furnace efficiency were already discussed.

Now, let me solve few more problems to clear the concept. So, I will be presenting to you first of all the problems which I am going to take:

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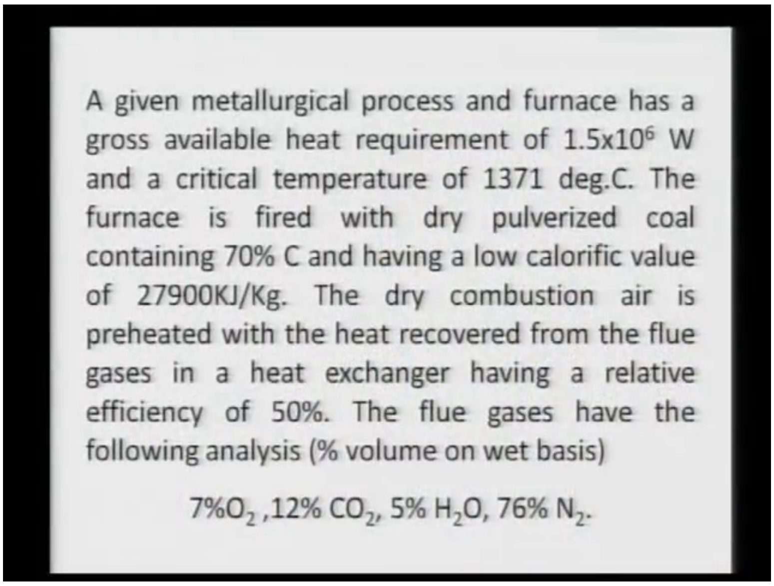

The first problem, a given metallurgical process and furnace has a gross available heat requirement of 1.5 into 10 to the power 6 watt and a critical temperature of 1371 degree celsius. The furnace is fired with dry pulverized coal, containing 70 percent carbon and having a low calorific value of 27900 kilo joule per kg. Now, here I will like to tell you that please read the problem very carefully, because for the calculation how carefully you read that will help you. For example, one is that I am telling the critical temperature of 1371 degree celsius this means that, the flue gases will also be leaving at the temperature of 1371 degree celsius point number one, point number two: it is said in this particular problem that coal has a low calorific value of 27900 kilo joule per kg.

That means, that here the calorific value of the fuel is given by considering the gaseous state of the products of combustion. For example, C to C O and H to H 2 O vapor. So that is important, because while calculating the heat taken by the products of combustion, the standard state for input and output must be same otherwise, there will be an error in the solution of the problem. The dry combustion air is preheated with the heat recovered from the flue gases in a heat exchanger having a relative efficiency of 50 percent.

Now, the concepts of relative efficiency, furnace efficiency, regenerator efficiency, were already introduced in the earlier lectures. So, please get the concepts from there. The flue gases have the following analysis: percentage volume on wet basis, 7 percent oxygen, 12 percent C O 2, five percent H 2 O and 76 percent nitrogen.

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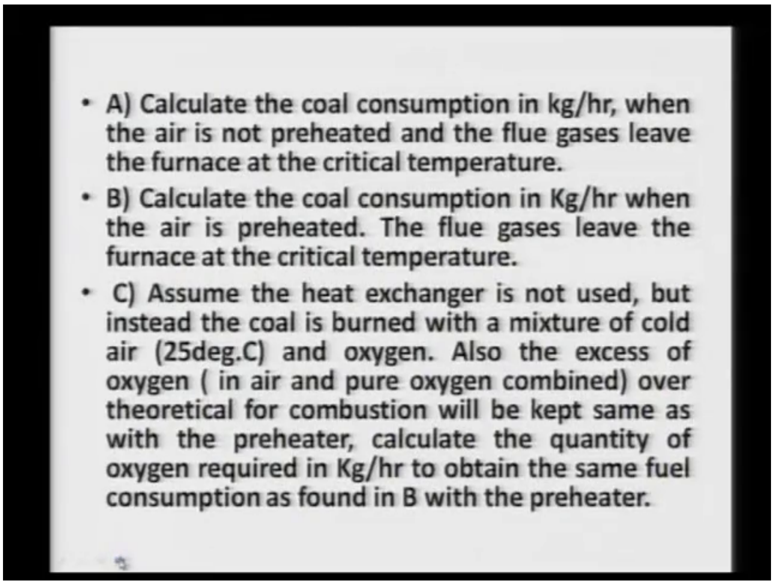

You have to calculate first, calculate the coal consumption in kilogram per hour, when the air is not preheated and the flue gases leave the furnace at the critical temperature. So, that critical temperature also the exit temperature of the flue gas that is for the assumption that you are making in this particular problem.

B: Calculate the coal consumption in kilogram per hour, when the air is preheated the flue gases leave the furnace at the critical temperature.

C: Assume, the heat exchanger is not used. But, instead the coal is burned, with a mixture of cold air that is 25 degree Celsius and oxygen. Also, the excess of oxygen in air and pure oxygen combined over theoretical for combustion will be kept same. Now, this is also important to know while solving the problem because excess air or excess oxygen in air and pure oxygen combined over theoretical for combustion will be kept same as with the preheater. So, calculate the quantity of oxygen required in kilogram per hour to obtain the same fuel consumption as found in B with the preheater. So this particular problem will illustrate the role of oxygen enrichment of the air on furnace efficiency. That means, you can improve the furnace efficiency by either preheating the air or by enriching the oxygen and the same I am going to illustrate by solving this particular problem.

