Fuels, Refractory and Furnaces

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Lecture No. # 33
Exercises on Heat Flow in Furnaces And Heat Exchangers

Earlier lectures on heat transfer from 28th lecture to 32, I have introduced you to the concept of heat transfer and application to heat exchanger, heat flow through furnaces and so on, radiation principle also; few problems, I have also solved in those lectures, to appreciate the fundamentals; today, I thought that, let me explain more, the theoretical concepts, by solving some more problems.

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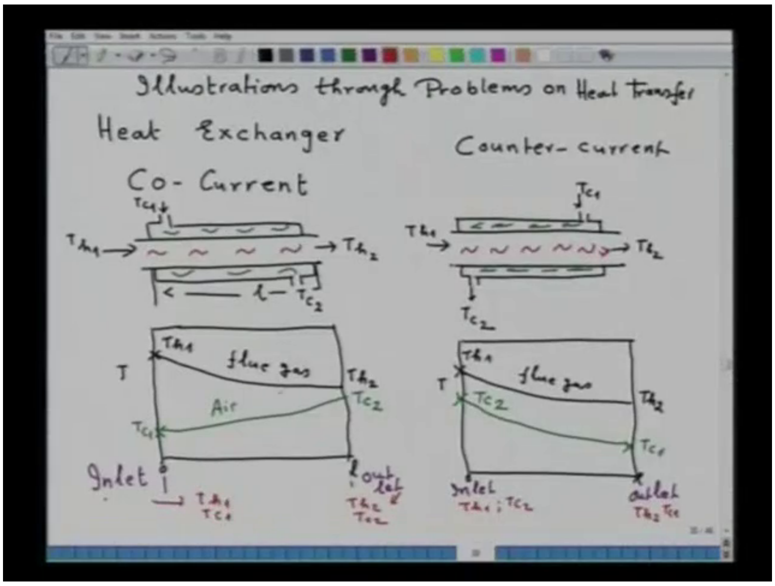

So, I have selected one of the important area, to illustrate the theoretical concept and its application, is the heat exchanger. Now, in fact, it is known that, all fuel fired furnaces, the thermal energy of the fuel is available in the form of product of combustion, as you have seen in the lecture on combustion. The products of combustion transfer their energy to the furnace, heat the product to the desired temperature, and depending on the furnace temperature or product temperature, the products of combustion exit the furnace. From energy, security point of view, also from environment sustainability point of view, as I have illustrated in my introductory lecture that, it is necessary to recover the heat of products of combustion, particularly, when the POC are exhausted at a high temperature, for example, 700 or above that degree Celsius. However, heat recovery at lower temperature is also important. So, it is from that consideration, high temperature industrial furnaces, those operating on fuel fired ones, or where the thermal energy is derived by combustion of fossil fuel, nowadays, it has become very important that, how to economize the consumption of natural energy resources, so that, for the future, the energy resources can be conserved. And, it is in this relationship, the government has enunciated several steps like carbon credit, carbon offset, clean development mechanism and so on, to encourage the entrepreneurs working on high temperature furnaces, to take measures to economize the fuel consumption.

Some of the idea of clean development mechanism, I have already introduced, when I was taking the lecture on carbonization, that is, the (( )) coal. Now, heat exchanger is one of the important concept, to recover the heat of product of combustion. Essentially, the fundamentals of heat exchanger, I have introduced in the lecture 31, 32; you can collect those fundamentals. The one of the important objective of heat exchanger is to exchange the heat between the hot fluid and the cold fluid; that is, the full reason. It is necessary for this that, you have to optimize the dimensions of heat exchanger; by the dimension, I mean the length of the heat exchanger for a given cross section area of the heat exchanger. Length is important because, that will decide the residence time, whereas, the cross sectional area will decide the velocity of the fluid, with which the fluid is moving in the heat exchanger. So, both will decide the residence time of the fluid, of the hot fluid and as well as cold fluid, and depending on the optimization of the residence time, the heat recovery is possible. So, those fundamentals, I have illustrated. Now, one can think of, for recovery of heat from flue gases, two possible ways; in one way, the hot fluid is flowing co-current to the air; that is, for example, you want to preheat the air, or you want to preheat the water, or whatever the fluid you want to have; one way is that, a co-current and another is the counter current. The situation can be represented by this.

For example, in a co-current flow, in a co-current flow, suppose, this is an heat exchanger, or you can call it as recuperator, where this is the hot fluid is flowing, say at temperature T h 1, and it is discharged at temperature T h 2; and here, in the co-axial tube, the cold fluid is entering; this is at temperature T c 1 and at temperature T c 2; and, this is the length of the heat exchanger; that means, here, a hot fluid is flowing this way, whereas, cold fluid is flowing this way. Ultimately, it is out. So, this is a co-current. Now, in another, we can also think of a counter current. In a counter current, it goes like this. So, I have illustrated, but for the sake of solution of the problem, I will just repeating important concepts. So, this is the one. So, here, you have hot gas, which is at temperature T h 1; this is at T h 2; here is the cold fluid; it could be air, or it could be water, because they want to exchange; the T c 1, and this the, here T c 2.

