Thermal Operations In Food Process Engineering: Theory And Applications

Prof. Tridib Kumar Goswami
Department of Agricultural and Food Engineering
Indian Institute of Technology, Kharagpur

Lecture – 53
Heat Exchangers (Contd.)

So, we if you remember in some one two classes earlier, we had given a problem to you and said that you try and solve it; and if you can very good, if you cannot then we will do some other day where it may take the whole class, because the concept as well the problem itself was very lengthy, right. Obviously, this type of problem cannot come in the exam; in the exam means when you are giving either end of this course exam or normally any college exam also it is very difficult, because if it is taking half an hour for us in the class, then it may take even 45 minutes to you in the normal exam class.

So, such a big problem may not come, but the advantage of doing it is that why you are then emphasizing. The advantage of doing it is that, many other associated things we will come across; and that will be one added learning from our side right. That is why I gave the problem and I wanted you to first solve; if you could have a were excellent, but if you could not then let us do it and that day itself I said that this problem, solution of the problem may need trial and error may be because the time may be over.

I did not do number of trials, but ultimately what would be the final or close to that I had given perhaps on this; and said that whatever has been asked for we have done that right. Perhaps you have been asked to find out the length, so for I remember, let us look into that right. So, this is the lecture number 53 for the continuation of the heat exchangers, right. So, lecture number 53 we are doing the perhaps the last class for the Heat Exchangers right.

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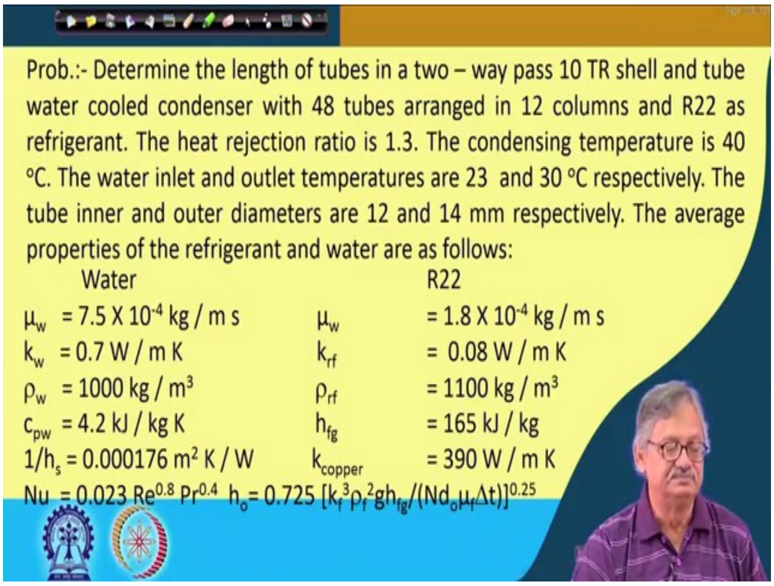

And in that case the problem which was given is like this; that determine the length of tubes in a two way pass 10 ton refrigeration TR, right. This TR is generally in refrigeration used and that is called tonnage of refrigeration, 10 ton refrigeration TR or 10 TR it is in short said, shell and tube water cooled condenser.

Now, this I purposefully gave and I had given one more problem which we had solved, if you remember correctly; that we had given a wall. And we said the along the wall and if this is the x direction right and if say this is the 0^{th} and this is the x direction right, for the thickness L or whatever right; there is a temperature distribution in the x direction and that temperature was a polynomial, distribution of temperature was a polynomial.

So, a + b x + c x^2 + dx things like that, right; so, that polynomial temperature that was solved and we found out different things in that right; and this is true in normal any cold store right. And in the cold store if it is the evaporator right, if there is a compressor here; then there is a condenser here and there is a expansion device here, and then this say from the expansion device it goes to the evaporator again. So, it is evaporator, this is compressor, this is condenser, and this is expansion device, right.

So, this is the cycle and, if we put arrows then they follow like this right. This is a normal vapor compression refrigeration unit; where this evaporator corresponds to 10 way pass to two pass two way pass 10 ton TR shell and tube water cooled condenser, not the evaporator right. It is the condenser, this one; condenser is 10 ton refrigeration equivalent and that is water cooled. Now, again these condenser tubes are of several kilometers in normal cold storages; these are several kilometers length right, and this is a here it is said for that length of tubes in two way pass, right.