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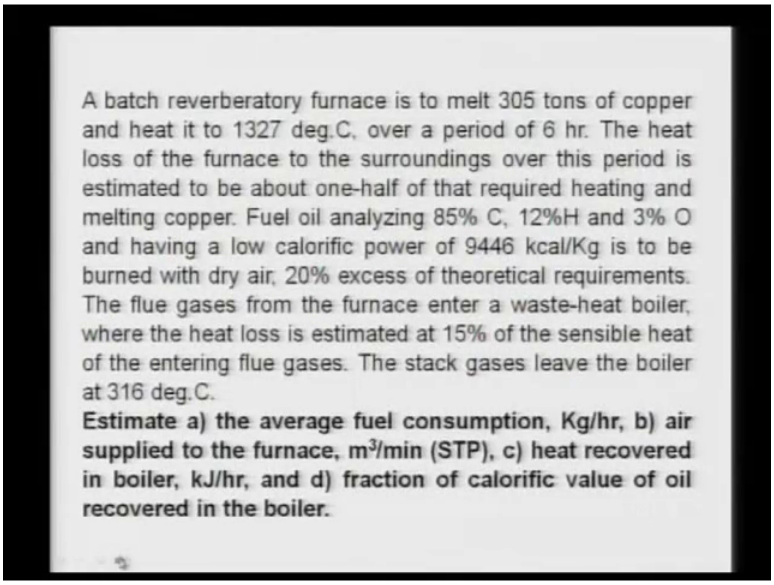

Problem number two: A batch reverberatory furnace is to melt 305 tons of copper. A typical problem on melting and heat it to 1327 degree Celsius or we may recall here the temperature is 1327 degree Celsius over a period of 6 hour. The heat loss of the furnace to the surrounding over this period is estimated to be about one-half of that required heating and melting copper. So, the heat losses are also given but, in a different form, it is said that whatever amount of heat that you require to heat copper for 25 degree Celsius to its 1327 degree Celsius half of that will be the heat lost to the surrounding. Fuel oil analyzing 85 percent copper, 12 percent hydrogen and 3 percent oxygen and having a low calorific power of 9446 kilo calorie per kg is to be burnt with dry air, 20 percent excess of theoretical requirements. The flue gases from the furnace enter a waste-heat boiler where the heat loss is estimated at 15 percent of the sensible heat of the entering flue gases. The stack gases leave the boiler at 316 degree Celsius. Here estimate a: the average fuel consumption, b: air supplied to the furnace, c: heat recovered in the boiler and d: fraction of calorific value of oil recovered in the boiler that is the problem number two.

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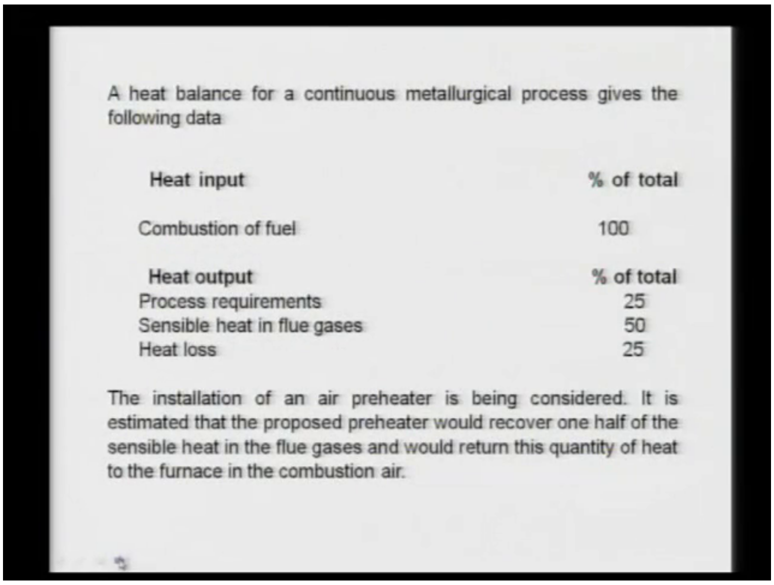

Now, problem number three is a very simple problem, is a very tricky problem and it will tell you how much of the heat balance of a furnace you have understood. Though, I will be presenting the solution of all the three problems but, my appeal to the viewers of this video lecture is that, please attain to solve the problem before you see the solution, because ultimately you have to see that you have understood it or not. Now this problem is very simple, but it requires a clear cut understanding of the heat balance of the various process.

The problem is as follows: a heat balance for a continuous metallurgical process gives the following data: heat input, combustion of fuel that is 100 percent of the total. Heat output, process requirement takes 25 percent of total, sensible heat in flue gases take 50 percent of total and heat losses 25 percent of total. The installation of an air preheater is being considered.

