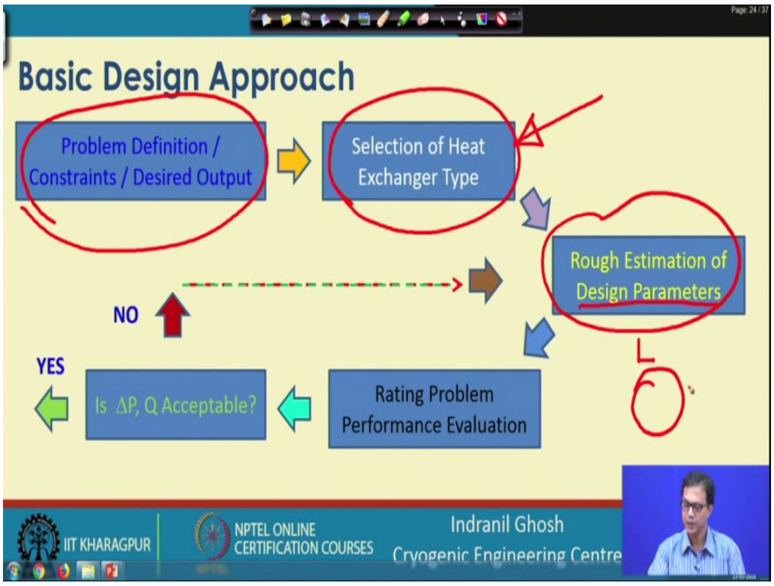
Heat Exchangers: Fundamentals and Design Analysis
Prof. Indranil Ghosh
Cryogenic Engineering Center
Indian Institute of Technology, Kharagpur

Lecture – 14
Tubular Heat Exchanger: Shell - and - Tube Design

Welcome to this lecture. In this lecture we are trying to explain you the shell and tube design approach in details. You may remember in the last class, in the last lecture, we have talked about the shell and tube heat exchanger design approach and here with an example we will try to elaborate the same.

(Refer Slide Time: 00:43)

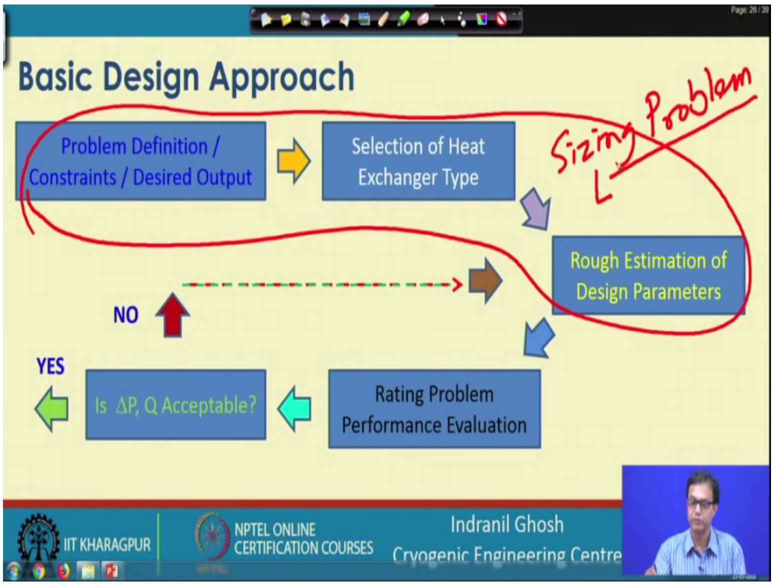


Now, just to recapitulate, what we have talked in the last class first, of all we need to define the problem like what is the problem definition, what are the constraints what are the desired outputs. And based on that if we have that all these information's with us we have to first select the type of exchanger that we are planning to design.

So, we will select the type of exchanger we are going to design. Now, for this case it is already fixed and we have decided this is the shell and tube type. Now, once we have decided the heat exchanger type when now need to establish certain design parameters like what would be that expected heat transfer coefficient for a typical heat exchangers like shell and tube for a different kind of fluids.