So, this is one another, may be another way like that right. Things like that so many are there right. And over this they are spread of water that is what water cooled, right. And that in many cases this water is which is being spread is not a good water for which the problem is associated, there may be a scale farming which we have already said what is scale farming that is falling, right. So, falling is happening on the tubes and that is the damaging part, right. So, what we said two-way pass 10 TR shell and tube water cooled condenser with 48 tubes arranged in 12 columns and R 22 as refrigerant, right.

So, the refrigerant which was getting through this condenser is R 22, right. So, that is going through this, because it is after as we said after the compressor the condenser is there. So, compressor is increasing the temperature and the vapor is being cooled through the condenser; then it is just cool phase change from the vapor to the liquid it is happening there, and this condenser is cooled by water. The heat rejection ratio, this is also a new thing perhaps in the last class we had given you some idea, so that you can solve the problem; however, we will redo that. The condensing temperature is 40 °C, right.

The water inlet and outlet temperatures are 23 and 30 °C. In this connection since we are also saying this, and as I said this may be some additional information to you; not only doing the problem, but also how the problem is being solved and associated things, that you can cool down the temperature only to the level of wet bulb. So, you must know psychometric and dry bulb DB and wet bulb WB temperatures must be known, right. So, from the dry bulb you can come up to wet bulb not below that, right.

That is the reason why that in many cases you will see, in many cities during summer that typical what we call that there is a blow of fan over a piece of not cloth, a piece of some water absorbent right or there is a trickle them. So, that is not being used in many cities, where the humidity is very high right; if the humidity is very high, this difference will not be very high. So, unless this difference is high the effectiveness of that will not be so good, or effectivity of that will not be so good that is called desert cooler, right. So, those desert coolers are not used in many cities where the your humidity is very high, ok

So, this is 23 to 40 °C that is the temperature outlet of the water by which it is being cooled. The tube inner and outer diameters are 12 and 14 mm respectively. The average properties of the refrigerant and water are like this, that for water viscosity of water is 7.5×10^{-4} k g per meter second. Thermal conductivity of water is 0.7 W/m.K; density of water is 1000 kg/m^3; Cp_w of water that is it capacity or specific heat rather in this case not heat capacity; heat capacity is m c p right there is the heat capacity

But here it is specific heat 4.2 kJ/kg.K or °C whatever you write; 1 / h_s right surface heat transfer coefficient is 0.000176 m/m.K or m. °C / W right; that is 1 / h_s, that is surface heat transfer coefficient is h_s, o inverse of that is the resistance ok. So, μ_w for R 22, that μ_w is the viscosity at 12. So, here also viscosity at 12 for R 22 it is 1.8×10^{-4} kg/m.s; k refrigerant is 0.08 W/m.K it was 0.7 for water, 0.08 for the refrigerant; ρ_{rf} that is density of the refrigerant is 1100 kg/m^3, so it is heavier than water.

Then h_{fg} or this is called latent heat or the phase change right; latent heat for phase change that is for either condensation or evaporation whatever of the refrigeration. Then refrigerant rather that is 165 kJ/kg. And conductivity of copper, because maybe the tubes are made of copper, so copper conductivity has to be known. So, that is 390 W/m.K or °C, whatever you will write. Then we were also given that Nu = 0.023 $Re^{0.8}$ $Pr^{0.4}$ right. And h_o or heat transfer coefficient outside is 0.725 k_f^3 ρ_f^2 g h_{fg} /N that is number of tubes row or column, right.

So, N d_o or d_o μ_f or μ, yeah in this case μ_f ΔT; not small generally temperature difference is denoted by ΔT and ΔT maybe time difference right. But time is independent, so generally that is why whenever it is used, you may not be misled; because here it is used as a variable right and time is independent. So, that cannot be, so it is point to the power 0.25; of course, I do not say that it cannot be ΔT also, T also maybe in some expression depending on what you are ultimately finding out, ok.

So, from this the outside heat transfer coefficient is this, inside heat transfer coefficient is not given and we have to find out determine the length of the tubes right. We have 48 tubes arranged in 12 columns. So, N is 4, 48 tubes in 12 columns like this the tubes are there; and this column number is for 12. So, each column we have 4 tubes, right. So, N is then becoming 4, right.

