Fuels, Refractory and Furnaces

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Lecture No. # 18

Heat Utilization in furnaces, energy flow diagrams

We will continue with our lecture on heat utilization in furnaces. We have seen in earlier lecture that gross available heat and net available heat, they are in fact the of the heat utilization. Also we have defined and tried to calculate the fuel consumption and there we have told that, fuel consumption is gross available heat required per unit of time divide by gross available heat per kg of the fuel. I have also said the various factors that affect heat utilization, the various factors that affect fuel consumption and in that relation we have seen, how the gross available heat is affected by excess air? And how the fuel consumption is affected by the excess air?

In that connection, the another important variables is oxygen enrichment, though in that last lecture I have listed several factors, which affect gross available heat and fuel consumption I explained also those factors. About the oxygen enrichment I have to say something more.

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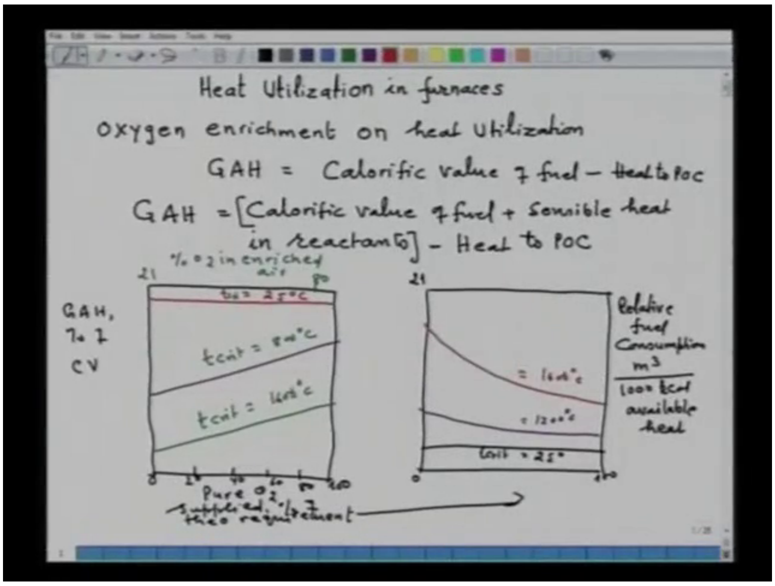

Heat Utilization in furnaces

Oxygen enrichment on heat Utilization

GAH = Calorific value of fuel – Heat to POC

GAH = [Calorific value of fuel + Sensible heat in reactants] – Heat to POC

So, the effect of oxygen enrichment on heat utilization now, as we all know that gross available heat, that is equal to calorific value of the fuel, calorific value of fuel minus heat to P O C when the reactants are not preheated. If the reactants are preheated, then gross available heat, that is equal to calorific value of fuel plus sensible heat in reactants minus heat to P O C. So, in principle the gross available heat is dependent on, how much heat will be carried out by the products of combustion.

Now, as we all of know, air is 21 percent oxygen and 79 percent nitrogen. So, in normal air that is 29; 21 percent oxygen and 79 percent nitrogen. The nitrogen is inert and the heat which is carried out by the nitrogen is the principle component in heat to p o c. Whereas, oxygen of air is utilized for combustion and for stoichometric amount of oxygen, no oxygen is available in the heat to p o c, but whatever amount of nitrogen is discharged with the air the entire amount is available with the heat to p o c.

Therefore, if we enrich the oxygen, if we enrich the air, how we can enrich the air? In that the nitrogen amount is reduced and proportionately oxygen amount is increased so, that is called oxygen enrichment of the fuel. So, it is logical when we enrich air by adding more amount of oxygen then of course, the nitrogen content of the oxygen enriched air will be less, and accordingly less heat will be carried by p o c and as a consequence more gross available heat will be available.

So, naturally when large amount of gross available heat is available, naturally fuel consumption will be less. So, this is what I can show you in a diagram for example, if we plot here I am showing symmetrically just to illustrate the variables on x axis, I take pure oxygen supplied as percentage of theoretical requirement. And on y axis I plot gross available heat as percentage of calorific value of the fuel. So, as such if it is zero, this is 0 and somewhere here is 21 and somewhere here is 20, 40, 60 and 80. That means you are enriching air by oxygen so, for a process critical temperature t is equal to 25 degree Celsius.

All the heat will be available now, as the temperature or the critical process temperature of the furnace increases for example, if you take say here t critic that is equal to say 1600 degree Celsius and here t critic that is equal to say 800 degree Celsius and this is also t critic. So, all that it says that has, we enrich the oxygen that as we increase the amount of oxygen in air the gross available heat increases. Now, somewhere here, we have the in terms of percent O 2 in enriched air. Now somewhere here we have 21 percent oxygen and as we go somewhere here, we get 80 percent oxygen enrichment.

So, that is how, now the gross available heat when it increases, with the decrease in the process critical temperature or we can also say gross available heat increases with the increase in the oxygen enrichment of the air whichever, way you want to understand. Now, let us plot it about the fuel consumption. So, if we plot over here the x axis is same as this one, I am not writing x axis once again is the same whatever, I have written for the left hand side of the diagram it goes from 0 to 100. Of course, zero percent of that means, that 21 percent enrichment and here I am plotting here, relative fuel consumption in meter cube here gaseous fuel is taken as example divide by 1000 kilo calorie available heat.

