

Materials and Energy Balance in Metallurgical Processes

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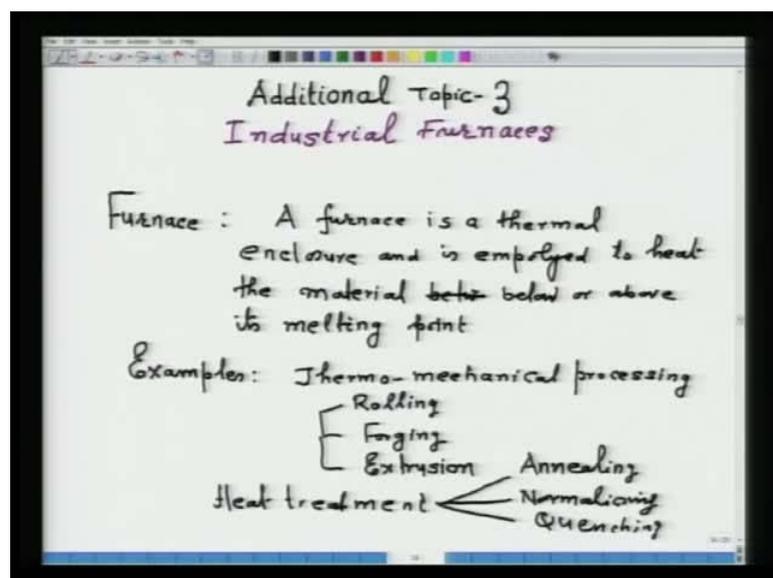
Module No. # 01

Lecture No. # 38

Additional Topics-IV Industrial Furnaces

In today's lecture, I have introduced one more additional topic. That is on industrial furnaces. Now, considering the importance of furnaces, I thought that, it will be appropriate to give you some account of the material and heat balance in industrial furnaces because for high temperature operations, whether they are performed below the melting point of the material or above the melting point of material, the furnaces play a very important role. Furnaces also play an important role, particularly, for high temperature applications - the consumption of energy and also the emissions of Carbon dioxide; I will try to illustrate both the aspects in this particular lecture.

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So, let us see first of all, what is meant by a furnace. In fact, what I want to define? A furnace; I want to say, a furnace is a thermal enclosure and is employed to heat the material below or above its melting point. Now, there are certain examples.

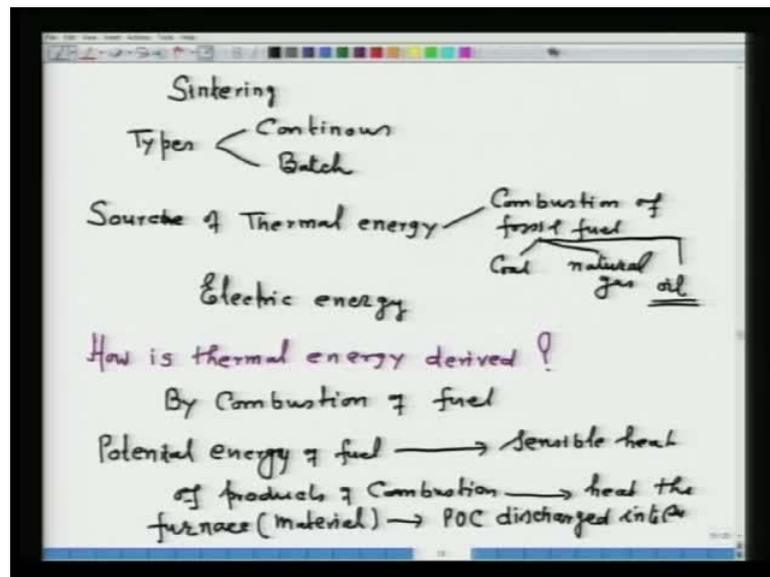
For example, examples of furnaces that are employed to heat the material below the melting point - those furnaces are used to perform, for example, Thermo mechanical processing. What I mean under this is that, when a material is mechanically processed and when material is heated at high temperature - for that, furnaces are used. The reasons are obvious, because the material becomes plastic at that particular temperature so that the mechanical processing is easier. So, one of the important application of furnaces is to heat the material below the melting point for thermo mechanical processing.

Thermo mechanical processing - that could be rolling; that could be forging; you must have heard hot forging or that could be an extrusion. Here, the objective is to heat the material below the melting point. For example, steel - it is often heated between 1000 and 1200 degree Celsius, and Copper and Aluminum below their respective melting point. It is one of the important objectives of the furnace.