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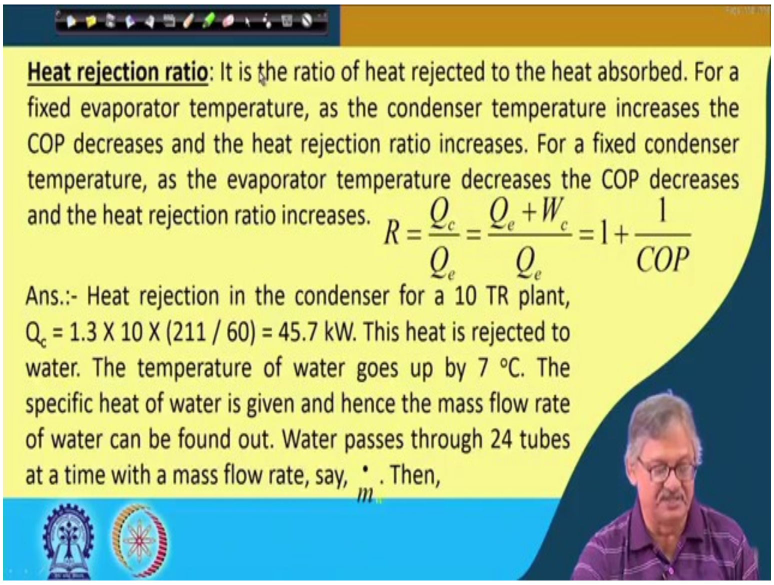

So, that is what we are doing. And before doing it, as we said that heat rejection ratio which was told that; what is that? It is the ratio of heat rejected to the heat absorbed right; whatever heat has been rejected by the condenser to the whatever heat has been absorbed by the condenser. So, that is the ratio or heat rejection ratio it is called. It is not tolerance that has to be condenser can be evaporator, because anything that will be accepting something and then giving up something, right.

So, the ratio of whatever absorbed or rejected to the absorbed right. For a fixed evaporator temperature as the condenser temperature increases the COP decreases and the heat rejection ratio increases. For a fixed condenser temperature, as the evaporator temperature decreases the COP decreases and the heat rejection increases, right.

So, we can write R = Q_c / Q_e. And since Q_c from the first law of thermodynamics we can say, Q_c is Q_e + W_c; means that work of the compressor right over Q_e.

So, this becomes 1. So, 1 + W_c / Q_e is nothing, but inverse of COP; or Q_e / W_c right. We call that COP is coefficient of performance is that inverse of W_c / Q_e or it is Q_e / W_c compressor. So, whatever we get the cooling or refrigeration and how much work the compressor has to be has to do for that, this ratio is the COP or coefficient of performance, right.

So, if we do this then we can write, that heat rejection in the condenser for a 10 ton refrigerant plant is Q_c = 1.3 × 10 × 211 / 60, right. So, for a 10 ton refrigeration plant, the heat rejection in the condenser Q_c is 1.3 ×10 ×211 / 60 that is 45.7 kW right. This heat is rejected to the water, because we said that we had this condenser like that and we have the sprays, right. So, water sprays were like this right, through the reverse. So, water sprays were like that, and condenser tubes were like that.

So, this water is absorbing heat from the condenser and condenser is giving away the heat. So, the temperature of the water goes up by 7 °C. The specific heat of water is given and hence the mass flow rate of water can be found out. Water passes through 24 tubes in a time with a mass flow rate say $\dot{m}_w$ if.

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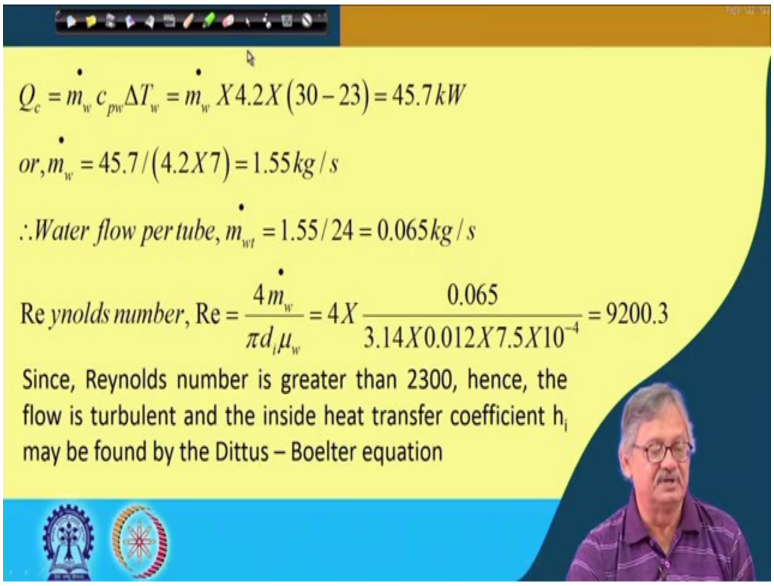