Just make it dimensionless so, here again for t critical, this is t critical equal to 25 degree Celsius, because there no heat will be taken out so, the naturally the fuel consumption will be minimum. So, if we increase the process critical temperature for example, we go to 1200 degree Celsius and this is what, that is equal to 1200 degree Celsius and if we further increase for example, around 1600 degree Celsius that is equal to 1600 Celsius. So, what it all says is that? The fuel consumption, it rather decreases with the increase in the oxygen enrichment, also fuel consumption is more when the process critical temperature is high.

So, what is said over here? That is in fact effect of oxygen enrichment it helps to reduce the fuel consumption. However variable wise the fuel consumption decreases, if the process, if the percentage oxygen in theoretical air increases, but natural because now the more amount of heat will be available. So, that is all about the so called the fuel the heat utilization and fuel consumption. Now, at this point it is important to have a critical note on flue gas temperature.

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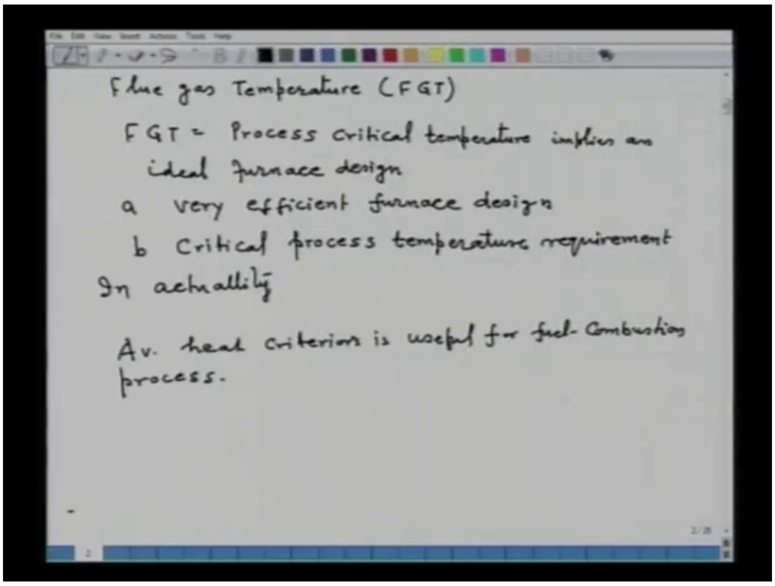

Flue gas Temperature (FGT)

FGT = Process critical temperature implies an ideal furnace design

a very efficient furnace design

b Critical process temperature requirement

In actuallity

Av. heat criterion is useful for fuel- Combustion process.

On flue gas temperature I shortly put F G T. Now, so far in all our discussion what we have taken is that, flue gas temperature is equal to the critical process temperature. So, that is what we have taken, that a flue gas temperature is equal to process critical temperature that is, what we have taken in our entire discussion. Now, if fuel gas temperature equal to process critical temperature, that implies and now, when this is equal so, this implies an ideal furnace design, which means that heat transfer is uniform. And the products of combustion are able to deliver its heat to the furnace, on account of which the fuel gas temperature has become equal to the process critical temperature.

Now, this means also a very efficient furnace design that is why I have said, very efficient furnace design. That means heat transfer from the P O C to the furnace or to the charge is very uniform, the entire volume of the furnace is uniformly heated that is what an ideal furnace design means. It also means that the critical process temperature requirement is in fact, determined by more or less static requirement of the process. That means we have made our calculation, we have thought that we have to carry out process at 1200 degree Celsius. Keeping in view that, heat transfer will be very good furnace design is very efficient and the rate of heat demand to the entire process will be same, because you design a furnace for a particular value of the rate of heat demand.

But in actual thing; in actuality under many operating conditions, the controlling requirement is the rate of heat demand. To meet higher than normal heat demand what is required? You have to have a temperature difference between P O C and the furnace or in the charge to be very large, why you should have larger temperature difference? Because then and then flow of heat will be very large. Now, in this particular case, if the furnace is not designed for high heat transfer rate, what will happen? Very high flue gas temperature will be obtained.

I repeat once again, in reality to meet higher than normal heat demand, larger temperature demands between the products of combustion and the furnace charge is required naturally, then and then heat flow will be fast because the flow of heat is proportional to temperature gradient. If the furnace is not designed for higher rate of heat demand of course, the flue gas temperature in that particular case will be higher then what you have thought of it. So, what I mean to say from here, that it is rate of heat demand that is important for a particular flue gas temperature. It will not be necessary that the flue gas temperature will always be equal to the process critical temperature.

If you have higher heat demand, higher temperature difference that is fast and higher temperature difference is required for the faster flow of heat, and faster flow of heat will result in the higher flue gas temperature. If another situation, if we have the lower heat demand a flue rate in excess of process needs will rise the flue gas temperature and possibly the material temperature also. So, what in summary? What I want to say that, the flue gas temperature it also depend upon the rate of heat demand and furnace design, you design a furnace for a particular value of the heat demand.

If for some reason higher rate of heat demand required will for higher rate of heat demand, you have to have higher temperature difference. And in that case the flue gas temperature will be higher and in another case, when there is a lower heat demand and you are using the same amount of fuel then also the flue gas temperature will be higher and also material temperature will be higher. So, what it leads to is that, it may not be necessary that all the heat available in the flame and P O C is utilized in the furnace and process. That is what, the important thing I want to say that depending on the heat of demand a flue gas temperature can be higher than the process critical temperature.