Now here, you consider yourself to be working in a company and your boss has come and he has told you that well, “I want to install a preheater. I want to know how much fuel I am going to save. So you have to tell him, by installing a preheater what amount of fuel is going to be saved. So what he is asking you, he is asking you the following two questions: the installation of an preheater is being considered. It is estimated, that the proposed preheater would recover one-half of the sensible heat in the flue gases and would return this quantity of heat to the furnace in the combustion air.

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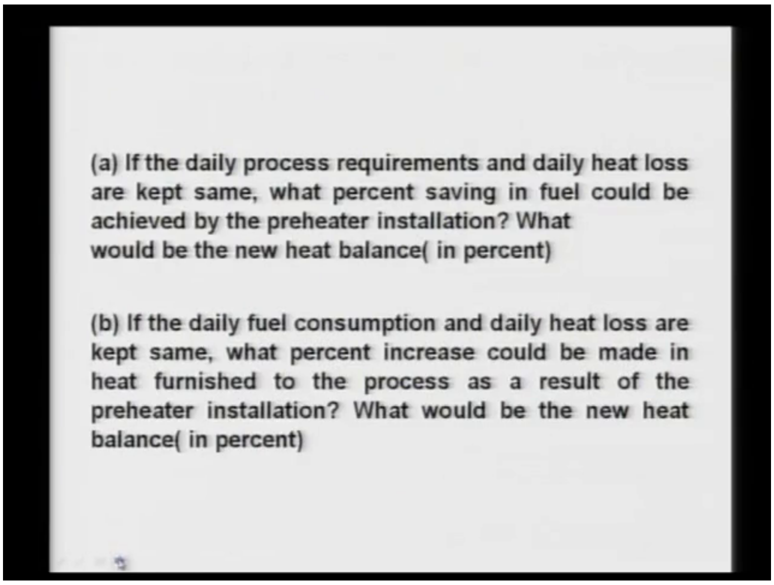

Now, he wants to know two things: because he is going to have a big investment for installing a preheater, because ultimately that preheater has to be integrated with a furnace, so he wants to know beforehand that what fuel he is going to save in order to see whether his investment is compatible with the fuel saving or not. In fact, from the business point of view the profit or the fuel saving should be greater than the proposed cost for installation of the preheater. So, it is with that idea he wants to know the following:

a: if the daily process requirements and daily heat loss are kept same remember, what percent saving in fuel could be achieved by the preheater installation and what would be the new heat balance in percent?

b: if the daily fuel consumption and daily heat loss are kept same, what percent increase could be made in heat furnished to the process as a result of the preheater installation? What would be the new heat balance in percent? So that is the problem number 3. So these all these three problems I will be going to solve. But, I will again appeal that before seeing the solution of the problem please try to attempt yourself. So here I will go with the solutions of this problem.

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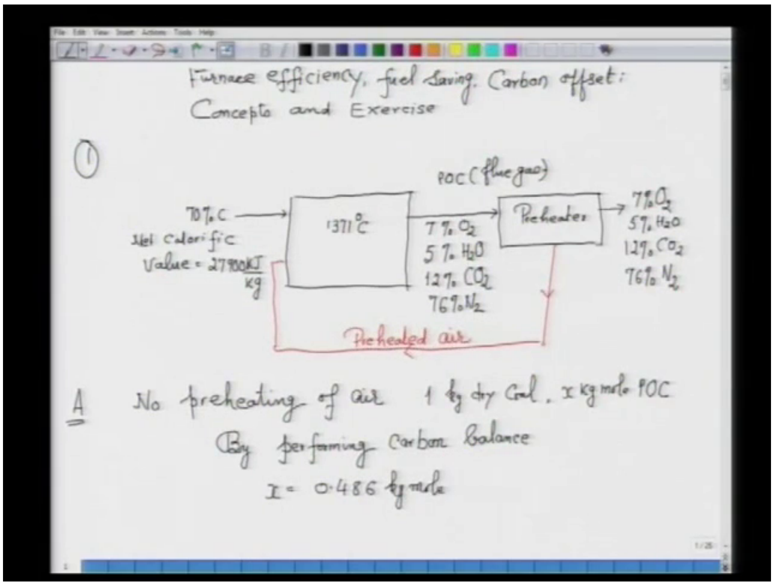

Problem number 1: I will try to draw a block diagram, which represents the material balance and heat balance of the process. So the process said, that this is a furnace this is operating at 1371 degree Celsius the input is you have a fuel which is 70 percent carbon and its net calorific value, which is also called low calorific value that is given to you 27thousand 900 Kilo Joule per kg. Now, it dissolves to out the flue gases the composition of flue gases is given, so this is you got either products of combustion or you can also call flue gas. The composition is given. It has 7 percent Oxygen, it has 5 percent H 2 O, it has 12 percent CO 2 and it has 76 percent Nitrogen. So this enters into preheater and the preheated air which enters into the furnace, this is the preheated air. enters into the furnace and the exit of the preheater is again you have the same flue gas percentage because the material is not lost because the material is not lost in transferring its heat, only its temperature would decrease. So, this is the output of a preheater. So this is what the problem is given to us.

Now, first of all we have to calculate, the we have to calculate the coal consumption in kilogram per hour, when the air is not preheated and the flue gases leave the furnace at the critical process temperature, that is the part a. So I will be calculating first of all A: where the flue, where the air is not preheated. So the case is no preheating of air. Naturally, first of all I must know the amount because at the several places I have told that heat balance cannot be made unless you do the material balance, because you have to know what amount of material are being exiting the furnace.