That is, this is the direction of flow of hot gas and this is the direction of flow of cold air. And, there, I have also said that, in utilizing the expression for heat exchange, it is important that, the temperatures are chosen; they are the inlet and exit temperatures of the heat exchanger. While teaching this course for several times, at IIT Kanpur, invariably I observed that, most of the students, they do error in substituting the temperatures. They think that, the temperatures involved in the expression, they correspond to the fluid temperature. No; remember, it is strictly no. The temperatures involving in the expressions are the temperatures at the inlet of the exchanger and at the outlet of the exchanger. So, if we now plot, for example, here, we take on this axis as T, temperature; here, it is the zero length, at the entry and here is the length of the exchanger. Now, I just complete it; same thing, I will do it also here; this is the length of the exchanger and here, I take the temperature. Now, in the co-current, this my point is T h 1; this is my T h 1. So, this 0, that, let us call, this is inlet of the heat exchanger; this is the inlet and this is the outlet; or, you can call entry and exit temperature. So, same way for the counter current one, this is the inlet and that is the outlet. Mind you, these are the inlet and outlet of exchangers. So, in this way, this one is a counter current; this is the counter current.

So, if you want to show, how the temperatures are varying at the inlet and exit, and those temperatures are to be substituted, mind you, because several students do these type of mistakes invariably; that is what I have observed. So, I thought I will explain to you. So, how the temperature of hot gas, it varies, say entry, then, it goes somewhere here, and this is the temperature T h 2. Now, similarly, for air, this is the one T c 1, and the air temperature, it increases and goes to T c 2. Now, also remember that, the temperature of hot air can never exceed, at any point, the temperature of the flue gas. So, this is, for example, the variation of temperature for flue gas and this one, for example, the variation of temperature of air. Now, this is also important to note that, the students also do the mistake while showing the variation of temperature, they sometimes cross the air temperature at some length of the heat exchanger to the temperature of the flue gas, which is impossible; air cannot be heated, at any length of the heat exchanger to the temperature above that of the flue gas. Remember, and that mistake should not be done. So, that is how, this is for the co-current and in the co-current, you notice that, the inlet temperatures are T h 1 and T c 1, whereas, outlet temperatures are T h 2 and T c 2. These are the inlet temperatures and these are the outlet temperatures. Now, let us see how, for a counter current this looks. In a counter current, say we have here, no doubt, this is the T h 1 and this is the variation of flue gas T h 2; this is that of the flue gas. Now, here, the T c 1 is somewhere here; remember, this is the T c 1 and the temperature increases and there you have, here you have T c 2.

So, the inlet temperature of a counter current heat exchanger, that is T h 1 and T c 2, whereas, that of the outlet is T h 2 and T c 1. So, that is the main difference while applying the equations which we have developed for heat exchange in counter current, or co-current flow of the flue. The temperatures, again and again I will say that, the temperatures are inlet and exit of the heat exchanger; that is the important thing. And, as I had said that, the difference in temperature between flue gas and air, or between, whether it is co-current or counter current, is because of the irreversibilities that is introduced by thermal resistance of the wall of the heat exchanger, and because of the flowing flue. So, those things are to be optimized in order to obtain the maximum heat transferred from flue gas to the heating fluid. So, that is the important thing, please remember.

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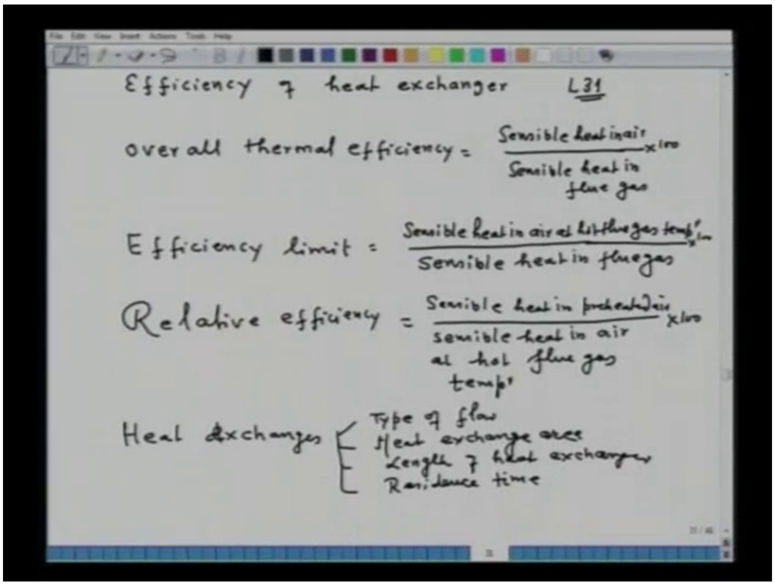

Efficiency of heat exchanger L31

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

$$\text{Efficiency limit} = \frac{\text{Sensible heat in air at hot flue gas temp}^{r}}{\text{Sensible heat in fluegas}} \times 100$$

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

Heat exchanges
- Type of flow
- Heat exchange area
- Length of heat exchanger
- Residence time

Now, having said this thing, as also I have said that, in order to define the efficiency of heat exchangers, I have introduced these formulas; let me write once again. So, efficiency of heat exchangers, refer details in lecture number 31; these details are given and I am just giving you the formula for use in the solution of the problem. There we have defined overall thermal efficiency, overall thermal efficiency and this, we have defined as sensible heat in air, sensible heat in air upon sensible heat in flue gas; you recall that, sensible heat in flue gas multiplied by 100. We had also defined the so called efficiency limit, and the concept of efficiency limit is that, an exchanger of given length and given cross sectional area can recover the maximum amount of heat; and, this efficiency limit, we have defined as the sensible heat in air, sensible heat in air at hot flue gas temperature, because this is the maximum that you can derive it, upon sensible heat in flue gas. And, this efficiency limit is a term here, one can note that, what is the maximum amount of heat that can be recovered from the flue gas.