A flue gas temperature can be higher depending upon the areas in the furnace, where overheated areas or under heated areas. So, that is what it means and it can also be said that, it is not always necessary that the all the heat available in the flame and P O C is utilized in the furnace and process. Therefore, the available heat criterion is useful for fuel combustion process. Available heat criterion it does not determine the furnace efficiency, because furnace efficiency we define the ability of the furnace to raise the temperature of the charge to a particular value of the temperature.

So, what it amounts to say is that, in many furnaces improvement in furnace design to improve the heat transfer rate and to decrease the fuel consumption or and to decrease the flue gas temperature. It is more important I repeat once again, in many furnaces improvements in furnace design to improve the heat transfer rate and to decrease the flue gas temperature is more important fuel economy, then to change the combustion to yield more amount of heat. That means by changing the combustion process it is not necessary that we will be able to increase the furnace efficiency. All that if we want to decrease the flue gas temperature of course, not lower than the critical process temperature, then the another parameter that is important is the heat transfer rate in the furnace.

So, if you want to improve the heat transfer rate the equally important is also the furnace design that is what it says.

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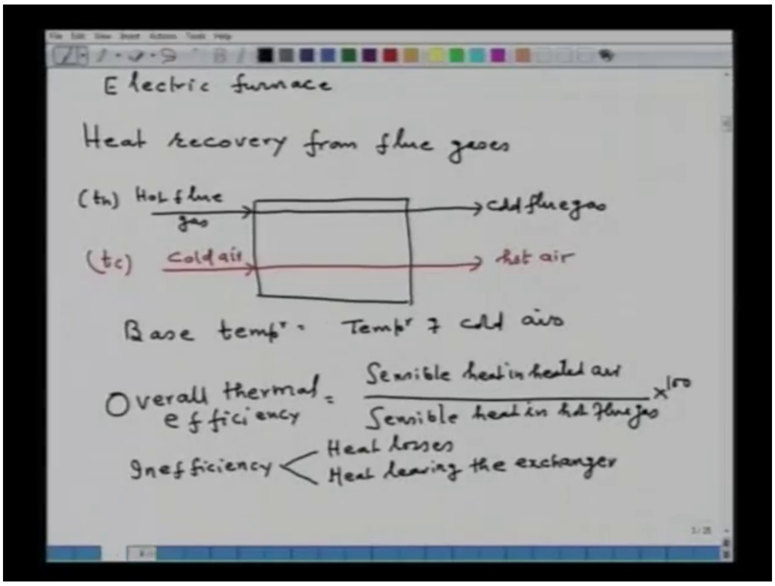
Electric furnace

Heat recovery from flue gases

Base tempr = Tempr of cold airs

Overall thermal efficiency = $\frac{\text{Sensible heat in heated air}}{\text{Sensible heat in hot flue gas}} \times 100$

Inefficiency < Heat losses / Heat leaving the exchanger

In this connection, if you take the electric furnace now, in the electric furnace all the heat will be available and we can say the gross available heat, because there is no products of combustion are created. So, whatever amount of heat is obtained through the electrical charge, all the heat will be available for the process and therefore, electric energy is favored in contrast to the fuel heating, because in the fuel heating the P O C heat is not available to the furnace. So, whereas, in electric heating all the heat is available so, that is what little about the electric furnace.

Now, as we have seen that the heat from the heat taken out by the flue gases is a very important component of the fuel fired furnace. Therefore, it is essential that the heat recovery on the best cases is also an important part of the fossil fuel combustion, because the heat taken by P O C it will also, depend on the temperature. Higher is the critical process temperature, higher will be the amount of heat carried away by the flue gas temperature therefore, the heat recovery from flue gases is important. Heat recovery from flue gases is important now, for example, if you consider this system say here hot flue gas so, it transfer here and we have here cold flue gas. Let us say this is at temperature th, and this is a cold air whose temperature is tc, and here we have hot air.

So, the heat recovery form flue gas consists of first of all recover the heat of flue gas and use this heat to heat for example, air or gaseous fuel. So, here in order to define, let us say the best temperature for all these calculation is temperature of cold air. Now, in order that, this system work efficiently to be defined certain parameter and one of the parameter is overall thermal efficiency. Now, this is defined as sensible heat in heated air, upon sensible heat in hot flue gas, multiplied by 100.

Now, in this overall thermal efficiency, the sensibility in heated air were not defined the temperature. So, it appears as if the air can be preheated to the temperature greater than the flue gas temperature which is thermodynamically not possible. You cannot heat air to a temperature which is greater than the flue gas temperature, when you want to heat the air by the heat of flue gas. Also inefficiency, they are because of two factors, one is the heat losses that we have not considered in this definition, another these heat losses will be through the walls or through the openings or whatever and also heat leaving the exchanger. These two things they are not addressed in the formulation of overall thermal efficiency therefore.