Another example is - for the heat treatment purposes. Now, for the heat treatment purposes, again, the materials are heated, of course, below the melting point and then they are cooled. I have no intension to deal or to go into the details of heat treatment, but the various operations under heat treatment are..., for example, Annealing. Now, in annealing, material is heated below the melting point in the furnace and is cooled in the furnace. Then normalizing material is cooled outside the furnace in the air and quenching.

Of course, there are other operations, but for this particular lecture, what I wanted to say - the different objectives of the furnaces. There are still other objectives of the furnace is that of sintering.

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In various powder metallurgical operations and ceramic processing, you heat the material for sintering operations so that you develop an appropriate strength. Now, here itself, if I want to extend the application of furnaces because I defined a thermal enclosure, then, a very important function of the furnaces is for processing the material above the melting point. As we have seen in all the lectures on material and heat balance - the thermal enclosure like matte smelter, like roaster, like blast furnace and so on - there you heat the material above the melting point of the material. So, now, here, specifically I will go in detail to the material and heat balance of the industrial furnaces, which are employed below the melting point of the material, keeping in view - the energy requirement and Carbon emissions into the environment. These are the two objectives.

Now, in this connection, just to give an idea the types of furnaces, there are normally two types of furnaces. Furnaces can be classified in various ways: continuous and batch furnaces. In continuous furnaces, there is a constant input and constant output. In batch, you heat the material for certain time and after certain time the material is out.

You can also classify the furnaces on the way in which the furnaces are used. For example, if the furnace is used for annealing, you call this - annealing furnace. A furnace is used for rolling or for forging, you call - forging furnace, but essentially, they are all thermal enclosure.

Now, in this particular connection, it is also important to see the source of energy with which we are concerned in this particular lecture; particularly, if you heat the material, for example, steel - you heat above 1200 degree Celsius.

So, let us see the sources of energy or source of energy; source of Thermal energy. Now, source of thermal energy is combustion of fossil fuel. Now, under fossil fuel, we have coal, we have natural gas, and an important fuel is oil; it is derived from petroleum; that is why I am not putting under fossil fuel but the derivative of petroleum - that is an oil. Again, I will mention that oil is derived from petroleum, but oil is frequently used in high temperature furnaces. So, these are the sources of energy.

Another important source of energy is Electrical energy, but, as long as electric energy is derived from combustion of fossil fuel, though one can say electric energy is also dependent upon the use of fossil fuel, around 70 to 75 percent of the electrical energy requirement is being met from combustion of fossil fuel - that is particularly coal. You use electrical energy and you say that I am using electrical energy, but it is coming from somewhere, where fossil fuel is used to generate electrical energy. Around 70 to 75 percent is the contribution of the electrical energy out of the total energy consumption.

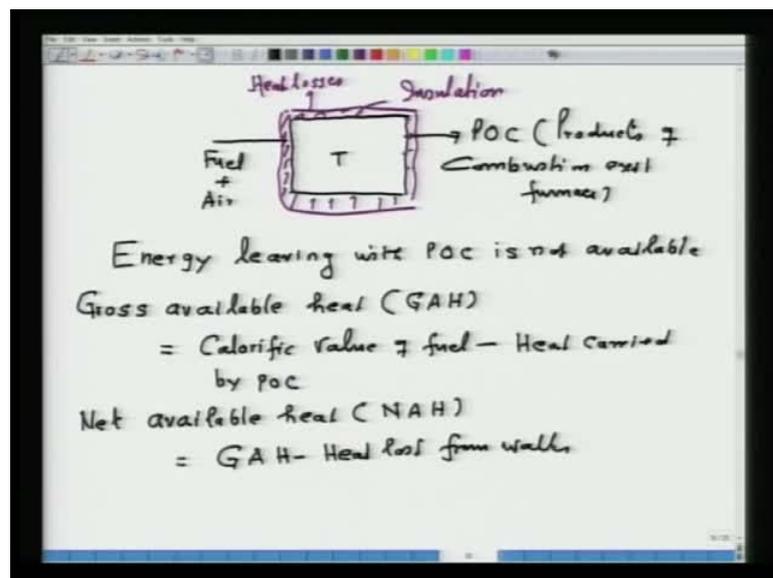
Now, having known the source of thermal energy which is the fossil fuel, the natural question comes before us. The question which I am posing - how is thermal energy derived from fossil fuel? Because fossil fuel - it contains potential energy. You bring the fuel from the mines; put it on the earth; it has energy, but it has only potential energy. So, the potential energy of the fuel - you have to convert it for the useful energy. So, the thermal energy from fossil fuel is derived by combustion of fuel.

By combustion of fuel, the potential energy of the fuel is obtained in order to heat the furnace or anything at a particular temperature; what is that involved in the combustion of fuel?