Then, we also defined the relative efficiency; we also defined the relative efficiency, and, this relative, this relative efficiency, in fact, it compares the behavior of different heat exchangers in different locations; because this relative thermal, relative efficiency, it tells you how much amount of air, or how much amount of heat is being extracted by a particular exchanger and that is defined, as you recall, that is, sensible heat in air, sensible heat in preheated air upon sensible heat in air, in air, at hot flue gas temperature, hot flue gas temperature into 100. So, really, if you want to compare, how the heat exchangers are working in two locations, then, you just calculate the relative efficiency and one which has a higher efficiency, that works better as compared to the another one.

Now, also to note that, heat exchange, it depends upon, heat exchange, it depends upon the type of flow, that is, whether it is co-current or counter current; but in our derivation which I have derived for the heat flow through the exchanger, this co-current or counter current does not enter into our derivation; (( )) that whether co-current or counter current, it does not affect the derivation part of it; but the co-current or counter current, it affects the inlet and exit temperature of the heat exchanger; that point is to be noted. Heat exchange also depends upon the heat exchange area; heat exchange area, because you require certain minimum area for transfer of heat; then, length of heat exchanger; length of heat exchanger; and residence time of cold fluid and hot fluid and definitely, the residence time is being determined, when the cross section area of the exchanger area is fixed and the flow rate will determine…So, what I mean, the problem now can be formulated considering these four points under consideration.

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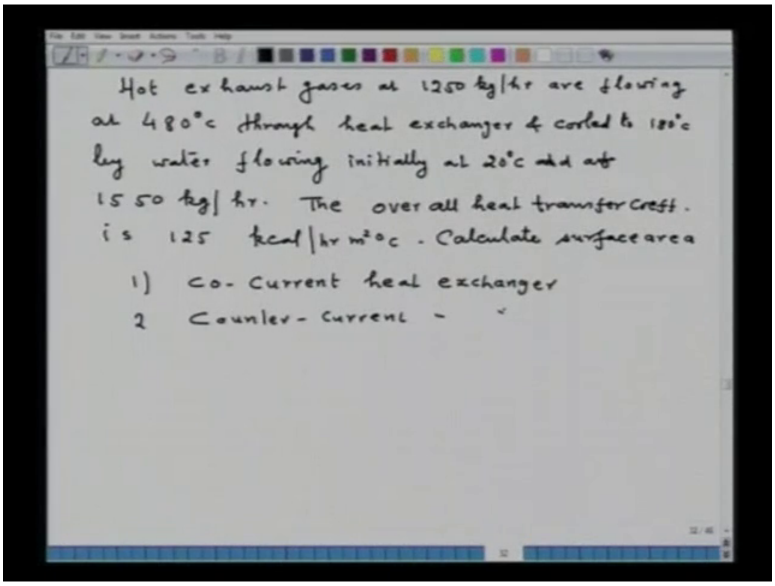

Hot exhaust gases at 1250 kg/hr are flowing at 480°c through heat exchanger & cooled to 180°c by water flowing initially at 20°c and at 1550 kg/hr. The over all heat transfer coeff. is 125 kcal/hr m²°c. Calculate surface area

1) Co-Current heat exchanger
2 Counter-Current " "

So, let me take one problem to illustrate this thing. Let us take it for example, hot exhaust gases, hot exhaust gases at 1250 kilogram per hour are flowing at 480 degree Celsius through heat exchanger and cooled to 180 degree Celsius by water flowing initially at 20 degree Celsius and, and at, and at 1550 kilogram per hour. The overall heat transfer co-efficient, the overall heat transfer co-efficient is 125 kilo calorie per hour meter square degree Celsius.

Calculate surface area, calculate surface area required under two condition; one condition, when the heat exchanger is co-current type; that is for co-current heat exchanger, and when heat exchanger is of counter current type. So, this is what we have to find out, the area which is required. So, as such, in order to proceed this problem, first of all, we have to know what are the inlet and exit temperatures of the heat exchangers.

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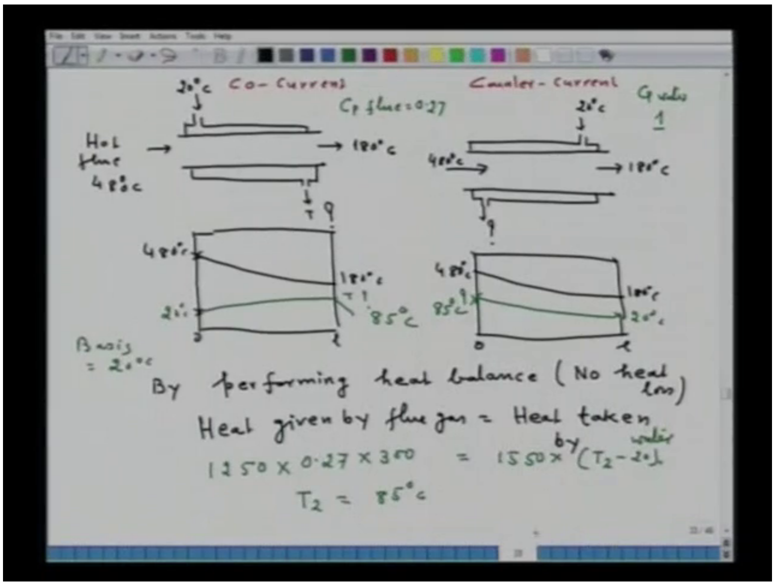

