Energy Conservation and Waste Heat Recovery
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Lecture - 32
Heat exchanger (Contd.)

Hello everyone. We were discussing Heat Exchangers. Heat exchangers are very useful equipment as such and they have got enormous importance in energy conservation and waste heat recovery.

Now, we have seen that there are two methods of heat exchanger analysis that is LMTD and Correction Factor method or FLMTD method and effectiveness NTU method. In fact, there are other methods, but these two methods are most commonly used and we have also discussed in what type of problem these methods or a specific method is to be used and we have got to know that the effectiveness NTU method is more versatile. Many cases if we apply effectiveness NTU method, then number of iterations can be avoided, but there are some problems, specific problems where FLMTD method or LMTD also gives the solution very quickly.

Now, effectiveness and NTU, they are parameters which gives us some more information regarding the heat exchanger. As I have told NTU gives us some idea regarding the volume of the heat exchanger. Suppose we have got a same kind of a particular class of heat exchanger let say a surface condenser for steam power plant application, then let say there are 2-3 different type of condensers and we have got NTU values of each of them, then we can make a comparison and generally NTU gives an idea regarding the volume of the heat exchanger or heat transfer area available in the heat exchanger.

Again one can see that it is the residence time of a particular fluid within the heat exchanger. So, as it gives us regarding, I mean gives us some information regarding the characteristic of the heat exchanger, for typical heat exchanger there are ranges of values for NTU and effectiveness as they are very closely related. So, for a typical heat exchanger or for a class of heat exchanger, we can get a range of value for NTU and for effectiveness.

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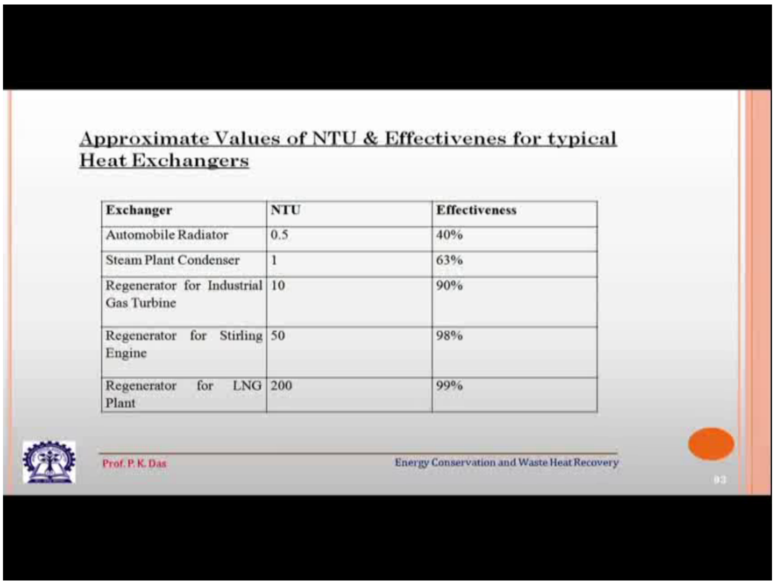

So, if we now concentrate or if we now pay our attention to this particular slide, then you see automobile radiator, it will have NTU of the range of 0.5 and effectiveness of the order of 40 percent. It could be 40 percent 50 percent like this. Steam power plant condenser NTU value will be of the order of 1 and the effectiveness will be 63 percent of the order of 63 percent. That means it could be even up to 70 percent or below slightly below 60 percent also.

So, in that range it will vary. Regenerator of an industrial gas turbine NTU quite high 10 and effectiveness is also high, that is 90 percent. Regenerator for stirling engine, then NTU is 50 and effectiveness is 98 percent. Regenerator for ING plant, NTU is 200 and effectiveness is 99 percent. So, we see with the increase of NTU effectiveness also increases, but the rate of increase will not be that high as we go on increasing the value of NTU.

So, again from this slide we can see whereas, for a regenerator of stirling engine for NTU 50, the effectiveness is 90 percent. So, only for 1 percent increase in 99 percent, the NTU should be increased to 200. So, this is kind of exponential behavior and you know that effectiveness a theoretical value without violating laws of thermodynamics could be one and to approach one effectiveness or 100 percent effectiveness, we have to have NTU of the order of infinity. That means, the heat exchanger should be infinitely large or the heat transfer area, infinite amount of a transfer area is available.