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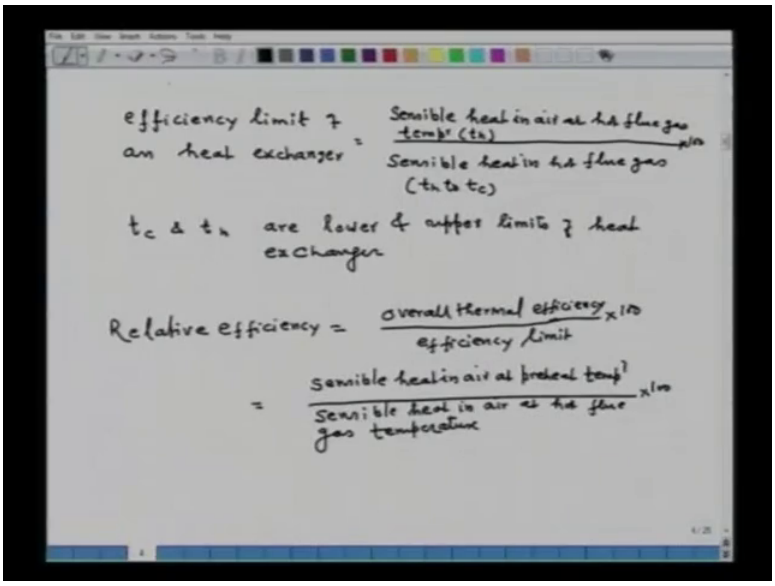

$$\text{efficiency limit of an heat exchanger} = \frac{\text{Sensible heat in air at hot flue gas temp}^r\ (t_h)}{\text{Sensible heat in hot flue gas } (t_h \text{ to } t_c)} \times 100$$

t_c & t_h are lower & upper limits of heat exchanger

$$\text{Relative efficiency} = \frac{\text{overall thermal efficiency}}{\text{efficiency limit}} \times 100$$

$$= \frac{\text{sensible heat in air at preheat temp}^r}{\text{Sensible heat in air at hot flue gas temperature}} \times 100$$

We define another parameter which is called efficiency limit of an heat exchanger and this is equal to sensible heat in air at hot flue gas temperature. That is th divide by sensible heat in hot flue gas, from th to tc into 100. So, now this checks the upper efficiency limit of the heat exchanger, where remember tc and th they are lower and upper limits of heat exchanger. Now, if you want to compare the different heat exchangers then, we define a term which is called relative efficiency. Now, relative efficiency is defined as overall thermal efficiency limit into 100.

If we substitute for overall thermal efficiency and efficiency limit from the above formulation, then we will be getting relative efficiency is sensible heat in air at preheat temperature, upon sensible heat in air at hot flue gas temperature of course, you have to multiply by hundred. Now, this particular definition of relative efficiency, it determines the capability of an exchanger to heat the air at a particular temperature. On that basis of the relative efficiency, we can compare the two different heat exchanger a heat exchange will be good, if it can heat air to higher temperature.

In comparison to exchanger which heats the air to a lower temperature for the same amount of heat so, that is what this relative efficiency is an important concept in deciding the heat recovery from flue gases through heat exchangers. Now, of course, we will taken a problem to illustrate this concept now, here that two types of heat exchangers are available one.

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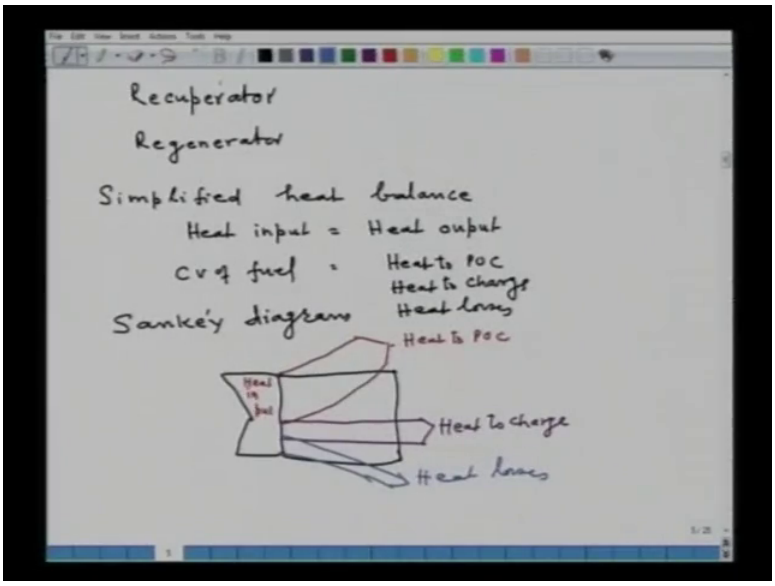

Recuperator

Regenerator

Simplified heat balance

Heat input = Heat ouput

CV of fuel = Heat to POC
Heat to charge
Heat losses

Sankey diagram

One is a recuperator, in the recuperator the flue gas heats the surface of the pipe and the cold air flows from the wall of the pipe, the heat transfer occurs to the air and that then that is the way the air gets preheated. So, the recuperator is normally suitable for low temperature, it is not used for very high temperature of the flue gases. That means in the case of recuperator, the thermal conductivity of the material is very important, because in one pass the hot flue gas, heats the wall of the pipe or wall of the tube or whichever whatever, material is being used for recuperator design and then air is passed and then heat transfer occurs.

Another heat exchanger is regenerator, in regenerator we have the heating element for example, refractory bricks. So, in the first cycle, the flue gas is passed and the refractory bricks are heated up, in the next cycle air is passed and the heat from the heating element or refractory brick is recovered to preheat the air. So, normally two regenerators are used one for the heating cycle and another for the cooling cycle. In the heating cycle the heating elements are heated, in the cooling cycle the air is heated up. So, in the heating cycle, the heating element is heated and the second regenerator it works on the cool cycle and the second regenerator works on the heating cycle and then the first regenerator acts as a cooling cycle so, they work alternatively.