By performing heat balance (No heat loss)

Heat given by flue gas = Heat taken by water

$1250 \times 0.27 \times 360 = 1550 \times (T_2 - 20)$

$T_2 = 85°c$

So, for that, we again schematically sketch; say, this is the one; here, hot flue gas is at 480 degree Celsius, coming out at 180 degree Celsius; here, water is flowing at 20 degree Celsius; this temperature is not known; exit temperature is not known; so, this is definitely a sort of co-current here. Similarly, for counter current, you can also draw it. So, counter current, this is entering at 480 degree Celsius, going out at 180 degree Celsius; water is entering at 20 degree Celsius. We have to find out the exit temperature, these are not known. So, if you want to represent, over the length of the heat exchanger, just now I had explained. So, this is 0; this is the length l; 0 and length l, this is for the counter current, for the counter current. Now, the hot flue gas, its temperature will vary, for example, from 480 degree Celsius, it will go to 180 degree Celsius; and here, it is starts from, say, this water starts from 20 degree Celsius and we have to find out, what is this temperature; in case of here, the hot flue gas goes this way; this is 480 degree Celsius; this is 180 degree Celsius; whereas, this water is, here is 20 degree Celsius and we have to find out this particular temperature. So, that is what, to start such type of problems with representation is very good; if you can represent it, then, you know what is to be done. Now, first of all, we have to find out the outlet temperature of water, and for outlet temperature of water, we can find out by doing the heat balance.

So, by performing heat balance, by performing heat balance, what does it mean; that means, heat given up by the flue gas, that will be equal to heat taken up by the water, on the assumption that no heat losses are there; on the assumption no heat loss are there. Then, heat given up by the flue gas, that will be equal to heat taken by the water. So, we can write down as a qualitative statement, a heat given by flue gas, that will be equal to heat taken by water. What I have to do, I have to now simply substitute heat given by flue gas. So, if I substitute, say, by flue gas, the flow rate is, for example, 1250. Let me give you one more value, that you will be requiring. So, let us take C p of flue gas, that is, take equal to 0.27 and C p water, let us take equal to 1, in S I units. So, 1250 into 0.27, heat taken by water. So, water is flowing at the rate of 1550 into 1 into T 2 is the temperature of exit, water at the exit, minus 20. So, our basis of our calculation is, say, 20 degree Celsius. So, if you solve this equation, we will be getting the, for example, T 2, that will be equal to 85 degree Celsius. So, this temperature, now, we have determined equal to 85 degree Celsius; this is here, 85 degree Celsius.

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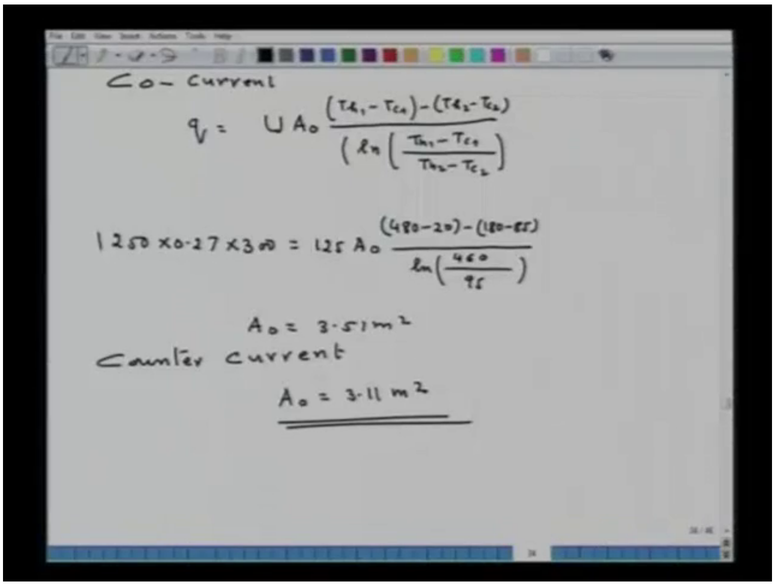