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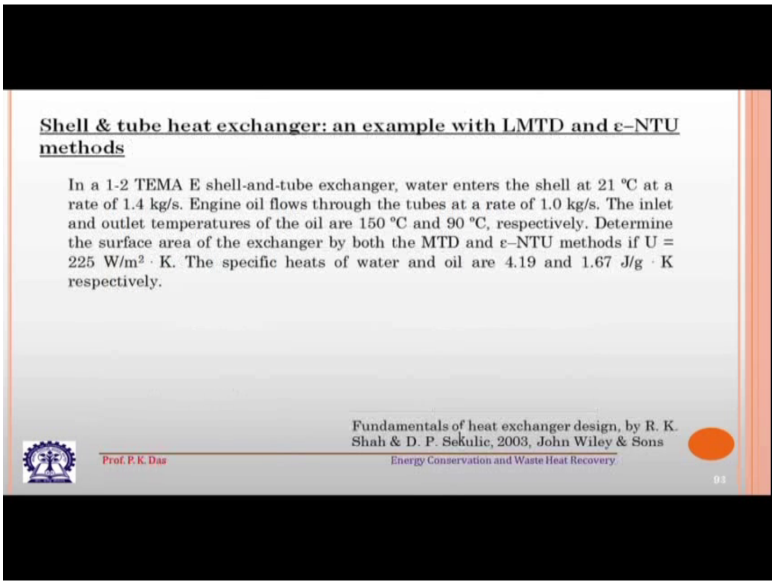

So, with this let us take an example where we get to know how to use the LMTD and effectiveness NTU method for the analysis of heat exchanger. We will take a simple problem and only one problem, but we will try to solve it by both the methods that is LMTD method and effectiveness NTU method. The problem we have selected could be from the domain of or it has got some relevance for a waste heat recovery.

Let us see the problem and then, it will be clear in 1-2 TEMA E shell and tube heat exchanger, water enters the shell at 21 degree celsius at a rate of 1.4 kg per second. Let us explain certain things. 1-2 shell and tube heat exchanger, it means in shell side there is one pass in the tube side, there are two passes. It means that the tube side fluid traverses the shell length two times before it goes out of the shell and tube heat exchanger TEMA E shell. Obviously, you can understand E is some sort of a nomenclature for a particular type of heat exchanger and TEMa tube heat exchanger manufacturers association. So, this is a body for having different kind of codes and standards for heat exchanger, specification of heat exchanger, design of heat exchanger etcetera.

Then, water entry temperature we know and we know the flow rate of water engine oil flows through the tubes at the rate of 1 kg per second. The inlet and outlet temperature of the oil are 150 degree celsius and 90 degree celsius respectively.

So, engine oil is to be cooled as I have told it could be an example from the domain of waste heat recovery. So, engine oil that will get heated up and then, when we are cooling it probably we can extract certain amount of thermal energy and there could be some specific need where the water which will be heated up for due to cooling this engine oil can be utilized. Determine the surface area of the exchanger by both LMTD or MTD method and effectiveness NTU methods. If u is equal to U capital, u is the overall heat transfer coefficient that is 2 to 5 watt per meter square. The specific heat of water and oil are 4.19 and 1.67 joule per gram Kelvin respectively.

So, fluid flow rates are given. Fluid specific heats, these property we need this property. So, that is given and inlet and outlet temperature of the hot fluid that is given and inlet temperature of the cold fluid that is given. So, we have to calculate the area needed for this cooling purpose.