Then we can write. if $\dot{m}_w$ is the mass flow rate of water that; then $Q_c = \dot{m}_w C_{pw} \Delta T_w = \dot{m}_w \times 4.2 \times (30-23) = 45.7 kW$; inlet temperature was 23 and exit temperature of water was 30. So, this is 45.7 kW, right

So, from both the Q_c s, we can write $\dot{m}_w$ = 45.7 / 4.2 × 7 which we have just said, right. So, this is equals to 1.55 kg/s. So, water flow rate is 1.55 kg/s; therefore, water per tube is there are 24 tubes, 1.55 / 24 that is 0.065 kg/s is the flow rate of water in one tube or every tubes. Reynolds number is Re = 4 $\dot{m}_w$ / π d_i w μ_w. So, that is 4 × 0.065/ 3.14 for π d_i is 0.012 m and μ_w given 7.5× 10^{-4} = 9200.3.

Since Reynolds number is greater than 2300, 9200, hence the flow is turbulent and the heat, inside heat transfer coefficient h_i may be found by the Dittus Boelter equation right; which we had already said earlier.

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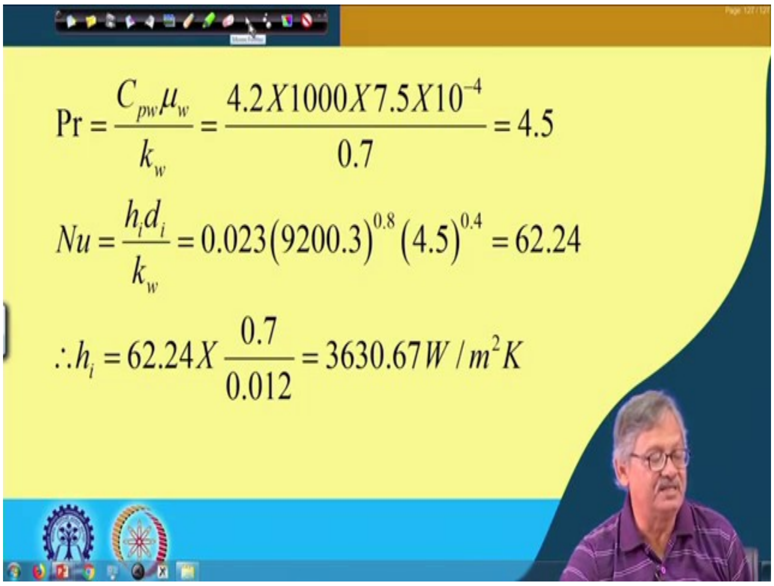

So, from that Dittus Boelter equation h_i, If we find out, to do that what we need to know; first the Prandtl numberP prandtl number is C_{pw} μ_w / k_w = 4.2 × 1000 ×7.5×10^{-4} / k_w is 0.7 given. So, it is 4.5. Nusselt number we need to know is h_i d_i / k_w is this is the relation; Nusselt number is 0.023 into any $Re^{0.8}$ that is $9200.3^{0.8}$ and $Pr^{0.4}$ that is 4.5 we have found out to the power 0.4. So, this comes to 62.24 Nusselt number Nu, which is h_i d_i / k_w

So; that means, h_i is equals to 62.24 this right, 6 × 0.7 that is k_w / d_i that is 0.012 and this comes to 3630.67 W/m^2 . K or °C right.