Co-current

$$q = U A_o \frac{(T_{h_1} - T_{c_1}) - (T_{h_2} - T_{c_2})}{\left(\ln \left(\frac{T_{h_1} - T_{c_1}}{T_{h_2} - T_{c_2}} \right) \right)}$$

$$1250 \times 0.27 \times 300 = 125 A_o \frac{(480-20)-(180-85)}{\ln \left(\frac{460}{95} \right)}$$

$$A_o = 3.51 m^2$$

Counter current

$$\underline{\underline{A_o = 3.11 m^2}}$$

Now, we can apply our equation, that is, q U A 0, T h 1 minus T c 1, minus T h 2 minus T c 2, upon l n T h 1 minus T c 1, upon T h 2 minus T c 2, this is for the both co-current or counter current; all that we have to substitute are the proper value of the temperatures. So, if we do that, now, the value of q we know; that is, 1250 into 0.27 into 300; U is given to us, 125; A 0 we have to find out. Now, for co-current, I am writing down for co-current, 480 minus 20, minus 180 minus 85, upon l n 460 upon 95. So, if I solve, I will be getting A 0, that is equal to 3.51 meter square; that is for the co-current. Now, the value which I have substituted, from that value itself we can know that, these are for the co-current, because that you can see, what inlet and exit value I have substituted in the equation, so, it is for the co-current. Now, similarly, I substitute for countercurrent; similarly, I substitute for countercurrent. So, for countercurrent, I will leave this exercise to you; you substitute the proper temperatures and you will be getting A 0, that is equal to 3.11 meter square. So, please substitute the correct value of the inlet and exit temperature of the heat exchanger. I am leaving this exercise; you should do it and to get the answer, that is 3.11 meter square.

Now, what this result means? Though in the derivation of the heat transfer in the heat exchanger we have said that, the derivation, it does not take into account co-current or countercurrent, in terms of the temperature. But now, we can see that, the co-current or countercurrent, they will be good or bad, depending upon the how much heat exchange area is required. So, you have seen a countercurrent exchanger requires less heat exchange area as compared to a co-current heat exchanger, and it is well known, the heat transfer by the flowing fluid will always be better, when there is a countercurrent as compared to when there is a co-current. So, that is what the illustration to this particular problem. I will take one more problem, because in industry, for high temperature heat recovery, sometimes regenerators are used. Now, the recuperators are used when the temperature of the hot flue gas is lower, because they are of the metallic construction and hence, lower, they are suitable for lower hot flue gas temperatures. If you want to go for higher flue gas temperature, then, they regenerators are used. And, as I have said that, the regenerators, their construction is that of the brick (( )). In the heating cycle, the flue gas flows and heat is recovered in the brick. In the cooling cycle, air passes and heat is transferred from the brick to the air. Keeping this analogy, we have said that, thermal resistance are comparable to that of the recuperator and we have said that, the similar expression will be applicable, as we have derived for considering the heat exchanger, say, in case of recuperator. So, let me illustrate by taking an example of a regenerator.

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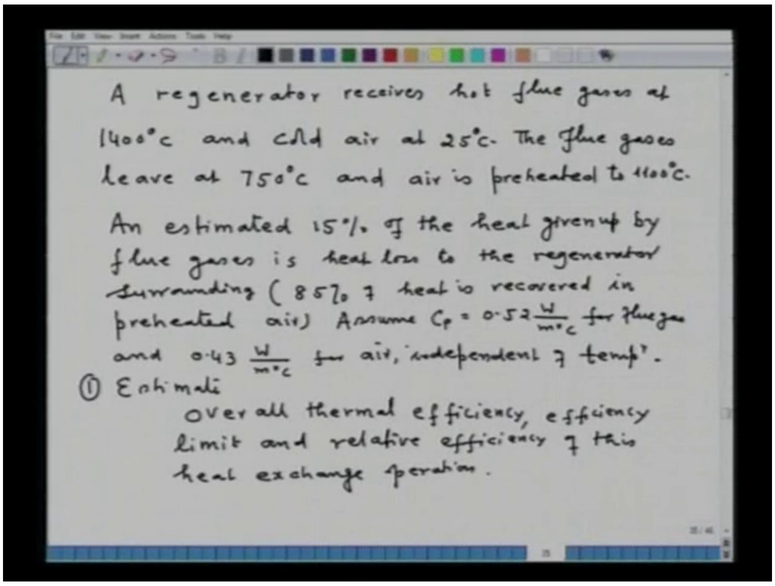

A regenerator receives hot flue gases at 1400°c and cold air at 25°c. The flue gases leave at 750°c and air is preheated to 1100°c.

An estimated 15% of the heat given up by flue gases is heat loss to the regenerator surrounding (85% of heat is recovered in preheated air) Assume $C_p = 0{\cdot}52 \frac{W}{m°c}$ for flue gas and $0{\cdot}43 \frac{W}{m°c}$ for air, independent of temp'.

① Estimate

overall thermal efficiency, efficiency limit and relative efficiency of this heat exchange operation.

So, a regenerator, a regenerator receives hot flue gases, hot flue gases at 1400 degree Celsius and cold air, and cold air at 25 degree Celsius. The flue gases leave, the flue gases leave at 750 degree Celsius and air is preheated, air is preheated to 1100 degree Celsius. An estimated, an estimated 15 percent of the heat, of the heat, given up by flue gases, by flue gases is heat loss to the regenerator surroundings, regenerator surroundings; that means, 85 percent of heat, 85 percent of heat is recovered in preheated air, in preheated air. You may assume, assume C p, that is equal to 0.52 watt per meter degree Celsius for flue gas and 0.43 watt per meter degree Celsius for air, independent of temperature, independent of temperature. Now, estimate, first, part a, part a, estimate overall thermal efficiency, overall thermal efficiency, efficiency limit, efficiency limit and relative efficiency, relative efficiency of this heat exchange operation, of this heat exchange operation. So, this is an illustration of calculation of overall thermal efficiency, efficiency limit and relative efficiency. Then, in the next part, we will see, how to calculate the other parameters. So, this is the problem. I am presenting a solution to this problem, but my request to the listeners of this video lecture, or my request, or my appeal to the listener of the video lecture is that, please solve this problem yourself, before seeing the solution of the particular problem; because if you can solve this problem, many things would be clear. So, I again appeal to the listeners of this video lecture, to please solve this problem without going into the solution. So, let me solve this particular problem. Now, here, flow rates of air, or flue gas, they are not given. So, as such, seeing the problem, the calculations of overall thermal efficiency, relative efficiency limit and efficiency limit, it is not possible to calculate; because those values are required, when you want to calculate the efficiency, (( )), so on, so forth.