Now, as we see, the fossil fuel - they are containing most of the time, a large amount of Carbon. For example, coal - a good quality coal has 75 to 80 percent of Carbon; Oil - 85 to 86 percent of Carbon; Hydrogen is very very less; in natural gas, you also have C H 4, though Hydrogen is there, but still Carbon is sufficient amount.

Therefore, it is important to know, how thermal energy is obtained. So, what is being done is that, the potential energy of the fuel is converted into sensible heat of products of combustion. These products of combustion heat the furnace or so called material, which is required to be heated. Then, after heating, the products of combustion are discharged by the furnace. They are discharged into surrounding at a temperature which is equal to, at least equal to the furnace temperature.

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So, if I can represent, for example, If this is a furnace - just an enclosure, and if I supply a fuel which contains potential energy, I combust with air. Suppose, the temperature T , which is say 1000 degree Celsius, then on combustion, the potential energy of the fuel is converted into sensible heat of products of combustion. A heat exchange occurs between the products of combustion and the furnace enclosure and then the products of combustion exit the furnace. The products of combustion POC, which I call - Products of Combustion, exit the furnace.

What does that mean? That means - if the temperature of the furnace is, say for example, 1200 degree Celsius, then the minimum temperature of the products of combustion that are exiting the furnace, has to be equal to, at least equal to 1200 degree Celsius. If the temperature of the furnace is 1300 degree Celsius, then the temperature of POC which is exiting the furnace - it has to be around 1300 degree Celsius.

What does that mean? That means - the energy leaving with POC, say, energy leaving with POC is not available to perform any thermal energy operation inside the furnace. So, higher is the temperature of the furnace, higher will be the energy leaving with POC, and that is not available.

So, therefore, we can define now, two important parameters: one - we say, gross available heat, which I will call GAH - that is equal to calorific value of fuel minus heat carried by products of combustion. There is also an important term here because when you construct the thermal enclosure, then what you do? You put an insulating here (Refer Slide Time: 14:59). So, this is an insulating wall; you provide insulation and through the insulation, there will also be heat losses. Then another term is defined that is called Net available heat; net available heat, in short I will call NAH. That will be equal to gross available heat minus heat lost from walls of the furnace.

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Handwritten notes on a whiteboard:

Heat loss

$$\phi = -kA \frac{dT}{dx}$$

Multilayered wall k_1, k_2, \dots
 L_1, L_2, \dots

$$Q = \frac{T_i - T_o}{\frac{1}{h_i A} + \frac{1}{A} \sum \frac{L_i}{k_i} + \frac{1}{h_o A}}$$

For efficient utilization of fuel
 Capturing of heat & its utilization is
 important

Now, this heat loss through the walls of the furnace, say heat loss - that can be very easily calculated. Amount of Q which is a heat loss from minus KA dT by dX which is the **Four years law of heat conduction**, T is the temperature of the furnace wall and x is the thickness of the lining. If we have a multilayered wall because you can construct a wall not by a single material, but you can construct by two or three different materials. So, that is called a multilayered wall of thermal conductivity's K 1, K 2 and so on, and their thickness let us say L 1 and L 2 and so on.

Then, we can define the heat loss: That will be equal to T_i which is the furnace temperature minus T_0 that is the surrounding temperature upon thermal resistances which is h_i , where h_i is the heat transfer of coefficient from the combustion chamber to the wall plus thermal resistance offered by the multilayered lining that is equal to L_i upon K_i , where this is equal to 1 to n plus 1 upon h_0 into A , where h_0 is the heat transfer of coefficient from the wall to the surrounding. T_0 is a temperature surrounding and T_i is the temperature of the combustion chamber; that is, you can calculate the heat loss - This is for the multilayer lining.