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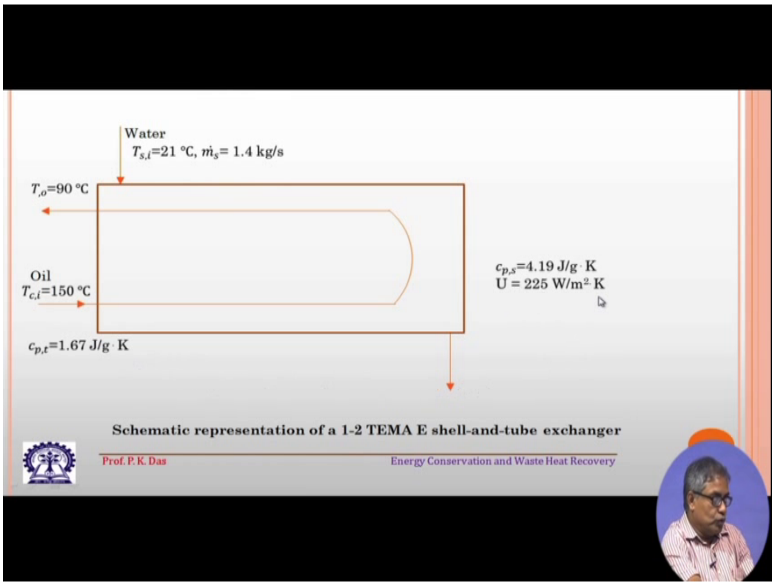

Next figure gives you a schematic representation of 1-2 E type shell and tube heat exchanger. So, you can see the tube side fluid has traverse, the total length of the heat exchanger two times. So, it has got two passes; this is first pass, this is the second pass whereas, shell side fluid has got only one pass. It has traversed the length of the heat exchanger only once.

So, water that enters at 21 degree Celsius, shell side fluid and mass flow rate that is 1.4 kg per second. S denotes the shell side fluid i is the inlet outlet temperature of water is not known, then tube side fluid through that is entering at 150 degree Celsius and it is going out at 90 degree Celsius. Then, cp of tube side fluid that is 1.67 joule per kg

Kelvin and cp shell side fluid that is 4.19 joule per kg Kelvin, a joule per gram Kelvin. Sorry both the cases it is joule per gram Kelvin and u that is the overall heat transfer coefficient that is 225 watt per meter square Kelvin.

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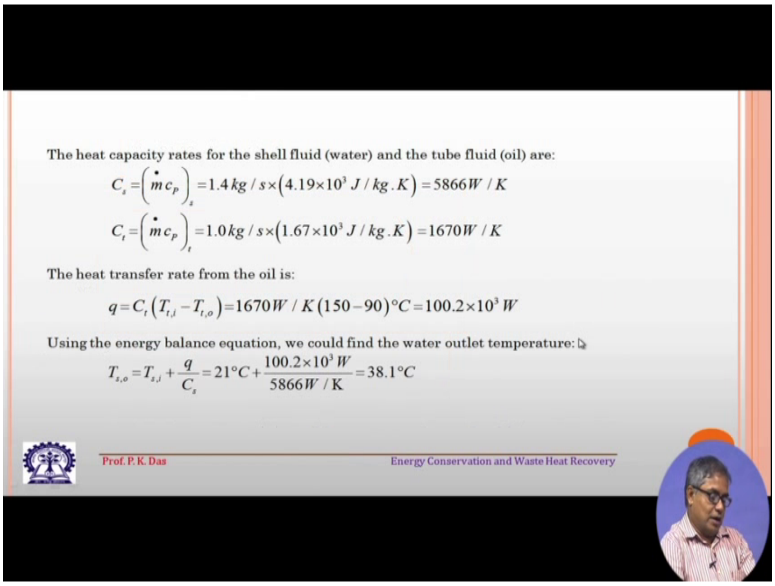

So, with this data if we want to determine the surface area needed for this heat exchange, we get heat capacity rates for shell fluid that is water and tube fluid, that is oil. So, C s that is heat capacity rate given by m dot cps all are for water. So, with the figures given, we get 5866 watt per Kelvin and C t, capital C t that is the heat capacity rate of the tubes, right. Side fluid that is m dot cpt and using the numbers etcetera, we get 1670 watt per kelvin the heat transfer rate from oil because you see oil we know the inlet and outlet temperature.