So, if you take for example, say let us take 1 kg dry coal and let us consider x kg mole, is products of combustion. Then by doing carbon balance, say by performing carbon balance, we can calculate the amount of products of combustion. All that you have to see, do proper balancing and the answer would be if I take x kg mole P O C then x will be equal to 0.486 kg mole. Now the next task is that to find out the amount. So, I will write down here:

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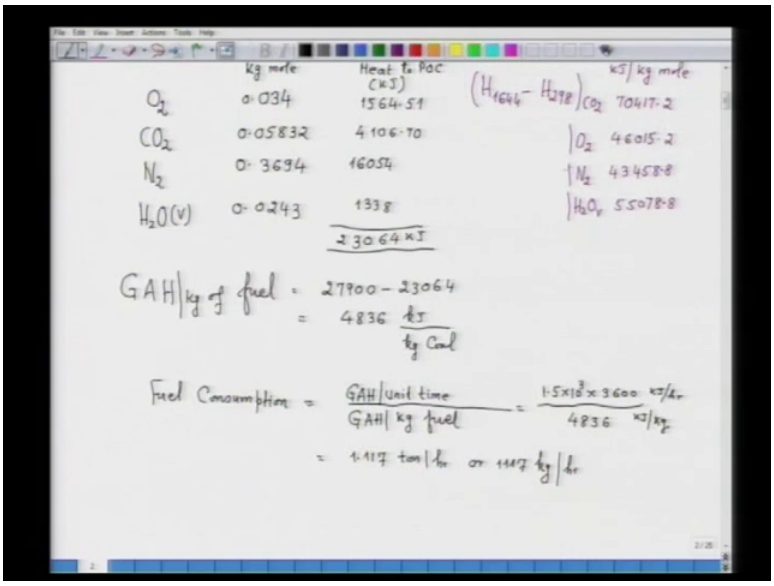

This is the oxygen, then we have CO 2, then we have nitrogen, then we have H 2 O vapor. Remember, that is very important accordingly, you should use the heat content. So, the kg moles as given to us as we can find out by multiplying. So, kg mole that will come here 0.034, here it is 0.05832 kg mole, then nitrogen is 0.3694 kg mole and H 2 O vapor is 0.0243. Now, to find out the heat to P O C , what you will require? You have to find out m c p into delta t. So, once you get the value of c p, you have to integrate the value of c p from 298 Kelvin to 1371 plus 273 Kelvin and the appropriate value of c p o 2, c p CO 2, c p n 2, c p H

2 O vapor you will write, integrate it and get the heat which is taken by the products of combustion.

What I have done for you, I have calculated those values and I am listing you the values for heat content, in the form of say heat content for example, H_{1644} minus H_{298}. This I am writing, Kilo Joule per kg mole. So, this value for CO_2 is 70417.2 kilojoule per kg mole, for oxygen this value is 46015.2, for nitrogen this is 43458.8 and for H_2O vapor this value is 55078.8. Now remember, select the correct value of c_p of H_2O vapor not for H_2O liquid, why? Because the calorific value of fuel is given it is the net calorific value where the standard state of products of combustion of h to H_2O is the vaporized state that is a important thing.

Now, once you know the heat content value, then I can calculate from here. So, heat to P O C that will be simply in kilo joule. So, I have to multiply appropriate value. So, for I have multiplied for you, so I am getting here for oxygen 1564.51, for CO_2 it is 4106.70, for nitrogen 16054 and for H_2O vapor it is 1338. So, if I sum total all, then I will be getting 23064 kilo joule. Now I know this the heat to P O C . The calculation of fuel consumption I had already introduced to you. We have to calculate gross available heat available upon gross available heat per kg of the fuel. So if you calculate that, now we have to calculate gross available heat per kg of the fuel, that will be equal to 27900 is its net calorific value minus 23064, so that will be equal to 4836 kilojoule per kg coal.

Now, you know fuel consumption I am repeating the formula though I have given at several places, fuel consumption that will be equal to gross available heat, gross available heat per unit time upon gross available heat per kg of fuel. So, we know now both the values so if I substitute these values that will be 1.5 into 10 to the power 3.It is given that in kilowatt into 3600 that becomes now it becomes in kilo joule per hour divided by 4836 that was kilo joule per k g. So, the fuel consumption is 1.117 ton per hour or 1117 kilogram per hour.

So you note, this is the fuel consumption without preheating. Now, let us do the second part of the problem. This says if suppose, we employ a preheater, then how much fuel will be consumed. So let us calculate now.