What is important in the regenerator as the heat exchanger is that, here the heating elements are used for example, refractory bricks and these are heated by the flue gas then the heat transfer occurs when air is passed into this. Now with this now we can understand little bit about the heat balance. So, simplified heat balance now, in fact heat balance and its representation on a diagram it tells us how the heat is flowing in a particular process.

Now, heat balance it simply consists of heat input that is equal to heat output. Now, in a very simple case if you use the fuel fired furnace so, heat input for example, we take say calorific value of fuel is the heat input and that must be equal to for example, we are heating a charge. Then heat output will be heat to P O C, heat to charge and the balance will be heat losses. So, more should be equal and this flow of the heat they are represented in a diagram which is called Sankey diagram. Now, in a Sankey diagram one takes a box and one decides this is the scale. If this entire scale represents the input of the heat, then we calculate the fraction and we represent over here for example, if this is the heat input, from here to here is the heat input.

Now, we calculate it to P O C and then we will present because this heat to P O C is going out depending on its amount, this we can say heat to P O C. Then amount of heat to charge this is heat to charge now, then this is the heat losses. So, this particular diagram tells you, the flow of heat that is how the heat is flowing, when it is a charge into the furnace. So, these diagrams are very helpful in order to represent the heat flow and then to identify the areas of heat losses to identify the improvement in the furnaces to identify the factors affecting the fuel consumption.

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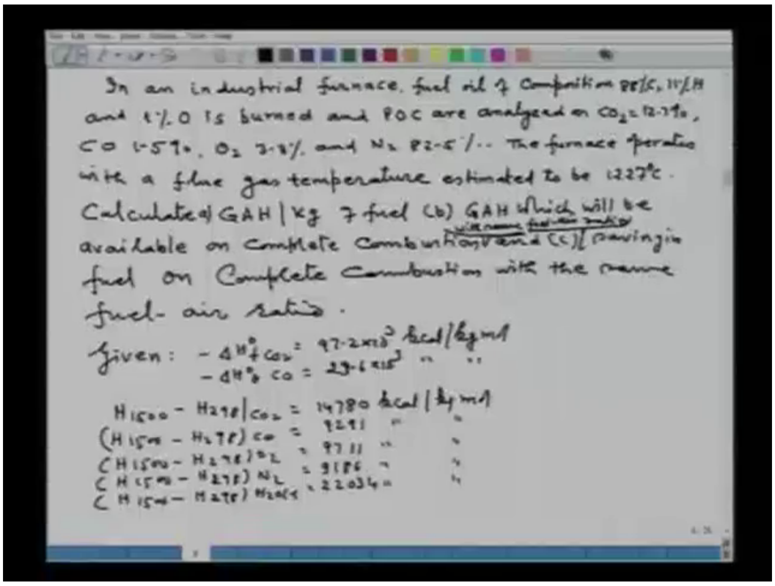

In an industrial furnace, fuel oil of composition 88% C, 11% H and 1% O is burned and POC are analyzed as CO_2 = 12.7%, CO 1.5%, O_2 3.3% and N_2 82.5%. The furnace operates with a flue gas temperature estimated to be 1227°C. Calculate (a) GAH/kg of fuel (b) GAH which will be available on complete combustion with same fuel-air ratio and (c) % saving in fuel on complete combustion with the same fuel-air ratio.

Given: $-\Delta H^\circ_f\, CO_2 = 97.2\times10^3$ kcal/kg mol
$-\Delta H^\circ_f\, CO = 29.6\times10^3$ " "

$H_{1500} - H_{298}|_{CO_2}$ = 14780 kcal/kg mol
$(H_{1500} - H_{298})_{CO}$ = 9291 " "
$(H_{1500} - H_{298})_{O_2}$ = 9711 " "
$(H_{1500} - H_{298})_{N_2}$ = 9186 " "
$(H_{1500} - H_{298})_{H_2O(g)}$ = 22034 " "

Now, after doing this let me take one particular example to illustrate what we have done. So, let us take a problem to illustrate whatever I have done on the heat utilization gross available heat fuel consumption and so on I read out the problem. In an industrial furnace fuel oil of composition 88 percent carbon, 11 percent hydrogen and 1 percent oxygen is burned and products of combustion are analyzed as CO 2 12.7 percent, CO 1.5 percent, oxygen 3.3 percent and nitrogen 82.5 percent. That means you must have noted that this is the case of incomplete combustion, because CO is there in the flue gas.

The furnace operates with a flue gas temperature estimated to be 1200 and 27 degree Celsius. Now, calculate gross available heat per kg of the fuel (b) gross available heat which will be available on complete combustion with same air fuel ration. What was used in problem (a) and (c)? Percentage saving in fuel, on complete combustion with the same fuel air ratio given heat of formation of CO 2 and CO and for illustration of the problem, I have taken the heat content at the respective temperature. After integration of cp is equal to (a) plus 2 (b) t plus c by t square ,you can do yourself from 298 to 500 1500 degree Celsius because 1227 degree Celsius or 1500 Kelvin is the flue gas temperature.

So, accordingly the heat content in CO 2, CO, O 2 and N 2, H 2 O liquid is given with the respective values.