So, once we have that knowledge with us we will be able to find out using the epsilon n T or the other techniques that we have learned in the earlier classes. So, basically we will be able to find out some of the parameters or design parameters. So, design parameters by saying that, we mean to say that we come to know about the length, maybe we come to know about the diameter of the tube we will be able to tell about the shell diameter etcetera.

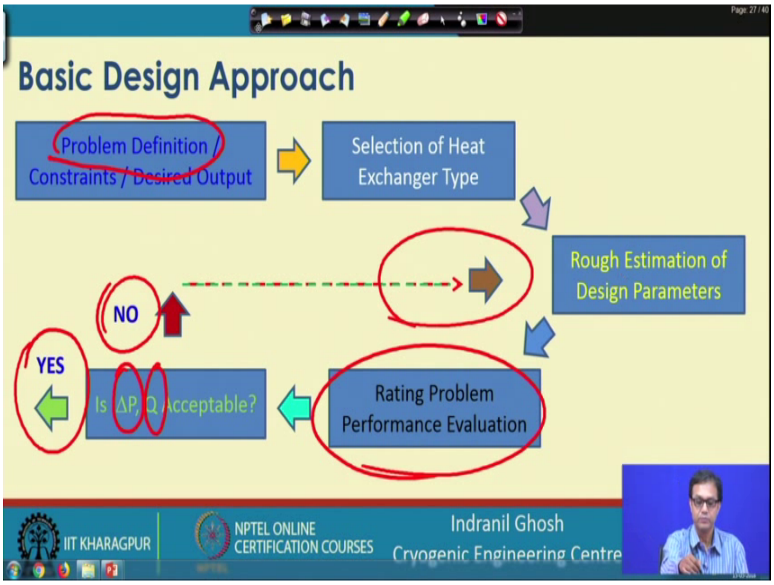
(Refer Slide Time: 02:46)



So, once we know all those parameters then what we do is that now, we go for a rating problem. Till now we were trying to solve up to this part we were trying to solve a sizing problem; that means, where all the inlet and flow conditions and the exit flow conditions temperature flow rate etcetera are known, and we try to estimate the heat exchanger length or the heat exchanger size etcetera etcetera.

So, this was what was the sizing problem as we have learnt in the earlier class. So, this was basically we are trying to solve a sizing problem in this one, but up to this part we will try to get an rough estimate of the sizing problem. Now, once we know the rough estimate of the design, then we go for the rating problem.

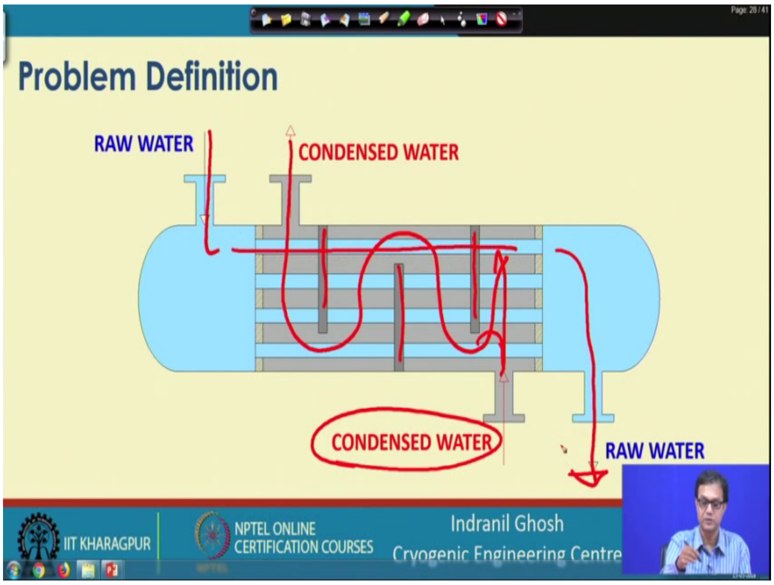
(Refer Slide Time: 03:48)



What is rating problem? Now as if we have the geometry of the exchanger known the inlet and of the 2 streams are known. And when we know the inlet condition of both the fluid streams and the heat exchanger configuration is known, we can find out what is happening to the exits fluid streams or rather we try to find out the performance of the heat exchanger. If we find that the heat exchanger performance is the acceptable like what is the pressure, what is the heat load etcetera that we have defined earlier in the first problem definition, it is comparable with or it is acceptable to our problem definition or no.