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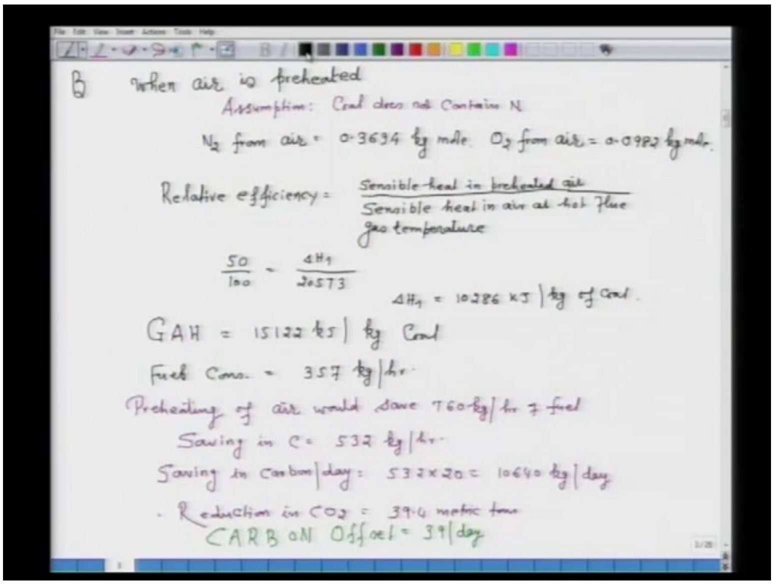

So B part; B part said when air is preheated.

When air is preheated, then you have to calculate now, when the air is preheated again you have to calculate the fuel consumption in kilogram per hour, all that you have to find out. Now how much amount of sensible heat is being supplied to the furnace, then you can find out. The first thing we have to find out the amount of air, so for that I am making one assumption, say assumption which I am making that, coal does not contain nitrogen, So, on that basis if I do nitrogen balance then, I can calculate nitrogen from air that is equal to nitrogen in P O C so that way I can calculate say nitrogen from air ,that is equal to already we have calculated 3694 kg mole and oxygen from air is 21 percent of this that is equal to 0.0982 again kg mole. I have given relative efficiency is 50 percent you know the definition of the relative efficiency. So relative efficiency, that will be equal to, well I again write down for you the definition that is equal to sensible heat in preheated air upon sensible heat in air at hot flue gas temperature. Now, you have to calculate all these things. So, if you do all these calculations then we get the then, let us relative efficiency given 50 upon 100 and let us say sensible heat that is, delta h 1 we have to calculate sensible heat in air we have to calculate that is 20573 sensible heat delta h 1 that will be coming 10286 kilo joule per kg of coal. So again, I have to calculate the gross available heat. You know how to calculate, so calculate it will come 15122 kilo joule per kg coal. I calculate now fuel consumption, fuel consumption that will come out to be equal to 357 kilogram per hour so that means, now our conclusion we can put it that, preheating would save that preheating of air, would save 760 kg per hour of fuel. So, you can imagine the importance of fuel saving, the importance of preheating in fuel saving and the and the consequently the effect of fuel saving is the reduction in CO 2 also that we can calculate.

So we can say now the saving in carbon this is fuel. So, saving in carbon that will be equal to 532 kilogram per hour because 70 percent is the carbon so saving in carbon per day that will be equal to 532 into 20 that will be equal to 10640 kilogram per day now mind you here I have assumed, that the furnace operates only for 20 hours not for 24 hours, that is why I have multiplied by 20. So reduction in CO 2 the concept already I have introduced to you, reduction in CO 2 that will be equal to 39.4 metric tons. Now see the inter relationship between carbon saving or fuel saving and the carbon offset. So, the carbon offset, the concept already I have introduced, that will be equal to 39 per day. So this particular problem clearly illustrates, the inter relationship between fuel saving, furnace efficiency and the carbon and the carbon offset and so on.

Now let us see, the part c of the problem it says that, if you do not use heat exchanger you keep the fuel consumption same as that of b then how much amount of oxygen you have to supply. That it tells you the alternate way of saving of fuel.

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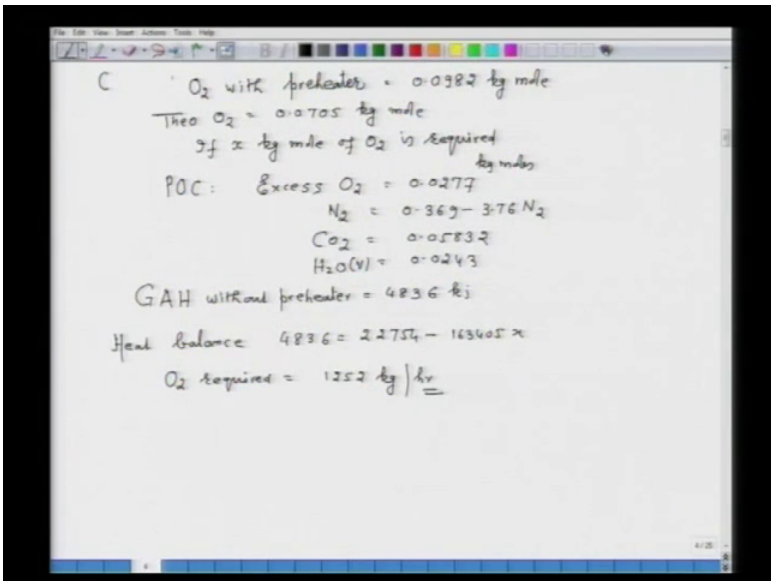

So, oxygen with preheater that we have already calculated. Oxygen with preheater that was 0.0982 kg mole. Now, you have to recalculate the products of combustion. Now, theoretical oxygen would be that will be equal to 0.0705 kg mole that will be calculating from products of combustion which has CO 2 and oxygen. Now, let us say if x kg mole of oxygen is required, if x kg mole of O 2 is required, to have the same fuel consumption as that of preheater what you have to do? you have to enrich the oxygen so that the heat which is carried away by the nitrogen it decreases that is the key of this particular problem.