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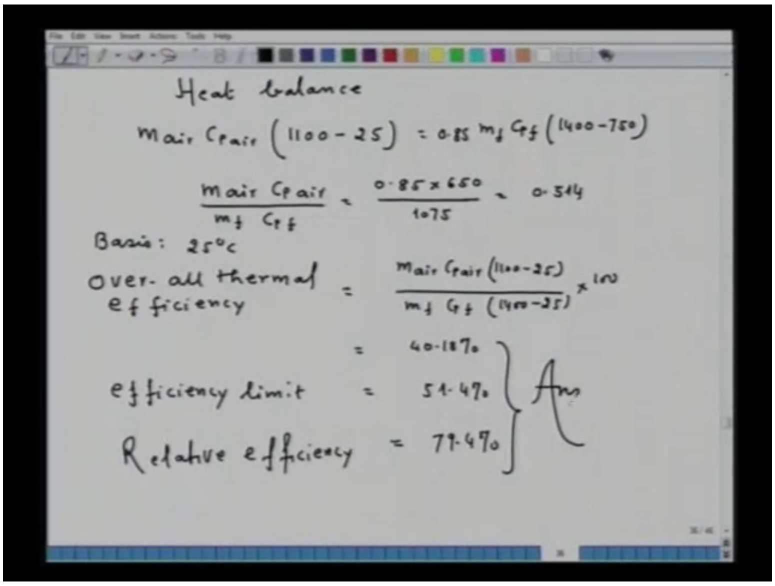

Heat balance

$$m_{air} C_{p\,air} (1100 - 25) = 0.85\, m_f C_{pf} (1400 - 750)$$

$$\frac{m_{air} C_{p\,air}}{m_f C_{pf}} = \frac{0.85 \times 650}{1075} = 0.514$$

Basis: 25°C

$$\text{over-all thermal efficiency} = \frac{m_{air} C_{p\,air} (1100 - 25)}{m_f C_{pf} (1400 - 25)} \times 100$$

$$= 40.18\%$$

$$\left.\begin{array}{ll} & 40.18\% \\ \text{efficiency limit} = & 51.4\% \\ \text{Relative efficiency} = & 79.4\% \end{array}\right\} \text{Ans}$$

So, further, if you do heat balance, the clue to solve this problem is the heat balance. If you do the heat balance, then, you can get some of the hidden variables like that, say, m air, that is heat recovered by air, m air, C p air, 1100 minus 25; that is equal to m flue gas, C p flue gas, recovered 1400 minus 750. Now, heat given by the flue gas, that will be equal to heat taken by the air; but now, here, it is given that, only 85 percent of the heat given by the flue gas can be recovered in air; so, we have to multiply this by 0.85. So, this is by starting for solution of this particular problem. Now, from here, we can get m air, C p air, divided by m flue gas, C p flue gas, that will be equal to 0.85 into 650 divided by 1075, and that will be equal to 0.5. So, we got this ratio now. Now, for example, we can calculate overall thermal efficiency; we calculate overall thermal efficiency.

And, you know, whenever you calculate any problem related to heat transfer, or related to heat balance, a basis of calculation is to be specified. So, here, as such, the basis of calculation is 25 degree Celsius. So, in the definition of overall thermal efficiency, sensible heat in preheated air, upon sensible heat in flue gas; you know this definition. So, I am directly substituting; that is, m air, C p air, 1100 minus 25, that will be equal to m f, C p f, 1400 minus 25, because here, now, the sensible, the sensible heat in flue gas and that sensible heat will correspond to your basis of temperature, remember; multiply by 100. So, you see now, m air, C p air, m f, C p f, you do not require their absolute values of m air, or m f air, or m f flue gas; directly you can substitute the ratio, into 100 and the answer will be 40.18 percent. Similarly, one can calculate efficiency limit, similarly, one can calculate efficiency limit; I leave it to you and the efficiency limit will come out to be equal to 51.4 percent. Please solve yourself; formula, everything is given and the next, you calculate relative efficiency. Calculate relative efficiency, is simply overall thermal efficiency, upon the efficiency limit, and the answer will be 79.4 percent. So, this is the answer for the problem which has been asked.