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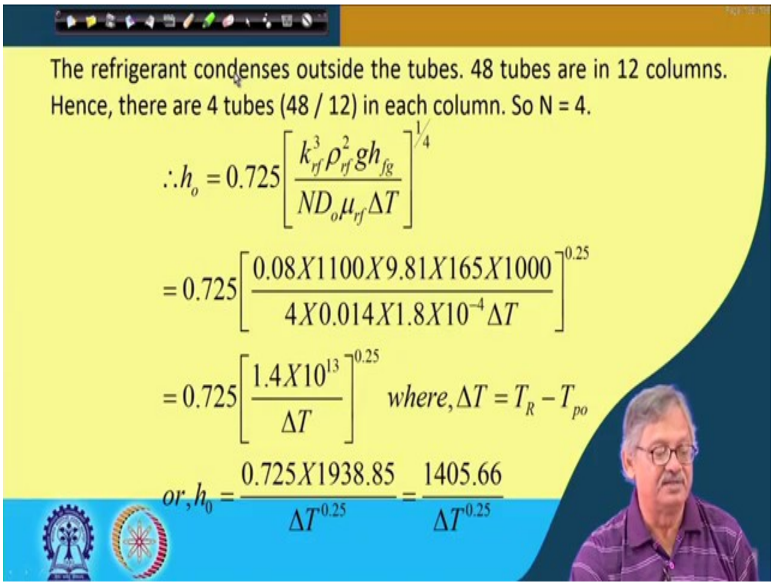

If this h_i is known, then the refrigerant condenses outside the tubes right. The refrigerant condenses outside the tubes 48 tubes are in 12 columns. Hence there are 4 tubes 48 over 12 in each column. So, N is equal to 4; 48 tubes 12 columns, so we have 48 by 12, there is 4 number of tubes in each column, right.

So, we can write h o outside heat transfer coefficient as 0.725 times $k_{refrigerant}$ to the power 3 $\rho_{refrigerant}^2$ g h_{fg} /N D_o μ_{rf} $\Delta T^{1/4}$ right. So, if we substitute the values and this is that we had corrected in the earlier one it was Δt. So, here we have corrected because ΔT is the temperature difference.

So, we can rewrite it as 0.725 values of the property values, k_{rf} 0.08, 0.725 right; 0.08^3 and ρ is 1100^2, g is 9.81, h_{fg} is 165 kJ/kg.s 165×1000, right joules divided by N is 3, D_o is 0.014, then μ_{rf} refrigerant is 1.8× 10^{-4} and ΔT which is not known yet.

So, by solving this we get 0.725; this whole part of course, here we have one cube and here we have one square, which you have not written, but you have taken care hopefully. And that is 0.725 times this numerator becomes 1.4× 10^{-3} / $\Delta T^{0.25}$, right.

So, we can write where ΔT is nothing, but T_r - Tproduct outside o right T_{po}; and h_o that is heat transfer coefficient outside is 0.725 into this on simplification can be written as 1938.85 and $\Delta T^{0.25}$, or these on simplification gives 1405.66 / $\Delta T^{0.25}$ right. Since we do not know ΔT, so it may be required that we do that delta by trial, right.

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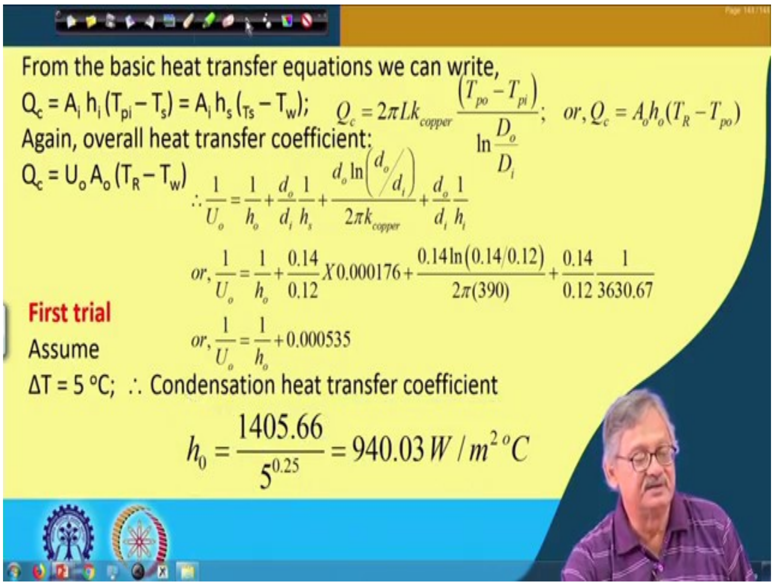

From the basic heat transfer equations we can write that what $Q_c = A_i h_i (T_{pi} - T_s) = A_i h_s (T_s - T_w)$; where and Q_c that can be written as $2 \pi L k_{copper} (T_{po} - T_{pi})$ right divided by ln (D_o /D_i) ; or $Q_c = A_o h_o (T_r - T_{pa})$ right. Again overall heat transfer coefficient that can be written as; $Q_c = U_o A_o$ or $U_o A_o (T_r - T_w)$.