So, now we write down again the products of combustion composition so P O C say excess oxygen that we have to kept the same as the problem illustrates, excess oxygen that is 0.0277 mind you they are all in kg moles. Now, nitrogen that will be equal to 0.369 earlier, now I am requiring x kg mole of oxygen so correspondingly, nitrogen will be 3.76 nitrogen will decrease. Now, CO 2 that is equal to same 0.05832 H 2 O vapor will also be same that will be equal to 0.0243. I will be calculating now gross available heat without preheater. So gross available heat without preheater, that we have got around 4836 kilo joule refer to a part of this problem kilo joule. So now heat balance, again you have to calculate the heat output heat of P O C and so on. So make the heat balance, so heat balance will be 4836 that is equal to 22754 minus 163405 x. So, if I solve for x then oxygen required, you will be getting in kg mole you have to multiply by hour and so on. So, oxygen required will be 1252 kilogram per hour would be the oxygen required, if you want to have the same fuel consumption as that of the as that not having preheater.

So, I am going to solve now the problem number 2

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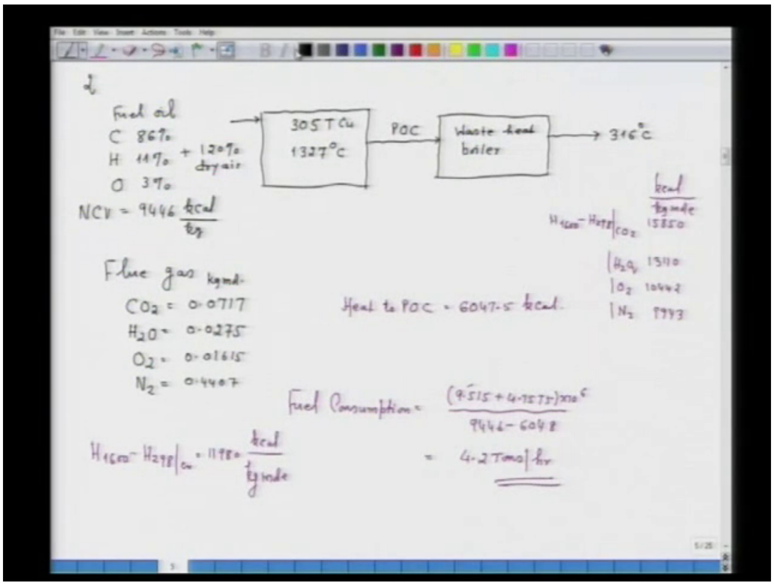

And the problem number two already I have enunciated. Now, I will draw the block diagram and the block diagram is as follows: this is for it is a melting of copper, so you are melting around 305 tons of copper and heating it to a temperature of 1327 degree celsius by using fuel oil fuel oil composition, carbon: 86 percent, hydrogen: 11 percent and oxygen: 3 percent it is combusted with 120 percent dry air that means 20 percent excess air as told in the problem. Now, the products of combustion they enter into a waste heat boiler.

Now recall, waste heat boiler is also a typical device for recovery of the heat. Waste heat boiler and it is used to produce super heated steam and ultimately the products of combustion they discharge at 316 degree celsius. Now, here it is given to us heat loss is 15 percent of the heat input, n c v is given n c v of the fuel is given 9446 kilo calorie per k g. This is given to us and from the furnace, the heat losses are said it is one-half of that required for heating. So, now we have to calculate first of all the average fuel consumption that is the first thing you have to calculate. Now, again we have to calculate, the first of all the composition of flue gas.

So, composition of flue gas we will be calculating say you have to must do the material balance and calculate it say CO 2 I am directly calculating 0.0717 H 2 O, 0.0275 O 2, 0.01615 and nitrogen is 0.4407. That is the flue gas in kg mole.

Now, again I have to give you the heat content value. So I am giving you the heat content value say H 1600 minus H 298, for CO 2, for H 2 O, for o 2 and for N 2. So, this value is 15850, 13110, this is H 2 O vapor and 10442 nitrogen is 9943. So, that is given to us. So, we can calculate the heat to P O C, so we just multiply so I have calculated it here I am straight away writing, heat to P O C you have to multiply each value by this one. So heat to P O C will be equal to 6047.5 that will be in kilo calorie. So, here the units which I am giving is kilo calorie per kg mole. So, once that is given so we can calculate now fuel consumption, fuel consumption that will be equal to 9.515 plus 4.7575 into 10 to the power 6 upon 9446 minus 6048 now this value of 9.515 that is coming, you have to first of all calculate how much amount of heat is required, to bring copper from 25 degree celsius to 1327 degree celsius. So for that it is given to us say, H 1600 minus H 298, copper is given to you 11980 kilo calories per kg mole.