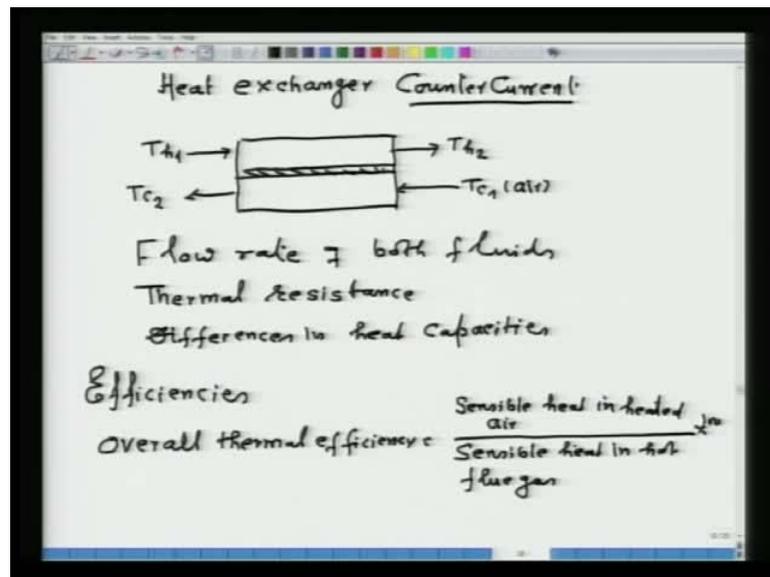
Now, given that there is a large amount of heat loss from the furnace, if we want to utilize the heat or the calorific value of the fuel, what is to be done? Because the calorific value of the fuel which is the potential energy, you wanted to obtain its thermal energy, you have combusted and you have noted that - the higher is the temperature, more amount of heat is the being lost.

So, what is the question that emerges? For efficient utilization of fuel, what is to be done? The heat which is exiting with the POC must be captured and then reused. So, for efficient utilization of fuel, capturing of the heat and its utilization is important. Because, by capturing the heat and its utilization, for example, back into the furnace, you are able to reduce the amount of fuel which is consumed; at the same time, you will be saving the fuel. As a result, you will be consuming less fuel. So, less Carbon will be emitted.

So, by capturing the heat, you are hitting the two birds with a single stone; you are reducing the fuel combustion; that means you are contributing to the energy security and you are saving the fuel. Since you are saving the fuel, you are doing less emissions of Carbon into the environment; that is, you are contributing to the so called environment sustainability - both these aspects, I will illustrate by giving a suitable example.

Now, when we say that the capturing of the heat is important, then we have to think how to capture the heat.

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Then, the basic philosophy of capturing the heat is designing a heat exchanger. Now, naturally, in this course, I may not be able to go into the details of heat exchanger. I request you to please see my lectures on fuel refractory and furnaces. There I have detailed heat exchanger; I will just give you the gist, so that I can use to illustrate the thing.

Now, imagine you have a heat exchanger. So, in the heat exchanger, a hot fluid is flowing. For example, at temperature T_{h1} - it is being out at T_{h2} and you have separated the hot fluid through a wall. Suppose this is a wall. Here (Refer Slide Time: 20:56) the cold fluid is entering for example, air, and hot air is being discharged and that can be used for heating into the furnace. So, you can imagine a heat exchanger where a hot flue gas is flowing counter current to the flow of air. So, this is typically a so called counter current heat exchanger.

Now, how the heat is being exchanged? As the hot fluid passes, the separating wall gets heated up and it transfers heat to the flowing cold air. So, it is essentially, the flow rate of the fluid; that is, flow rate of both the fluids, thermal resistance of the separating wall because if there is more resistance, less heat will be given to the colder fluid, and less will be heated up. Thermal resistance of the wall is also important. Another important thing is the differences in heat capacities.

Differences in heat capacities: These three will decide how high a flue gas can transfer and can heat the cold fluid to a temperature. Of course, higher is the temperature, better

is this, but then there is thermo dynamic limit. A flue gas which is passing at a temperature T cannot heat the cold air at a temperature greater than T; it is not possible; thermo dynamically, it is not possible. Therefore, we can define certain efficiencies say we define overall thermal efficiency.

Overall thermal efficiency - that is defined say sensible heat in heated air upon sensible heat in hot flue gas, multiplied by 100.

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The image shows a whiteboard with two mathematical formulas written in black ink. The first formula defines the Efficiency limit as the ratio of sensible heat in air at hot flue gas temperature to sensible heat in hot flue gas, multiplied by 100. The second formula defines Relative efficiency as the ratio of overall thermal efficiency to the efficiency limit, multiplied by 100.

$$\text{Efficiency limit} = \frac{\text{Sensible heat in air at hot flue gas temperature}}{\text{Sensible heat in hot flue gas}} \times 100$$

$$= \frac{m_a C_{pa} (T_f - 25)}{m_h C_{ph} (T_f - 25)} \times 100$$

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

Now, in this particular definition, it is inbuilt that, air can be heated above the temperature of the hot fluid, which is thermo dynamically not possible. Therefore, another limit is defined – it is called efficiency limit. Efficiency limit can be defined as sensible heat in air at hot flue gas temperature; that is the maximum you can get, hot flue gas temperature divided by sensible heat in hot flue gas.