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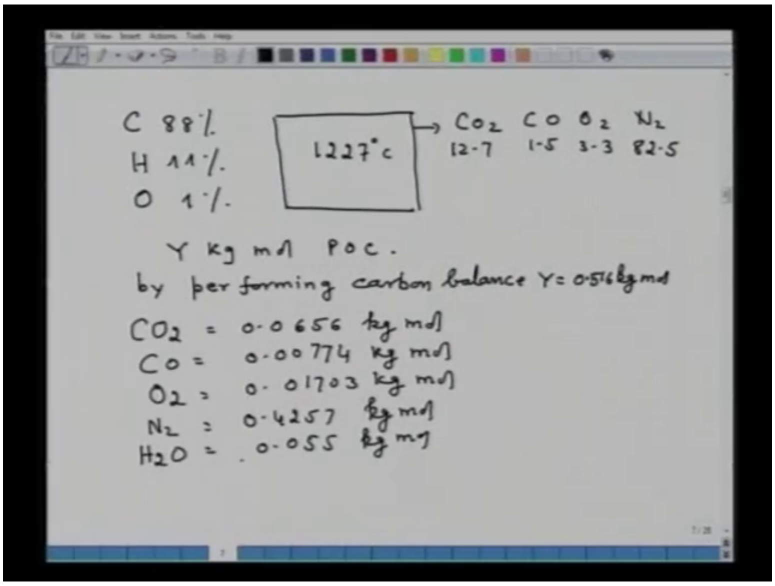

C 88%
H 11%
O 1%

1227°C

$\rightarrow$ CO_2 CO O_2 N_2
12.7 1.5 3.3 82.5

Y kg mol POC.

by performing carbon balance Y = 0.516 kg mol

CO_2 = 0.0656 kg mol
CO = 0.00774 kg mol
O_2 = 0.01703 kg mol
N_2 = 0.4257 kg mol
H_2O = 0.055 kg mol

Now, let us solve this particular problem. Now, before this I would like to represent whatever given in the form of a block diagram, so that while solving the problem we know what is given and what is not given. So, here carbon 88 percent, hydrogen 11 percent and oxygen 1 percent is given. Here temperature is 1227 degree Celsius products of combustion CO 2 12.7, CO 1.5, O 2 3.3, nitrogen 82.5, that is what is given to us and first of all we will solve for a gross available heat per kg of the fuel. Now, as such first thing that you have to do is the material balance. Now, as in the lecture 9 to 12, I have illustrated several problems on material balance of combustion, I will not go into the detail.

So, I will just say let us take Y kg mole of P O C then by doing carbon balance, by performing carbon balance, we can get value of Y that is equal to 0.516 kg mole. Now, once we get the value of Y, then we can determine the amount of P O C. So, we get amount of P O C; CO 2 that is equal to 0.0656 kg mole, CO 0.00774 kg mole, O 2 0.01703 kg mole, nitrogen 0.4257 kg mole and H 2 O that is equal to 0.055 kg mole. Now, note in the products of combustion nitrogen is the maximum amount and as I repeatedly said that nitrogen carries the maximum amount of heat. Now, once this is available to us now, we can calculate the heat carried by the P O C from the respective heat content values.

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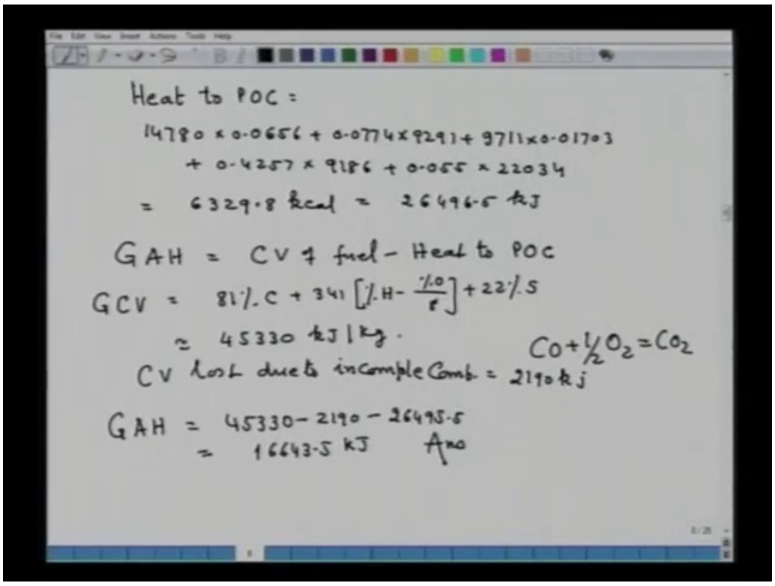

Heat to POC =

$14780 \times 0.0656 + 0.0774 \times 9291 + 9711 \times 0.01703$
$+ 0.4257 \times 9186 + 0.055 \times 22034$
$= 6329.8$ kcal $= 26496.5$ kJ

GAH = CV of fuel − Heat to POC

$GCV = 81\%C + 341\left[\%H - \frac{\%O}{8}\right] + 22\%S$
$\simeq 45330$ kJ/kg.