So, we can calculate what is the change in enthalpy and in terms of the specific heat and mass flow rate, we can get what the heat transfer from the oil is. So, that is 100.2 into 10 to the power 3 watt or 100.2 kilowatt using the energy balance equation. You see water side we do not know the outlet temperature. So, the outlet temperature for water side we can determine because now the total amount of heat transfer that has been calculated and we can use this formula, simple formula for energy balance and with that we can get the outlet water temperature is 20, sorry 38.1 degree Celsius. So, water enters at 21 degree Celsius and leaves at 38.1 degree Celsius.

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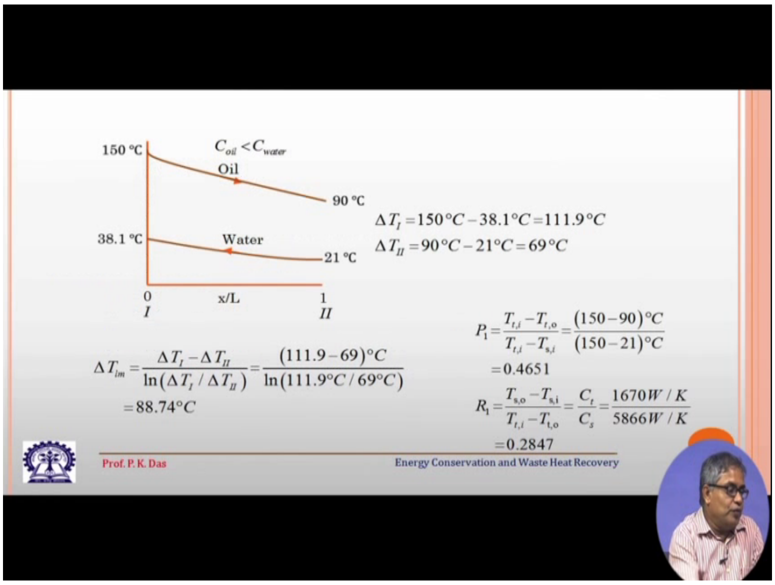

So, you see with this we have got four temperatures of the heat exchangers. So, 150 degree celsius oil enters, it goes out at 90 degree celsius, 21 degree celsius the water enters and it goes out at 38.1 degree celsius. For a simple schematic representation, we have shown as if it is a counter flow kind of or counter current kind of arrangement, but it is not so simple because we have seen that tube side fluid, the water, tube side fluid has got two passes. So, it will not be simply this kind of arrangement, but schematically we have shown that it has got this kind of an arrangement.

Delta T1 that will be 150 degree celsius minus 38.1 degree celsius. Let me go back to this diagram. So, let us once again see the four temperatures; 150 degree celsius that is the inlet temperature of the oil and this is the outlet temperature of water that is 38.1 degree celsius and outlet temperature of oil is 90 degree celsius, outlet temperature of water is, sorry inlet temperature of water is 21 degree celsius.

So, with these four figures, sorry if we go back, so how we define T1 T2. So, oil is entering at 150 degree celsius and water is going out at 38.1 degree celsius. Suppose we assume some sort of a counter current type of arrangement, then we can take this is our delta T1. Similar way we can delta T2, we can take 91 degree celsius minus 21 degree celsius. This is the outlet temperature of oil and this is the inlet temperature of water.

So, delta T1 and delta T2 we have got we are assuming that it is in the counter current flow arrangement. So, with these two values, we can get delta T lm or LMTD log.

Logarithmic mean temperature difference. We can get this as the formula very well known formula and then, from there delta T lm we get 88.74 degree celsius, but as I have told though this represents some sort of counter current flow arrangement, this also we have calculated assuming that it is counter current flow arrangement, but the heat exchanger is not a counter current heat exchanger. So, along with LMTD we have to use some sort of correction factor. If we use the LMTD which we have calculated assuming counter current flow arrangement, we have to also use some sort of correction factor. For this correction factor generally these correction factors are obtained from some sort of chart or graph.

We need two values; one is P1. P1 is given by this kind of a formula and then, it becomes you see this gives the actual kind of I mean this is representative of actual heat transfer and this is representative of the maximum amount of heat transfer. That is possible by these four temperatures we can get and P1 becomes 0.4651. Then, R1 we can get simply from the ratio of heat capacity rate. This is C minimum and this is C maximum. Capital C minimum and C maximum. This also can be obtained in terms of temperatures.