Or then, accordingly we will go for the mechanical design. If we find that it is not in accordance to our desired output or what we intend to do, then we have to make a change in the estimation. So, basically you can understand that this is the kind of trial and error. So, we are starting with an initial or rough design, and we are trying to rectify that one according to our need. So, let us try to solve this one with a small example.

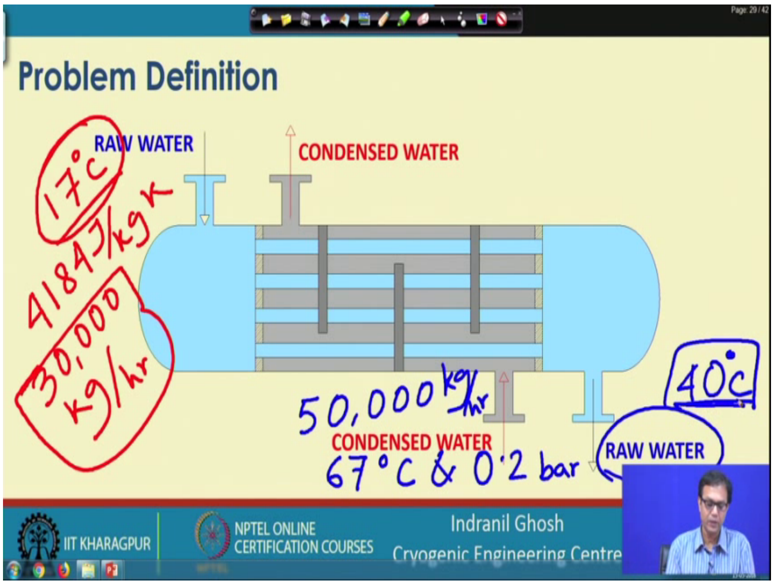
(Refer Slide Time: 05:17)



Here, in this problem definition this is as you can understand this is a single cell single tube heat exchanger. Here these are the baffles, and we have these are the baffles, we have these are the baffles and one feet is entering the condensed water is entering on this side and it will be flowing like, I am sorry, this is supposed to this is not a good design.

So, it is supposed to come from this end and it should come like this and it is suppose to come another baffle should be there. So, it should come out from here. So now, on the other side the raw water is coming and it is flowing like this. And finally, it will flow like this from this outlet. So, here what are the conditions or the problem definition that is given.

(Refer Slide Time: 06:30)