$CO + \frac{1}{2}O_2 = CO_2$

CV lost due to incomple Comb. = 2190 kj

$GAH = 45330 - 2190 - 26495.5$
$= 16643.5$ kJ Ans

Now, here then we can calculate heat to P O C. Heat to P O C that will be equal to 14780 into 0.0656 plus 0.0774 into 9291 plus 9711 into 0.01703 plus 0.4257 into 9186 plus 0.055 into 22034 so, if you solve this will be equal to 6329.8 kilo calorie or that will be equal 26496.5

kilo joule. One calorie is 4.183 joule. Now, in order to find out gross available heat, that is equal to calorific value of fuel minus heat to P O C. Now, in this particular problem the calorific value of fuel is not given. So, we can calculate the gross calorific value of the fuel by the dulong formula, which I have given in the lecture two.

So, utilizing the knowledge of lecture two, if the calorific value of the fuel is not given, then we can use the dulong's formula to calculate the calorific value, and since in the heat content we used H 2 O liquid. So, accordingly we will calculate the gross calorific value of the fuel so, you recall that formula. Gross calorific value of fuel, that was equal to 81 percent carbon plus 341 percent hydrogen minus percent oxygen upon 8 plus 22.; 22 percent sulphur, that was in kilo calorie kg. We substitute all these values then the gross calorific value will be getting around 45330 kilo joule per kg. So, that is what we have got now in this particular problem, you have to consider also that there is an incomplete combustion.

So, due to incomplete combustion the entire energy of carbon to CO 2 is not been obtained in the furnace. So, in the calculation of the gross available heat, you have to subtract the calorific value of CO from the gross calorific value of fuel, because the gross calorific value of the fuel when we calculate, we consider complete combustion. So, we have to subtract, the calorific value of CO from the gross calorific value of the fuel that you have calculated 45330. So, if you calculate the calorific value of the CO.

Then so, we can calculate now the calorific value of CO CV of fuel again, you have to consider the reaction CO plus half O 2 that is equal to CO 2. So, from here one can calculate what will be the heat of reaction for this, and accordingly one can find out what is as of CO. So, if I do all this, then the gross then the CV of the calorific value lost due to incomplete combustion. That is equal to 2190 kilo joule, then the gross available heat that will be equal to 45330 minus 2190, that we have not got because of the incomplete combustion and minus 26496.5. So, gross available heat will be equal to 16643.5 kilo joule per kg of the fuel and that is answer for part one.

Now part (b) says, if there is a complete combustion by utilizing same air fuel ratio, the excess oxygen of the flue gas will be used up in order to get CO 2, then we have to recalculate the products of combustion.

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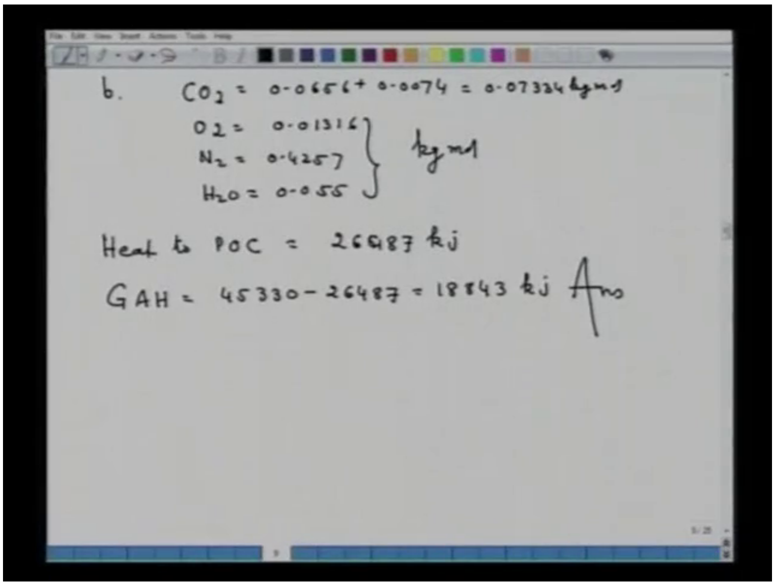

b. $CO_2 = 0.0656 + 0.0074 = 0.07334$ kg mol

$O_2 = 0.01316$

$N_2 = 0.4257$

$H_2O = 0.055$

$\left.\begin{array}{l} O_2 \\ N_2 \\ H_2O \end{array}\right\}$ kg mol

Heat to POC = 26487 kj

GAH = 45330 − 26487 = 18843 kj Ans

So, for (b) part we have to recalculate P O C composition, because now here is a complete combustion. So, if you recalculate the amount of CO 2, that will be equal to 0.0656 plus 0.0074 that is coming from CO plus half O 2 is equal to CO 2, that is equal to 0.07334 kg mole. Then O 2 that will be reduced, that will be 0.01316 nitrogen will remain same 4257 and H 2 O will also remain the same, they are all in kg moles. Now, CO 2 and O 2 will change because excess oxygen CO, whatever amount of CO was there plus half O 2 is equal to CO 2. So, oxygen of P O C will be used up so, it will be less and the CO 2 will be added into the amount of CO 2.

So, we again calculate the heat to P O C. Now, there is no CO in the P O C combustion is complete so, heat to P O C that will be equal to 26487 kilo joule, you can calculate again by multiplying the values. So, you will be getting now heat to P O C will come 26487 kilo joule. So, gross available heat will now, be equal to 45330 minus 26487 that will be equal to 18843 kilo joule, this is (b) this is the answer. Now, you recall what is the effect of incomplete and complete combustion, this particular problem illustrates that. If there is an incomplete combustion, then the gross available heat is less which is 16643.5 kilo joule.