So, if we calculate R1, we get 0.2847. So, P and R we have calculated for the problem once we know the four temperatures of the heat exchanger and once we know the heat capacity rate of the two fluid streams. So, this can be calculated readily and I have shown how to calculate it for this particular problem.

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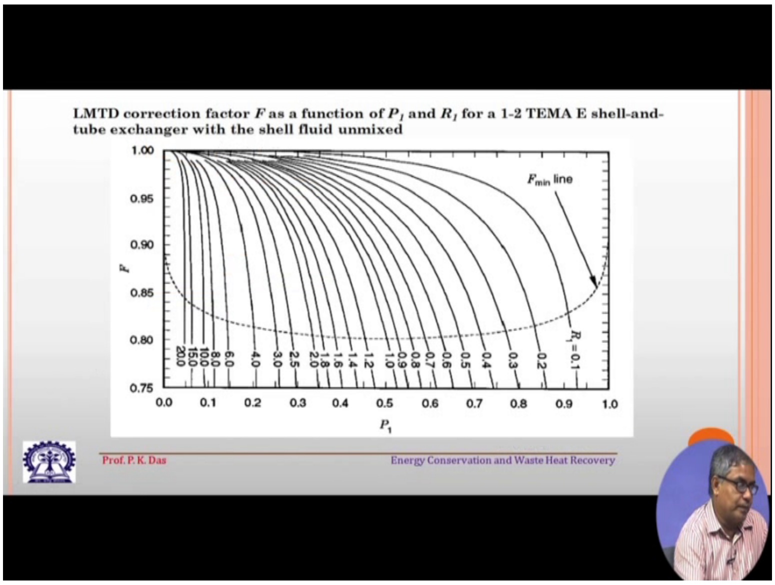

Then, you see we have got P1 plotted like this and these curves are for different values of R1. So, with our respective value of P and R, we can get a typical value of F from this figure and then, that F value we can pick up for our calculation.

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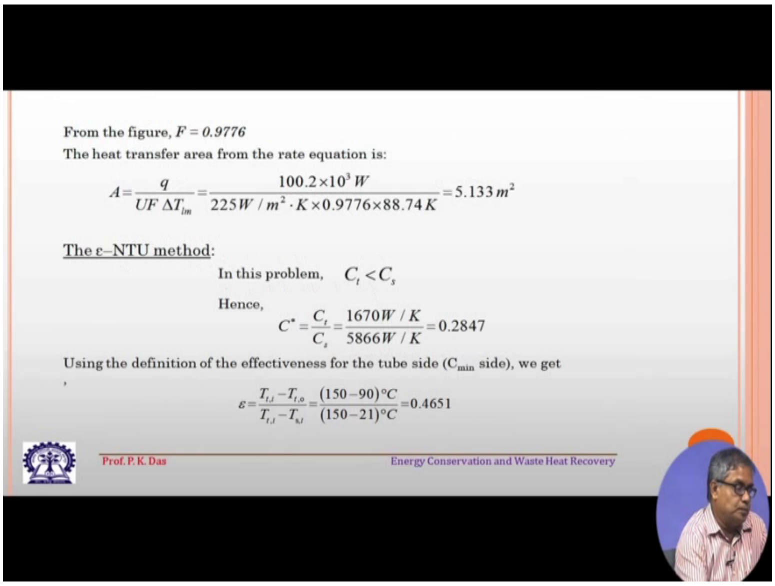

So, the surface area is equal to q by UF. This is the correction factor into delta T lm. So, the correction factor we have got U, we have got from the formula. The correction factor we have got F is equal to 0.9776 from the previous chart which you can also check and then, with this value of UF and LMTD, we have already calculated. So, putting all the values we get 5.133 meter square. So, this is the surface area needed for heat transfer. So, this will be the surface area of the tubes present in the heat exchanger.