Of course you have to multiply by 100 to get the percentage. Well, if you want to put it in a formula m_a is the mass flow rate of air C_{pa} is the heat capacity of the air and T_f is the temperature of the hot flue gas and 25 is the reference limit or the reference temperature. Similarly, m_h is the mass flow rate of hot flue C_{ph} is the heat capacity of the hot fluid or the flue gas and it is at temperature T_f . So, the maximum heat that you can, or the sensible heat in hot flue gas will be minus 25, where 25 degree Celsius is the reference temperature of my calculation. You can also take 298 Kelvin; that does not

matter at all; Of course, into 100. So, you can see, these both cancel out and ultimately efficiency limit is a ratio of the heat capacities of cold and hot flue.

Then, we define a relative efficiency. That means if you want to compare the two exchanges of different location, then it is equal to overall thermal efficiency; overall thermal efficiency upon efficiency limit into 100 - So, this definition, relative efficiency is equal to overall thermal efficiency upon efficiency limit into 100.

It can be used as a parameter to compare the heat exchangers of two locations because if we substitute the overall thermal efficiency and efficiency limit, then it simply turns out to be equal to sensible heat in air upon sensible heat in air at hot flue gas temperature. So, that is how the efficiency of the heat exchanger can be calculated. Now, I will simply explain by illustrating a problem.

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A heat exchanger receives hot flue gas at 1600 K and cold air at 298 K. The hot flue gas leave the exchanger at 900 K and air is heated to 1373 K.

15% of the heat of flue gas is lost to the surrounding.

$$\frac{C_{p,h}}{C_{p,c}} = 1.2$$

Heat balance

$$0.85 m_h C_{p,h} (T_{h1} - T_{h2}) = m_c C_{p,c} (T_{c2} - T_{c1})$$

$$0.85 m_h C_{p,h} (1600 - 900) = m_c C_{p,c} (1373 - 298)$$

$$\frac{m_c C_{p,c}}{m_h C_{p,h}} = 0.55$$

For example, let us say, a heat exchanger - let us consider that, a heat exchanger receives hot flue gas at 1600 Kelvin and cold air at 298 Kelvin because in this thermo dynamic definition, it is inbuilt that, whether the flow is counter current or co-current, the efficiencies are not affected (()) kinetic will be affected.

Now, the hot flue gases leave the exchanger at 900 Kelvin and cold air is heated to 1373 Kelvin. That means air is leaving the exchanger at 1373 Kelvin. It is also said that 15 percent of the heat of the flue gas is lost to the surrounding. That means what? That

means 85 percent of the heat of the flue gas is recovered to heat the air to the temperature which is 1373 Kelvin. It is also given C P h that is C P of hot flue gas upon C P air. Its ratio is given to 1.2 which is say, for this problem independent of temperature.

Let us do the heat balance. Now, let me illustrate the efficiency and so on. So, to solve this problem, let us do, first of all - heat balance. What this heat balance says is that, only 85 percent of the heat of the flue gas is recovered in air. So, that means 0.85 m h is the flow rate of the hot flue gas C Ph heat capacity of the hot flue gas into T h1 minus T h2 that is equal to m c C Pc T c2 minus T c1. So, if I substitute, I will be getting say 0.85 m h C Ph 1600 minus 1900 m c C Pc 1373 minus 298.

So, if I solve, then I will be getting, say, m c C Pc upon m h C Ph. This ratio is equal to 0.55. Now, with this ratio, I can now proceed to calculate the various efficiencies.

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Overall thermal efficiency

$$= \frac{m_c C_{pc} (1373 - 298)}{m_h C_{ph} (1600 - 298)} \times 100$$

$$= \frac{0.55 \times 1075}{1302} \times 100$$

$$= 45.4\%$$

Efficiency limit = $\frac{m_c C_{pc}}{m_h C_{ph}} \times 100$

$$= 55\%$$

Relative efficiency = $\frac{45.4}{55} \times 100$

$$= 82.5\%$$

So, first let me calculate overall thermal efficiency. Overall thermal efficiency, as already I have defined, straight away, I will be using the formula: That is equal to m c C Pc 1373 minus 298 upon m h C Ph 1600 minus 298 into 100; that will be equal to 0.55 into 1075 divide by 1302 into 100. So, overall thermal efficiency is 45.54 percent.

So, that is how you will be calculating the problems, whenever you come across to calculate the efficiency of the heat exchanger. Now, another thing is that, to calculate efficiency limit.