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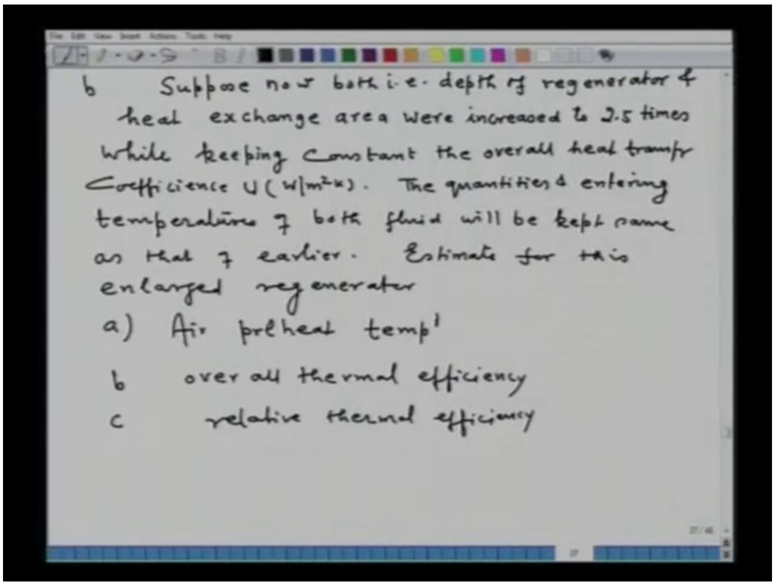

b Suppose now both i.e. depth of regenerator &
heat exchange area were increased to 2.5 times
while keeping constant the overall heat transfr
Coefficience U (W/m²K). The quantities & entering
temperature of both fluid will be kept same
as that of earlier. Estimate for this
enlarged regenerator
a) Air preheat temp'
b over all thermal efficiency
c relative thermal efficiency

Now, I am extending this problem to little, little further. What I am telling now, part b, suppose, now, suppose, now, both, that is, depth of regenerator, depth of regenerator and heat exchange area, and heat exchange area, were increased, were increased to 2.5 times, to 2.5 times, while keeping constant, while keeping constant, the overall heat transfer coefficient, the overall heat transfer coefficient; that is, U in watt per meter square Kelvin, the quantities, the quantities and entering temperatures, quantities and entering temperatures of both fluids, that is air and flue, of both fluids, will be kept same, will be kept same as that of earlier. Now, estimate for this enlarged generator, for this enlarged regenerator, a, air preheat temperature, air preheat temperature, b, overall thermal efficiency, overall thermal efficiency and c, relative thermal efficiency, relative thermal efficiency.

So, now, you have to solve this particular problem. Now, note that, in this problem, nothing is said, whether the flow is counter current or co-current; you have to apply your mind to see, first of all, how the fluid is flowing. If you do not apply your mind how the fluid is flowing, you are liable to do mistakes, 99 point, to the extent of 99.99 percent. So, first of all, you have to know, how the fluid is flowing, because the problem does not mention whether it is co-current or counter current; you have to apply your brain here. So, first of all, you have to decide, what are the entry and exit temperatures of the heat exchanger. In the earlier problem, those temperatures were defined; here, they are not defined.

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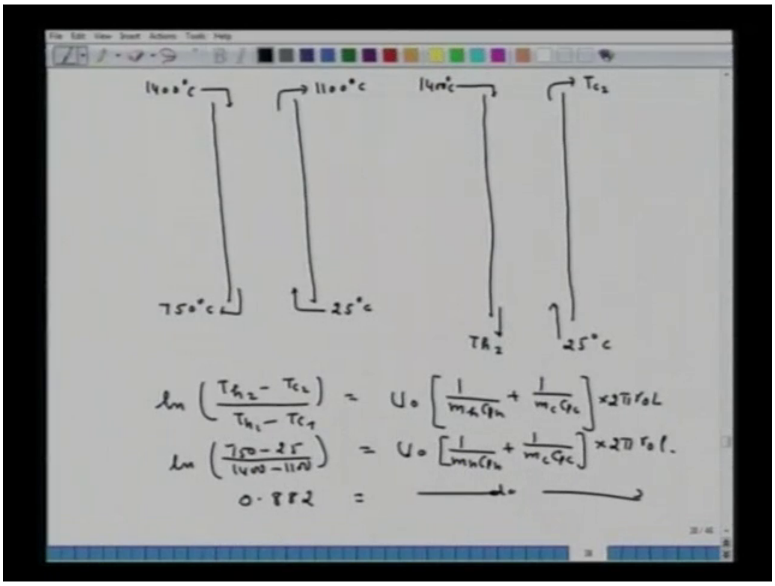


$$\ln\left(\frac{T_{h_2}-T_{c_2}}{T_{h_1}-T_{c_1}}\right) = U_o\left[\frac{1}{m_h C_{ph}}+\frac{1}{m_c C_{pc}}\right]\times 2\pi r_o L$$

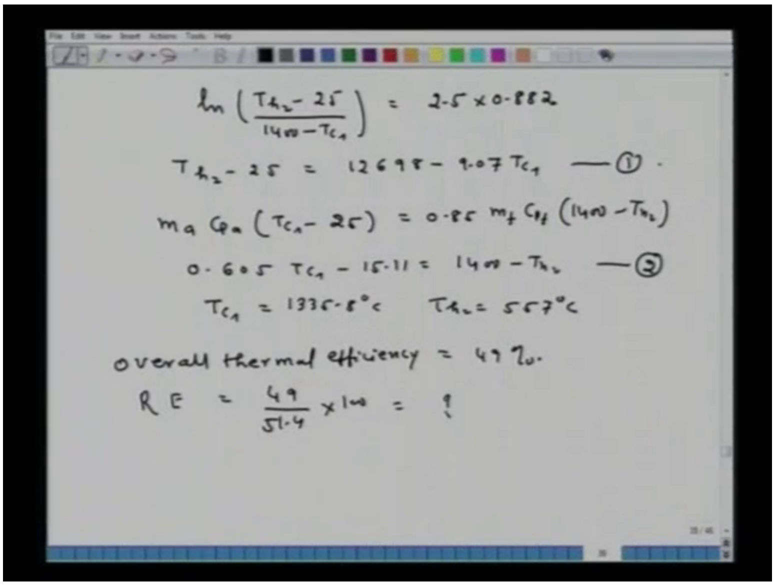
$$\ln\left(\frac{750-25}{1400-1100}\right) = U_o\left[\frac{1}{m_h C_{ph}}+\frac{1}{m_c C_{pc}}\right]\times 2\pi r_o l.$$