Now, obviously one can go for the decision of tube diameter, tube length, number of tubes, how they will be arranged? All these things, those are not within the scope of this particular course, but those are very essential thing and to complete the heat exchanger design, one has to do those things. Probably one has to go beyond that, probably one has to see the mechanical strength of the heat exchanger what kind of cell diameter we provide, what kind of heat exchanger head you are going to provide, what kind of tube heat you are going to provide, but as I have told this is not within the scope of this particular course.

Then, let us see the parallel method effectiveness NTU method. In this problem C t is less than C s. That means, heat capacity rate of the tube side that is less than the heat capacity rate of the shell side fluid, so C star which is C minimum by C maximum. So, we get 1670 by 5866, that is 0.2847. Using the definition of effectiveness, then we can get this temperature values are known. So, we can calculate now and we know which fluid stream is having minimum value for C and which fluid stream is having the maximum value of C. So, using this concept we can determine what the effectiveness is. The effectiveness of this heat exchanger is 0.4651.

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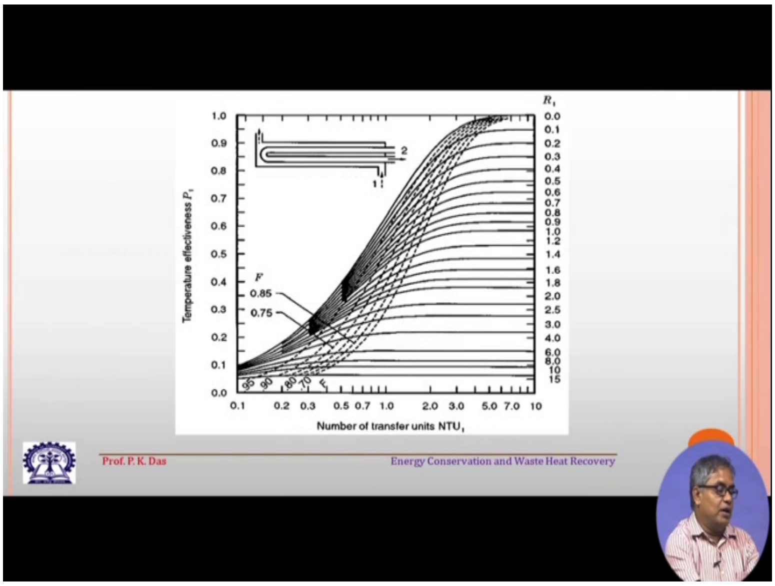

Now, if we go to the next step here we can see some sort of a chart. This chart what we can find out the P parameter we can find out P1 parameter, we can find out NTU and we can find out R parameters also. So, how it is? This is P, these R's. R for typical curves are there for different values of R and then, this is the value of your number of transfer unit or NTU.

So, that means if the four temperatures are known the way earlier, we have calculated P and R we can calculate. Now, we can use this chart P and R values are known. So, from there if we come here, we can calculate what the value of NTU is. So, this is one way of determining NTU. What is the other way? We know the type of heat exchanger, we know the effectiveness already. We have calculated the effectiveness and then, we know C star. So, knowing C star effectiveness and the type of heat exchanger, we can also calculate the NTU because effectiveness and NTU are connected. Only thing is that for a typical, for a few typical heat exchanger, we will have some formula or closed form relationship otherwise we have to go for some sort of a curve.

So, this is one curve from which we can know the temperature values, we can determine NTU.

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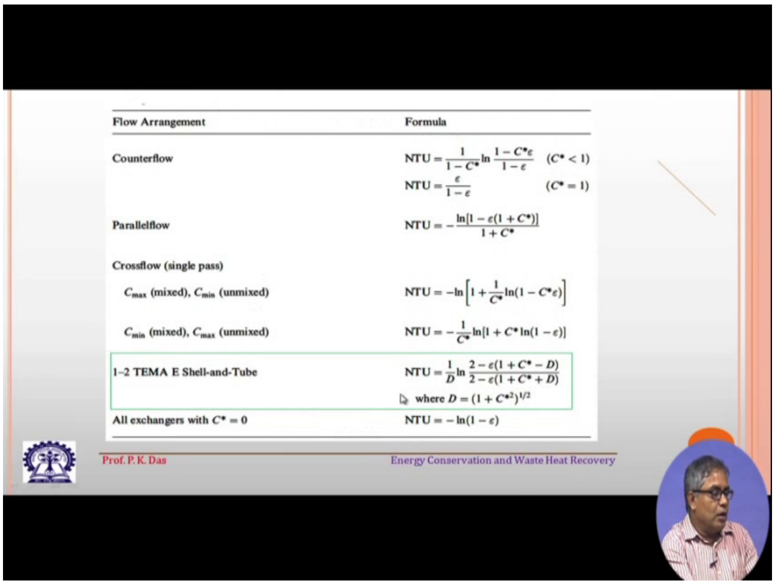