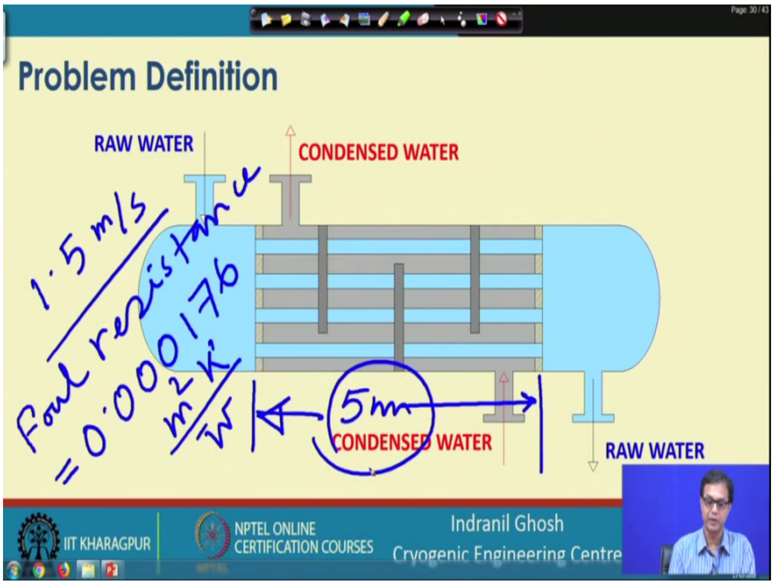


The raw water this is entering at 17 degree centigrade. And it is cp is also given it is 4184 joule per kg Kelvin. And, it is flow rate is also known this is 30,000 kg per hour. So, we know the flow rate of this water, and we know the inlet temperature of this raw water. What is about the condensed water? It is entering at 67 degree centigrade, 67 degree centigrade and at 0.2 bar. Now, it is flow rate has been specified as 50,000 kg per hour.

Now, we know the inlet temperature of the row raw water, we know the inlet temperature of the condensed water. What is expected that we have to design a shell and tube heat exchanger where the exit temperature would be 40 degree. So, this raw water is supposed to come out at 40 degree centigrade. It should not be less than 40 degree. So, this raw water is going to get heated up. And, it will be heated up by the condensed water and it is flow rate and it is inlet temperature is given. And, what we intend to do is that the raw water should always be it should not be any time less than 40 degree centigrade.

Now, what are the other condition that has been already specified. Let us look into that. It has been said that it should be a shell and tube and it should be a single cell and single tube pass not necessarily also I mean, but preferred is single tube pass.

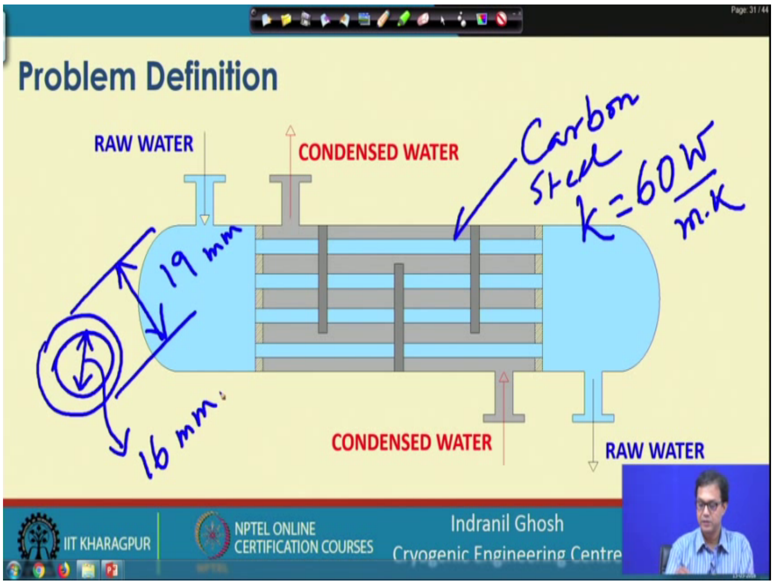
(Refer Slide Time: 09:16)



And coolant velocity is maximum 1.5 meter per second that is the maximum allowable velocity. There is some kind of form resistance or; that means, there is a possibility that over the time it will accumulate some kind of scale. And, that resistance that foul resistance will be that foul resistance is equals to 0.000176 it is unit would be meter square Kelvin per watt. Just inverse of what we get for the heat transfer coefficient.