$$0.882 = \text{——do——}$$

Now, let us draw, this is for example, a regenerator. This is the height of the regenerator, right. Now, what I am doing here, here, hot flue gas is flowing at 1400 degree Celsius; hot flue gas is flowing here at 1400 degree Celsius, and in the earlier problem, it was said that, it is exiting at 750 degree Celsius. Now, it is not possible to heat air, more than the flue gas temperature; correspondingly, this air has to be entered from here at 25 degree Celsius and air exit, that was given to us 1100 degree Celsius. We cannot show that, air entry from top at 25 degree Celsius and air exit at 1100 degree Celsius, because it is not possible; air temperature cannot go more than the flue gas temperature, at any height, or length of the heat exchanger; that is the clue to solve this particular problem; that, you should understand. You cannot show, once again I repeat, you cannot show that, air is entering from top at 25 degree Celsius and exiting at 1100 degree Celsius, which is impossible; because air cannot be heated up more than the flue gas temperature. Once you got this idea, then, the problem is very simple now. So, now, in the, in the problem which I just said, we will show again, we are given with the inlet and exit temperature. So, again here, it enters at 1400 degree Celsius; its exit temperature is not known. So, let us take it, this exit temperature for example, T h 2; this is not known to us.

Then, this is the inlet temperature, let us take, this is known to us, 25 degree Celsius and this temperature T c 2 is also not known to us. Now, once you have developed this feel of representation of this problem in this particular diagram, then, of course, the solution of the problem is very easy. So, now, what we can do now? If we take, because this b problem which I have given, is an extension of a, which I said, that, now, you are, you are, you are increasing the height of the regenerator to 2.5 times; that is what we are doing it. So, we have to calculate, first of all, we have to calculate, first of all, the heat transfer case for the first one. So, for the first one, you see, the equation which was there, say, l n T h 2 minus T c 2 upon T h 1 minus T c 1, that is equal to U 0 1 upon m h C p h, plus 1 upon m c into C p c into 2 pi r 0 into l. So, what we have to do now, we have to substitute the values here, and because this, we know it, l n 750 minus 25 upon 1400 minus 1100, that is equal to U 0 into 1 upon m h C p h, plus 1 upon m c C p c into 2 pi r 0 l. So, now, we can get…So, this value, that is equal to 0.882, that is equal to this particular thing. Now, the problem says that, we are increasing height 2.5 times. m h, C p h, they all remain the same.

(Refer Slide Time: 49:51)



$$\ln\left(\frac{T_{h_2}-25}{1400-T_{c_1}}\right) = 2.5\times 0.882$$

$$T_{h_2}-25 = 12698 - 9.07\,T_{c_1} \quad \text{——} ①$$

$$m_a C_{pa}(T_{c_1}-25) = 0.85\, m_f C_{pf}(1400-T_{h_2})$$

$$0.605\,T_{c_1} - 15.11 = 1400 - T_{h_2} \quad \text{——} ②$$

$$T_{c_1} = 1335.8^\circ C \qquad T_{h_2} = 557^\circ C$$

overall thermal efficiency = 49 %.

$$RE = \frac{49}{51.4}\times 100 = ?$$

So, now, our second equation will be l n T h 2 minus 25, divided by 1400 minus T c 1; that is equal to 2.5 into 0.882. So, that is what you will proceed to solve this particular problem. So, if you solve it, then, I will be getting T h 2 minus 25, that is equal to 12698 minus 9.07 T c 1; that is my equation number 1. Now, second equation I will be getting by heat balance, that is, m a C p a T c 1 minus 25, that is equal to 0.885 m f C p f, 1400 minus T h 2. So, I substitute all the values; then, I will get the second equation and second equation is 0.605 T c 1 minus 15.11, that is equal to 1400 minus T h 2. This is my equation 2. I can solve both equations simultaneously. So, I will be getting here, T c 1, that is equal to 1335.8 degree Celsius and T h 2, that will be equal to 557 degree Celsius. Please solve yourself; then, once I know this thing, then I can calculate the overall thermal efficiency. Overall thermal efficiency, that will be equal to 49 percent and relative efficiency will be equal to 49 upon 51.4 into 100; and this you can solve; that will come around to 50 or (( )) percent. So, that is how the solution of the problem. Now, I will request you to solve the same problem, suppose, the height of the regenerator is doubled; rest, everything remains the same. Then, try to see, what is the air preheat temperature and overall thermal efficiency. So, my whole objective is to illustrate the how to calculate and how to apply these equations to solve the heat exchanger related problems.