So, from this you can calculate the heat content 305 times you convert into kg mole multiply it that will be 9.515 half of it is lost from the furnace, so that is all you will be calculating and this answer will be equal to: 4.2 tons per hour. So, that is how you will be calculating the fuel consumption for a part now the b part says: now the b part says, you have to calculate air supplied to the furnace in meter cube per minute. Well, this is very simple.

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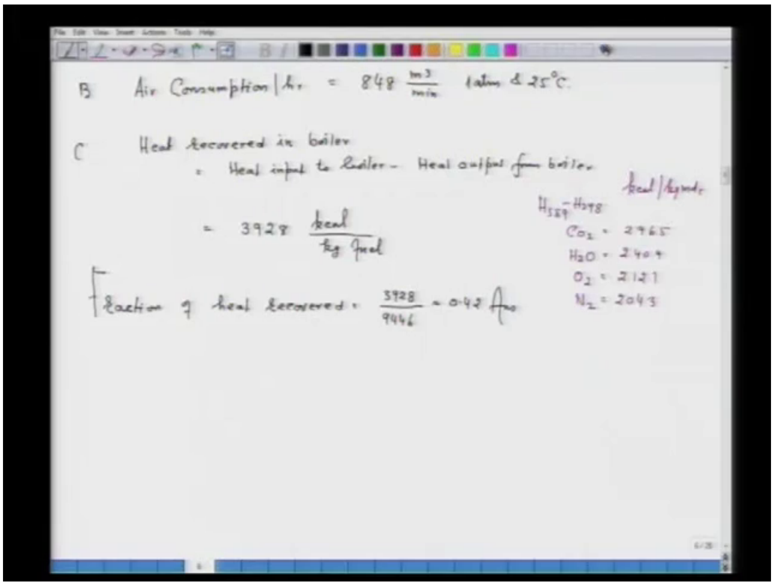

So, air consumption per hour, that can also be find out. Now you try to find out I am giving you the answer 848, this is meter cube, per minute at 1 a t m and 25 degree celsius, this is the answer for B part. Now the C part it says heat recovered in boiler, now heat recovered in boiler, that can be calculated that will be equal to heat input to boiler, minus heat output from boiler. Now heat input to boiler is what the heat carried away by the flue gases that already we have calculated in part a. Now, heat output to the boiler from boiler you have to calculate because from the boiler the flue gases are exiting at 316 degree celsius.

So, if I give you the value of H 589 minus H 298 again in kilo calorie per kg mole, so for CO 2 that is equal to 2965, for H 2 O that is 2409, for oxygen that is equal to 2121 and for nitrogen that is equal to 2043. So you can calculate these values, I do not need to calculate. So, if you do it then heat recovered in boiler that will be coming 3928 kilo calorie per kg of fuel that is the answer for them.

Then fraction of heat recovered in reference to the calorific value of the fuel that will be simply 3928 upon calorific value that is 9446 that will be equal to 0.42 that will be the answer for the part d. So that is how you will be solving this problem number 2. Now the last problem which I have said, it is a sort of a problem which tests your common sense, intelligence and your understanding of the heat balance part of this particular course.

Now again, I am telling you this particular problem which I am going to present now, that is the problem number three, is a required little bit of your knowledge and your understanding. Let us see that, now this problem gives you the heat balance of a process is given to you, you think yourself that you are a manager in a plant or you are working and your boss has come and he has given you the idea well, let I want to install a preheater give me how much saving I will be getting? So, you have to answer to him quickly now the idea of this particular problem is to answer him quickly and that is the way you will be proceeding.

Please solve first yourself before seeing the solution that is my humble request. So the heat input from the problem says, the problem you have to first of all find out the installation of a preheater is under consideration and the a part is that, if the daily process requirement and daily heat loss are kept same what percent saving in fuel could be achieved by the preheater installation.

So we will make again heat balance this is problem number three.

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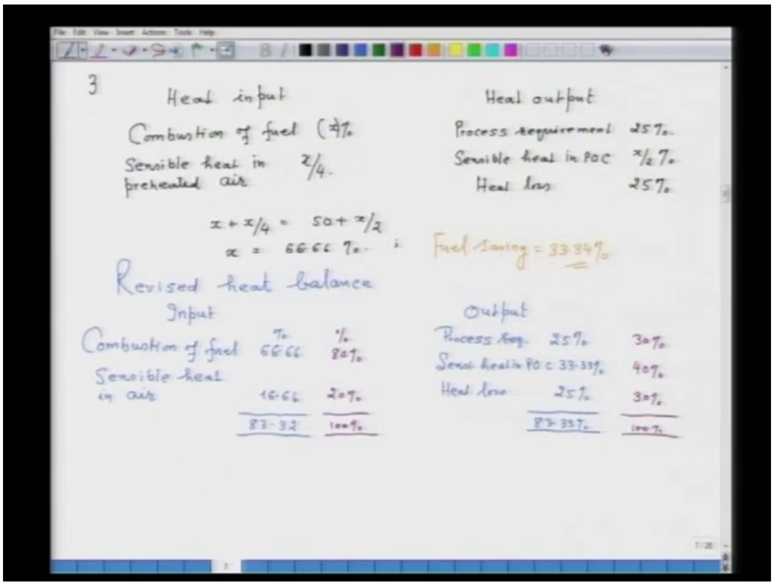