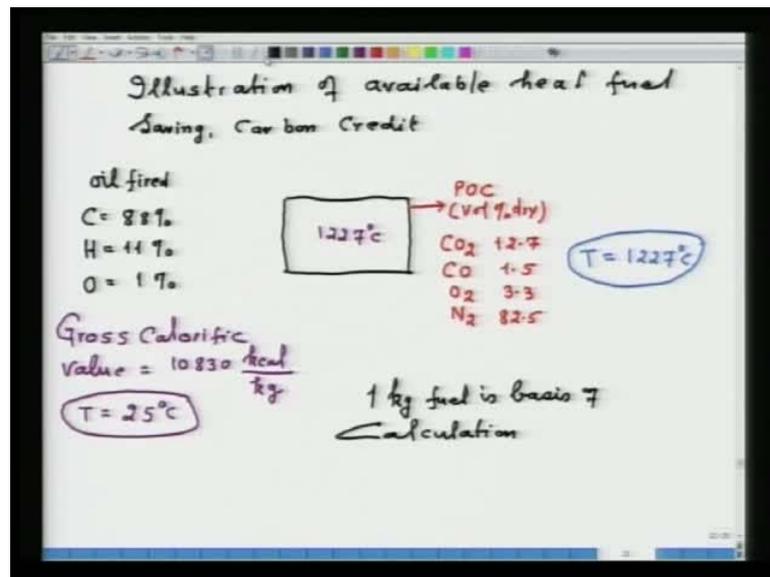
Efficiency limit: now, the physical significance of efficiency limit is very clear; that means each heat exchanger has some upper limit to which it can exchange the heat of the hot flue gas to the cold flue gas thermo dynamically because you cannot heat the cold air to a temperature above the temperature of the hot flue gas; thermo dynamically it is impossible.

That is what the physical significance of efficiency limit (()) and we have seen in the formula that the efficiency limit it is simply becomes equal to $m_c C_{Pc}$ upon m_h into C_{Ph} into 100. The temperature from both the sides, numerator and denominator - they cancel it. So, the efficiency limit in this particular case is equal to 55 percent. That means in this particular problem, the efficiency limit of that designed heat exchanger is only 55 percent and that depends totally on the difference in the heat capacities; higher is the difference, less will be the efficiency limit; so, that is all.

Then, we define another term which is the relative efficiency. The relative efficiency you have to define as overall thermal efficiency divided by the efficiency limit into 100. So, with this, we get 45.4 upon 55 into 100. So, your efficiency limit is now 82.5 percent. That is how you can calculate the efficiencies of heat exchanger because in several calculations, when you want to capture the heat and you want to recycle the heat for the heating of air and that pre heated air is supplied in the furnace, then you must be able to calculate what is the efficiency of the of the heat exchanger. Then you have to calculate the efficiency of the heat exchanger with one of the formulas that I have given. This is one illustration.

Now, another illustration. That, I am going to illustrate on the fuel saving and the Carbon credit. So, let me take the next problem.

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That is the illustration of available heat, say illustration of available heat fuel saving. Let me touch also Carbon credit.

Let us see, how we can calculate all this. Now, for this, naturally we have to perform heat balance and material balance. For that, let us consider a furnace and the furnace is operating at 1227 degree Celsius; that is, the temperature of the combustion chamber of the furnace is 1227 degree Celsius; this furnace is oil fired. Furnace is oil fired and the composition of the oil Carbon - that is equal to 88 percent, Hydrogen - that is equal to 11 percent, and Oxygen - that is equal to 1 percent. It is also given the Gross calorific value of fuel is given gross calorific value of fuel that is given to you and that is equal to 10830 kilo calorie per kg of the fuel.

The products of combustion - the POC, I am writing short form of products of combustion. Their percent is given; volume percent, dry volume percent and this composition is CO₂ CO O₂ and Nitrogen. CO₂ is 12.7 percent; this is 1.5 percent; O₂ is 3.3 percent and Nitrogen is 82.5 percent. It is combusted with air. Now, we have to calculate the various available heat fuel saving and so on.

Now, for this purpose, what we will do? Let us take, say 1 kg is the basis of our calculation. 1 kg fuel is our basis of calculation. Now, since we are going to perform heat balance also, it is also important to mention the temperature at which the materials are leaving and exit in the furnace. For this purpose, I am considering that, the temperature

of supply of the oil is 25 degree Celsius. The products of combustion - they are discharging at temperature T that is equal to 1227 degree Celsius.