Here I am showing some sort of a chart. There different kind of flow arrangements are there. If we know this flow arrangement, let say counter flow, then in NTU and effectiveness, they are connected by this correlation. So, here you see basically the correlation is between NTU C star and effectiveness that is epsilon follow a particular type of heat exchanger. Our heat exchanger is 1-2 TEMA E shell and tube heat exchanger. So, for that we have got a relationship like this. Fortunately we have got this relationship.

So, we can calculate once we know NTU and C star D is defined over here. So, once we know these values, then left hand side is known. Totally we can, sorry the right hand side is known totally. We can calculate the left hand side that is the NTU. So, again I like to repeat I have shown here two methods of determining NTU; one that we can use some sort of a chart. They are a different kind of chart, the chart which I have used that uses values of P and R to calculate in NTU or to estimate NTU. There could be chart where effectiveness and C star values are given and from there one can calculate NTU and in certain cases, there could be some formula or correlation given from there knowing effectiveness C star for a typical heat exchanger, we can calculate NTU.

So, both these have been shown and any one of these you can adopt.

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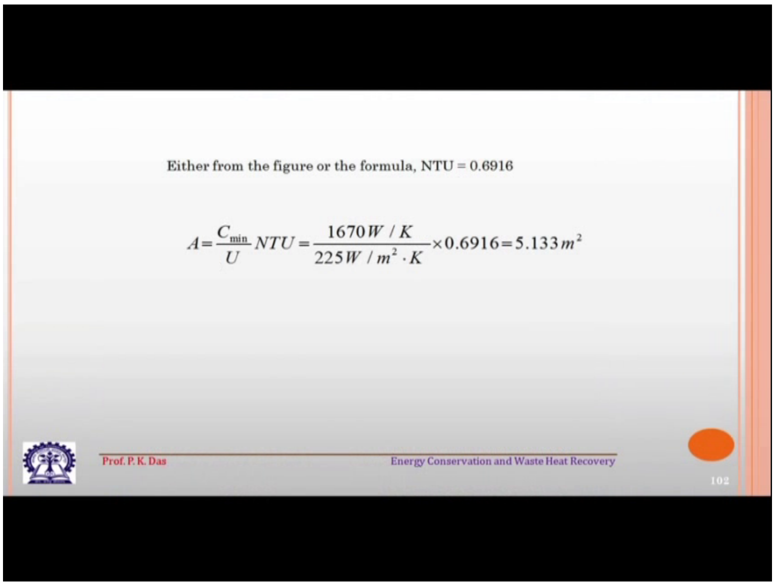

Then, NTU if you calculate, it is 0.6916 and area that is from NTU relationship, NTU is related to area by this particular formula A is equal to C min NTU divide by U. You know all these values C min, we know the value of NTU, we know the value of overall heat transfer coefficient. So, we are getting 5.133 meter square that is the area of the heat exchanger.

So, you see we have used F LMTD method or LMTD correction factor method by that for a heat exchanger, we have calculated the surface area needed, we have used effectiveness NTU method. By that also we have calculated the surface area of the heat exchanger needed, we have used a typical heat exchanger for which a value can be obtained from the chart and effectiveness NTU relationship has to be given to us either through a formula or through a chart. So, from there we can determine the required surface area and obviously, both the cases we are getting the same surface area because we are doing the calculation for the same heat exchanger. So, I hope this will give you some idea how to calculate or how to do some simple analysis for heat exchanger using the two methods which I have demonstrated.

Thank you.