So heat balance, let us say heat input and on this side heat output. Again in percent of total. Now, since it says it is the fuel input, so now the combustion of fuel let us say, it supplies x percent, x percent of heat is supplied by the combustion of fuel. Now, it says process requirement is say 25 percent that is same, sensible heat in P O C if the problem say if 100 percent 50 percent. So if x is the fuel, then x by 2 percent we will go as sensible heat in P O C. Heat loss are to be kept same as per the need of the problem. So heat loss is again 25 percent. So, we will just and half of the heat is been circulated, so x by 2 is out so, x by 4 will be in. So this will be sensible heat in preheated air, ok. So, we have to do it simple. x plus x by 4, that will be equal to 50 plus x by 2 we will solve the value of x. So x will be equal to 66.66 percent so, fuel saving will be how much? Fuel saving will be 33.34 percent. See now how quickly you get the answer.

So now, the problem says what is the revised heat balance? So let us put it. The revised heat balance will be say now input and here is the output. Combustion of fuel that is equal to 66.66 that is in percent, sensible heat in air that is 16.66. So, the total is 83.32 percent. Now heat output, say process requirement 25 percent, sensible heat in P O C that is 33.33 percent and heat loss that is equal to 25 percent again it makes 83.33 percent. Now, we can refer these value to the 100 percent. So, if I refer to the value, refer to the 100 percent, that will come here 80 percent, here it will be 20 percent. So, that makes you 100 percent. Similarly, I can make it referring to the 100 percent that will be here 30 percent, here it will be 40 percent and here it will be 30 percent. So again, you have the answer as 100 percent.

So you see, how quickly you can answer the you can answer to your boss that well, this preheating will save you that much amount of fuel so he will may be attracted to install a preheater and So, now the b part says: that if suppose fuel saving is not done, you consume the same amount of fuel as you have consumed earlier, then what percent increase in the heat will occur in the furnace as a result of preheater installer? That means now you are not changing the fuel consumption.

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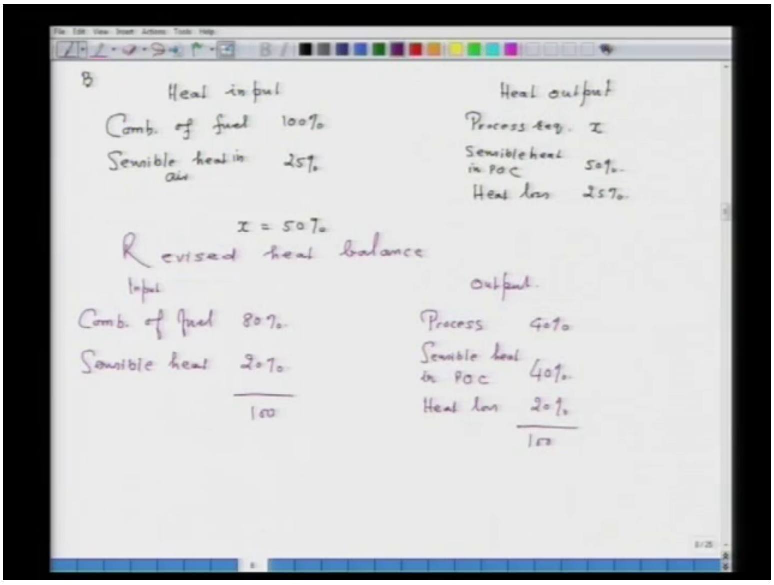

So now, so the part b again we will do the heat balance. So heat input, heat output, so heat input, say combustion of fuel, now it will remain 100 percent then the sensible heat in air you are recovering half the heat, this 100 will remain 100, now it has become 25 percent because half is coming over here. Now, heat output: the process requirement say we do not know now, it is x sensible heat in air, sensible heat in P O C - that is: 50 percent, as it was said heat loss - 25 percent. So again, we do the heat balance, so I am getting here x that is equal to 50 percent. So that means now, earlier it was 25 percent now it becomes 50 percent process available heat. So that means, I am increasing now the percentage increase in available heat is 100 percent. So now, the revised heat balance would look like this, revised heat balance that will be say input, here again output, combustion of fuel, that is equal to 80 percent and sensible heat that is equal to 20 percent, output say process, is 40 percent, sensible heat in P O C again 40 percent and heat loss 20 percent, I referred them to 100 percent so this becomes also here 100 percent and this is also 100 percent now you note here how quickly this problem help you to illustrate the role of preheater in an installation.

Now with this last lecture, I have completed all the lectures in fuel furnace in refractory. Now in all these lectures at various places I have given solved as well as unsolved problems my appeal to all the listeners of this video lecture that, please attempt problem by yourself before going to the solution of the problem. Though solution is there, but it is the in the best interest that if you solve the problem and develop some innovative methods for the solution of the problem.

Lastly, I will also like to point out that we never do after solving the problem. So please, see that you also analyze the solution of the problem. Now, it is very important that you analyze the problem because once you solve the problem and you get the solution you have built up yourself for the present. But, if you solve but, if you analyze the solution of the problem then you are adding a value to your future career.

So, again I will appeal that whenever you will solve the problem try to analyze the solution of the problem and develop a feel that what has been done, now this will help to develop your analytical skill and the analytical skill is always an asset.