And therefore, we can write to $1/ U_o = 1/ h_o + d_o / d_e (1 /h_s) + d_o / 2\pi k_{copper} (\ln (d_o / d_i)) + d_o / d_i (1 /h_i)$. Or $1/ h_o = 1/ h_o$ + the substitution of the values which comes equals to 0.000535 that is $1/ U_o = 1/ h_o$ plus this. Since we do not know ΔT, we are not able to find out what is the h_o.

So, for that let us first assume, first trial that ΔT = 5 °C that is $(T_{refrigeration} - T_{po})$, right. So, we can write that h_o is, condensation heat transfer coefficient h_o is 1405 / 0.66 which we found out to the power divided by $5^{0.25}$ is 940.03 WW/m^2. °C, right.

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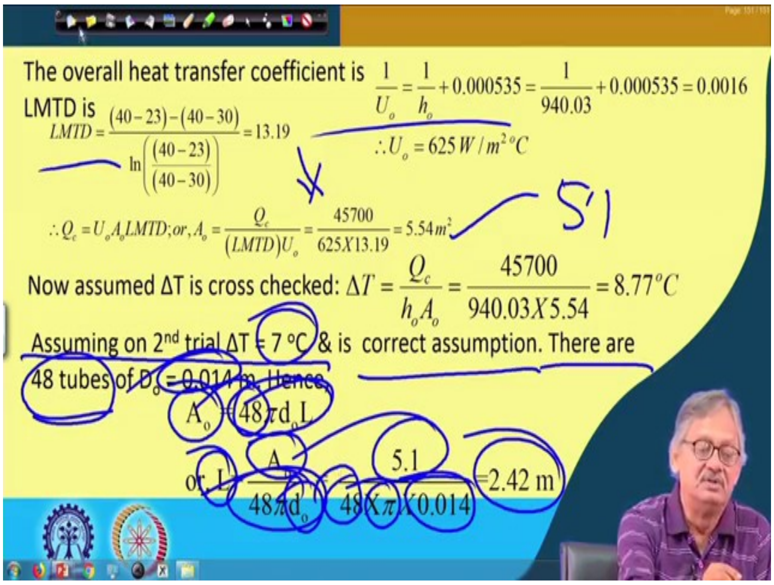

Therefore, the overall heat transfer coefficient that we can find out, as 1 / U_o = 1 / h_o + 0.000535 which we got expression earlier is equals to 1 / h_o now we will found out 940.03 + 0.000535. So, this is 0.0016, right. So, inverse of U that is U_o = 625 W/m^2.°C. And LMTD can be found out as (40 - 23 – 40) /30, because our outside temperature was constant; that is the temperature at least the condenser is getting the refrigerant fluid is at 40 degree Centigrade which is having only a phase change.

So, there will not be any change of temperature of the refrigerant, that will be at 40° ; but the temperature of the inlet of the water and outlet of the water varying. So, (40 - 23 - 40 - 23 30 / ln (40 – 23/ 40 – 30) that comes to 13.19; so, we know you, we know LMTD. So, Q_c = U_o A_o LMTD; or from there we find out A_o is Q_c / LMTD × U_o = 45700 /625 × 13.19 = 5.54 m^2, right, we assumed it.

So, assumed ΔT has to be cross checked. How, ΔT is Q_c / h_o A_o. So, that is 45700 /940.03 ×5.54. So, that becomes 8.77. So, this is higher than what we assumed 5°. So, we do a second trial and in that second trial same way we find out LMTD, we find out h_o, we find out U_o everything; and by doing that we have seen that the second trail, if it is ΔT is 7 ◦C instead of 5 and is correct assumption and there are 48 tubes of D_o, right 0.014 m. Hence A_o new or corrected A_o becomes 48 π d_o L right; where L is A_o / 48 π d_o. A_o we have found out here 5.54 in the second trial, A_o can be somewhere 5.1 or close to that, right. So, A_o is 5.1 48 π and d_o is 0.014 which becomes 2.42.

So, the length of the heat exchanger or length of that, yeah heat exchanger is 2.42 m per tube, right. Length of the per tube that was our perhaps the problem which we had been asked to do that what is the, yeah determine the length of the tubes. So, length of the tubes is 2.52 m, right. So, with this we have solved the problem and you do the second trial, and hopefully you will get the same result. So, with this let us stop, the time is up.

Thank you.