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a) GAV | kg of fuel
 Y kg mole is POC
 Carbon balance:
 $Y = 0.516 \text{ kg mole}$

Heat to POC:
 $14780 \times 0.0656 + 0.00774 \times 9291$
 $+ 3711 \times 0.01703 + 0.4257 \times 9186$
 $+ 0.055 \times 22034$
 $= 6330 \text{ kcal}$

GCV of fuel = GCV given - CV of CO
 on incomplete combustion = $10830 - (0.00774 \times 67.6 \times 10^3)$
 Combustion = 10307 kcal

$H_{1500} - H_{298}(\text{CO}_2) = 14780 \frac{\text{kcal}}{\text{kg mole}}$
 $H_{1500} - H_{298}(\text{CO})$ 9291
 O₂ 3711
 N₂ 3186
 H₂O(l) 22034
 $\text{CO} + \frac{1}{2} \text{O}_2 = \text{CO}_2$
 $-\Delta H^\circ = 67.6 \times 10^3 \frac{\text{kcal}}{\text{kg mole}}$

Throughout the temperature of discharge, now 1 kg fuel is the basis of calculation. So, first of all, let us calculate gross available heat per kg of fuel. Now, as you have noted down in the problem that the products of combustion contain Carbon monoxide; that means there is an incomplete combustion.

So, in the part, what we are going to calculate is the gross available heat per kg of the fuel, as given in the problem. But, the note is that, there is an incomplete combustion because CO is in POC. So, first of all, let us consider say Y kg mole is POC. Y kg mole is amount of POC. Then, on several occasions, we have done Carbon balance. So, if I do Carbon balance, I can find out the amount of POC. So, if I do Carbon balance, Carbon balance will give me the amount of POC Y - that is equal to 0.516 kg mole.

Now, once I have got the amount of POC which is 0.516 kg mole, I can calculate the amount of CO₂, the amount of CO, O₂, Nitrogen; do not forget to calculate Hydrogen which is coming exclusively from Hydrogen of the oil. So, you have to make that also to your calculation to make the product of combustion complete.

Now, the next thing that you have to calculate is heat to POC. In order to calculate heat to POC, what is required is that, you should know the value of the heat content that is the

sensibly heat of CO₂ or the heat content of CO₂ at 1227 degree Celsius. What I have done is - I am giving you the value of products of combustion at the temperature at which they are discharged.

The reference point in all thermo dynamic values is 298 Kelvin or 25 degree Celsius. So, as such I am giving you here H₁₅₀₀ minus H₂₉₈ CO₂ that is equal to 14780 that is in kilo calorie per kg mole. Similarly, H₁₅₀₀ minus H₂₉₈ for CO for O₂, then for N₂ and for H₂O liquid.

All you can calculate from their C P value CO that is 9291 9791 9186 and 22034. So, once these values are given to us, then we can calculate the heat to POC. Heat to POC will be simply the moles of the products of combustion multiplied by the respective value of the sensible heat. So, we get heat to POC - that will be 14780 into 0.0656 plus 0.00774 into 9291 plus 9791 into 0.01703 plus 0.4257 into 9186 plus 0.055 0.055 is coming H₂ H₂O of the fuel into 22034. So, heat to POC - that will be 6330 kilo calorie.

So, that is how you can calculate the heat to POC. Now, important thing. Here, while calculating that calorific value of the fuel because the gross available heat per kg of the fuel is the caloric value minus heat to POC, in this particular section which we are calculating, when the products of combustion contains Carbon monoxide, we cannot use the gross calorific value which is given, which is 10830 kilo calorie per kg, because this value is given on complete combustion. But part of the combustion is not complete because CO is there. So, you have to subtract the calorific value; mind you, the calorific of CO from the gross calorific value of the fuel which is given to you. So, that brings us say GCV of fuel. GCV of fuel - that is equal to GCV which is GCV of fuel on incomplete combustion in our problem. On incomplete combustion, that will be equal GCV which is given for complete combustion minus calorific value of Carbon monoxide; so that is an important thing.

Now, the calorific value of Carbon monoxide you can calculate - CO plus half O₂ that is equal to CO₂. So, minus delta H_{naught} say combustion - that will be equal to 67.6 into 10 to the power 3 kilo calorie per kg mole. That is how because heat of formation of CO₂ is separate from heat of formation of CO and then you get 67.6 into 10 to the power 3.

What we will do now? GCV given is 10830 minus calorific value of CO. You have to subtract - that will be 0.00774 into 67.6 into 10 to the power 3. So, that brings to us the gross calorific value available for that is 10307 kilo calorie.