But when there is a complete combustion, the gross available heat increases that is what I have said in the lecture also. It is obvious that there is an incomplete combustion and part of the calorific value of the fuel is not available in the furnace plus CO, which is forming it will also, carry the heat to the with the flue gas. When there is a complete combustion, then the entire amount of energy from combustion of carbon to CO 2 is available. Therefore, gross available heat is higher conceptually this is this and calculation we have, we are also getting this.

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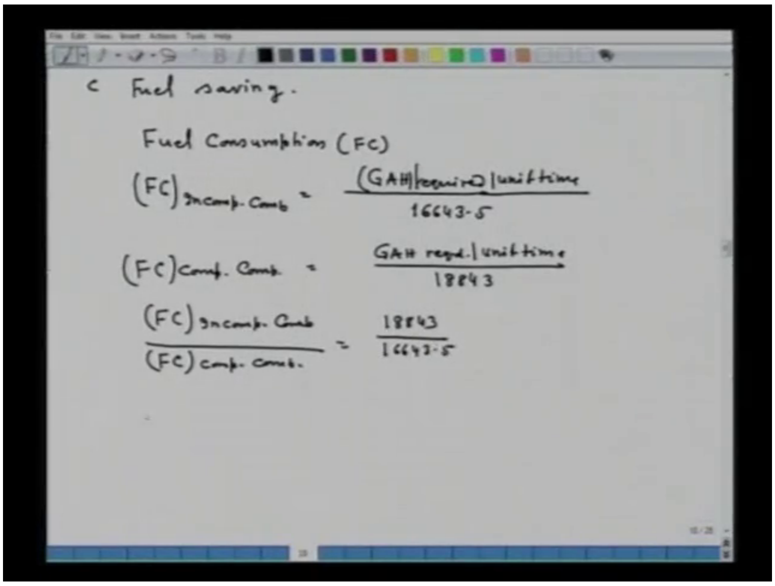

c Fuel saving.

Fuel Consumption (FC)

$$(FC)_{\text{Incomp. Comb}} = \frac{(GAH) \text{required}/\text{unit time}}{16643.5}$$

$$(FC)_{\text{Comp. Comb.}} = \frac{GAH \text{ reqd.}/\text{unit time}}{18843}$$

$$\frac{(FC)_{\text{Incomp. Comb}}}{(FC)_{\text{comp. comb.}}} = \frac{18843}{16643.5}$$

Now, the third part which is there, what will be the fuel saving? Let us calculate c fuel saving. So, we determine now fuel consumption in the subsequent I will write f c. So, f c in complete combustion, that will be equal to gross available heat required per unit time upon gross available, heat per kg of the fuel and which is here 16643.5. Same fuel consumption, on complete combustion that will be equal to same gross available heat required, per unit time upon 18843. So, that is how you also said, how to calculate the fuel consumption? The fuel consumption is simply gross available heat required per unit of time divide by the gross available heat per kg of the fuel. So, in both the cases you have determined the fuel consumption.

Now, we can take the ratio say, f fuel consumption on incomplete combustion divide by fuel consumption on complete combustion. Now, since gross available heat required per unit of time is same whether, you have incomplete combustion or whether you have complete combustion that does not matter. So, in that case that will be equal to 18843 divide by 16643.5.

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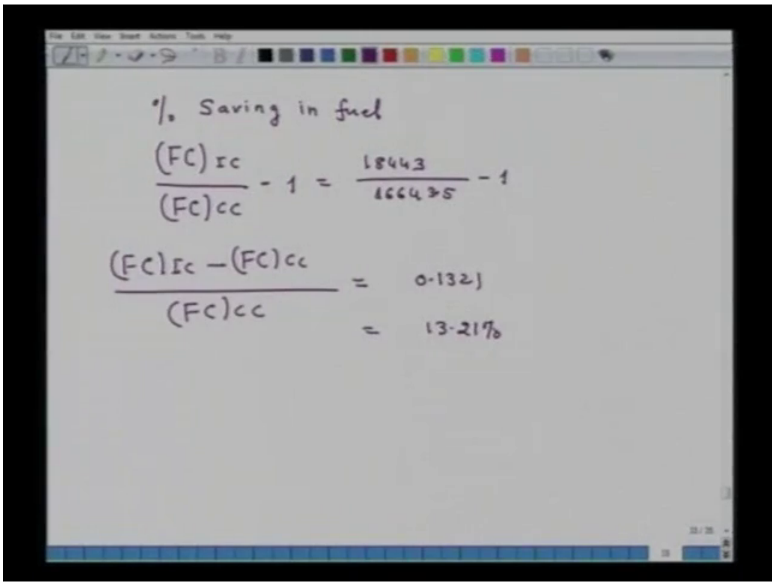

% Saving in fuel

$$\frac{(FC)_{IC}}{(FC)_{CC}} - 1 = \frac{18443}{16643.5} - 1$$

$$\frac{(FC)_{IC} - (FC)_{CC}}{(FC)_{CC}} = 0.1321$$

$$= 13.21\%$$

Percent saving in fuel that will be equal to, fuel consumption for incomplete combustion, upon fuel combustion, when complete combustion minus one that is equal to 18443, upon 16643.5 minus one. So, fuel consumption incomplete combustion minus fuel consumption upon complete combustion upon fuel consumption that is the fuel saving that will be equal to 0.1321 or that will equal to13.31 percent.