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$(GAH)_1 = 10307 - 6330 = \underline{3977 \text{ kcal}}$
 b) Complete Combustion
 $(GAH)_2$ POC = $\begin{matrix} \text{CO}_2 = 0.07334 \\ \text{O}_2 = 0.01316 \\ \text{N}_2 = 0.4257 \end{matrix}$ $\begin{matrix} \text{kg moles} \\ \\ \end{matrix}$ $\underline{1227^\circ\text{C}}$
 Heat to POC = 6328 kcal
 $(GAH)_2 = 10830 - 6328 = \underline{4502 \text{ kcal}}$
 c) fuel saving on Complete Comb.

$$\text{Fuel Cons. kg/hr} = \frac{\text{GAH Required/hr}}{\text{GAH/kg of fuel}}$$

$$F_1 = \frac{(GAH)_1/\text{hr}}{3977} ; F_2 = \frac{(GAH)_2/\text{hr}}{4502}$$

Next, we have to calculate the gross available heat that is what is being asked. So, I will put it. Let us calculate gross available heat and that will be equal to 10307 minus 6330 that is equal to 3977 kilo calorie. Now, in order to compare this b part, let us consider complete combustion.

Let us considered complete combustion with same air fuel ratio, as we have employed in part a. We have not changed any air fuel ratio. Only because of better mixing, we could obtain complete combustion.

Now, let us calculate, what will be the gross available heat for this case. Let me put that is equal to 2. Since I am mentioning complete combustion, that means CO will not be there. So, I have to recalculate the products of combustion. The products of combustion will be now CO 2 and that will be equal to 0.07334 kg moles, because here, I have to add CO 2 which was originally... and CO moles also.

Then, since the Oxygen which was rare in case a in the products of combustion, partly it will be utilized to combust CO. So, now, the Oxygen in POC will be less; so, that will be

equal to 0.01316. Nitrogen, of course, will not change because we are not changing the air fuel ratio; that will be 0.4257.

Now, we have got the renewed moles of products of combustion. They are exiting at the temperature; we are taking the same 1227 degree Celsius. Now, we can calculate the gross available heat 2. What we have to do? the gross calorific value will remain the same because it will not change. Only heat to POC you have to calculate; I have already given you the values of the various products of combustion at 1227 or 1500 Kelvin. So, you can calculate those values.

On calculation, the heat to POC in this particular case comes out to be equal to 6328 kilo calories. So, now, the gross available heat which is for complete combustion will be equal to 10830 minus 6328. So, that will be 4502 kilo calorie. So, you are seeing there is an increase in the gross available heat by just doing a good mixing in the combustion chamber on complete combustion.

Now, we can calculate C part. We will calculate fuel saving on complete combustion. Now, we can define. Fuel consumption is normally defined in kilogram per hour. It can be defined as a gross available heat required per hour upon gross available heat per kg of fuel. So, now, we can calculate F 1 which is the fuel consumption due to incomplete combustion - that will be equal to now.

A gross available heat required per hour will be same as gross available heat per kg of the fuel. So, I will put it as gross available heat required per hour upon, in the first case we have 3977.

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The image shows a whiteboard with handwritten calculations. At the top, the ratio $\frac{F_1}{F_2} = \frac{4502}{3977}$ is written. Below it, 'Fuel saving = 13.2%' is written with '13.2%' underlined. The next line says 'If 10,000 kg is fuel consumption.' followed by 'fuel saving = 1320 kg'. Below that, it states 'One metric ton of CO₂ reduction is equivalent to 1 Carbon credit and is equivalent to 270 kg C'. At the bottom, 'CARBON CREDITS 5' is written and underlined twice.

We can calculate now F_2 , that is equal to our complete combustion. So, G - gross available heat required per hour divided by 4502. Now, when the furnace is operating at the requirement of the gross available, it is same in both the cases. Therefore, what we can do, we can take the ratio of F_1 upon F_2 . The ratio of F_1 upon F_2 and that is equal to 4502 upon 3977. So, with this, now fuel saving – that, of course, 1 minus this and multiply by 100 that is equal to 32. 13.2 percent. So, you can see, just by introducing the measure of complete combustion, you are able to save 13.2 percent of the fuel.

Now, just to illustrate the concept of Carbon credit, for example, if we consider say if 10000 kg is the fuel consumption, then fuel saving will be how much? 13.2 percent per kg. So, for 10000, it will be 1320 kg. So, you will be saving 1320 kg fuel on account of complete combustion.

Now, about the Carbon credit, it is said that 1 metric ton of CO₂ reduction is equivalent to is equivalent to 1 Carbon credit or (()) and is equivalent to and is equivalent to 270 kg Carbon. That means if you are saving 270 kg of Carbon, then you are earning 1 Carbon credit. So, Carbon credit in this case would be, on account of complete combustion.

In this particular problem, that will be approximately 1320 by 270; it will be approximately 5. So, that is how the fuel saving can lead to two things simultaneously: saving of fuel which leads to energy security and reduction in the Carbon emission into

the environment. That contributes to the environment sustainability. In the next lecture, I am going to give you more problems on the industrial furnaces.