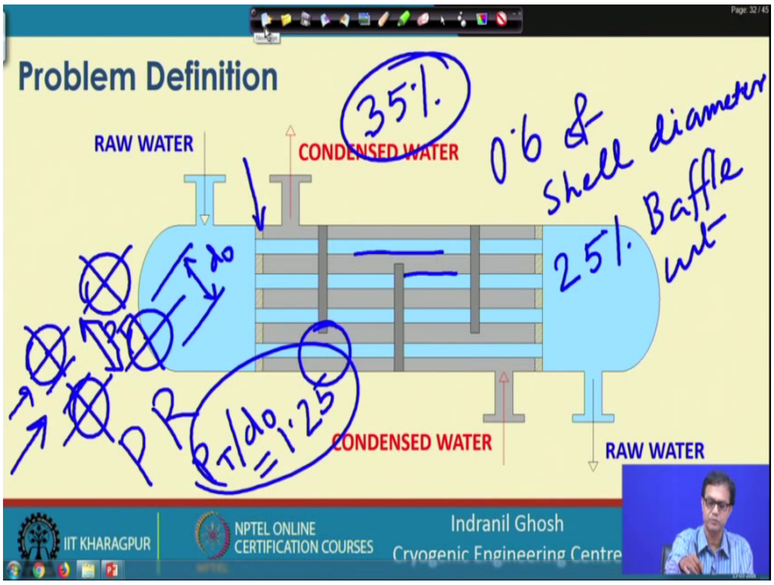
Now, this is the foul coefficient and a foul resistance and the tube length of this heat exchanger that has already been specified, because of the length constant or space constant it cannot be more than 5 meter. So, we will work with 5-meter maximum length. What it has been said is the tube material this tube materials are made of carbon steel.

(Refer Slide Time: 10:42)



So, that we know the thermal conductivity. So, it becomes k equals to 60 watt per meter Kelvin. Now, the tube diameter also has been specified. So, the tube diameter is also specified and it is basically od is 19 mm, and the id that is equals to 16 mm. The tube arrangement; that means, how are we going to arrange the tubes.

(Refer Slide Time: 11:41)



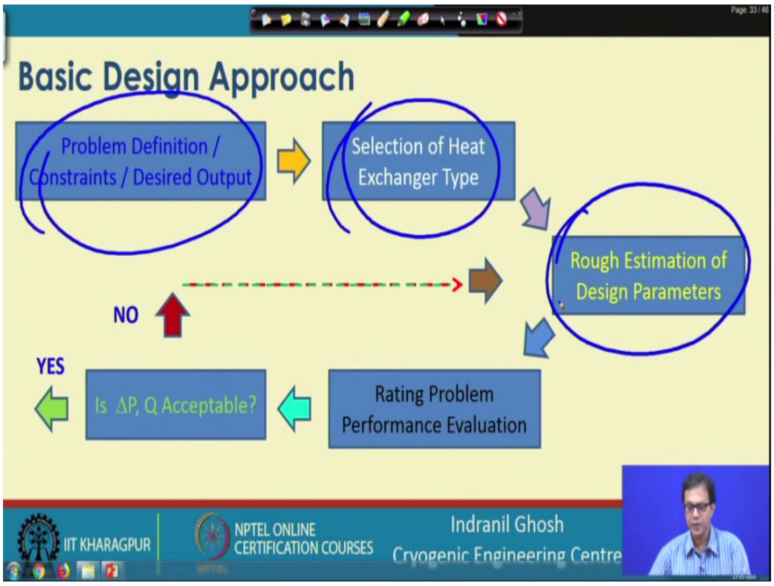
This is the tube sheet in the tube sheet. There will be arranged in the square pitch so; that means, it will be inline flow and this is how they are going to be arranged. This is the 4 tubes if we look at the flow is taking place like this and this is the minimum area we have already learned about it.

So, this tube arrangement has already been said it is square pitch and the pitch ratio that is pitch ratio PR, that is pt by d 0, where d 0 is the outside diameter and this is pt. So, that P T by d 0 is equals to 1.25. So, this has already been specified. And there is also the baffle spacing, the baffle spacing is 0.6 of the cell diameter. And it is baffle cut is 25 percent there is baffle cut.

So, if we look into this total baffle, 25 percent this part is 25 percent of the total one. And as we have said that, there is a possibility that there would be formation of scale. So, what we need anticipate that over the years, it will accumulate some kind of foul I mean the darts on it and scale on it. So, accordingly we have to slightly over design the heat exchanger and it should never be more than 30 per 35 percent. So, that we have to taken into account that considering the foul resistance our design should never be more than 35 percent of more overdesigned.

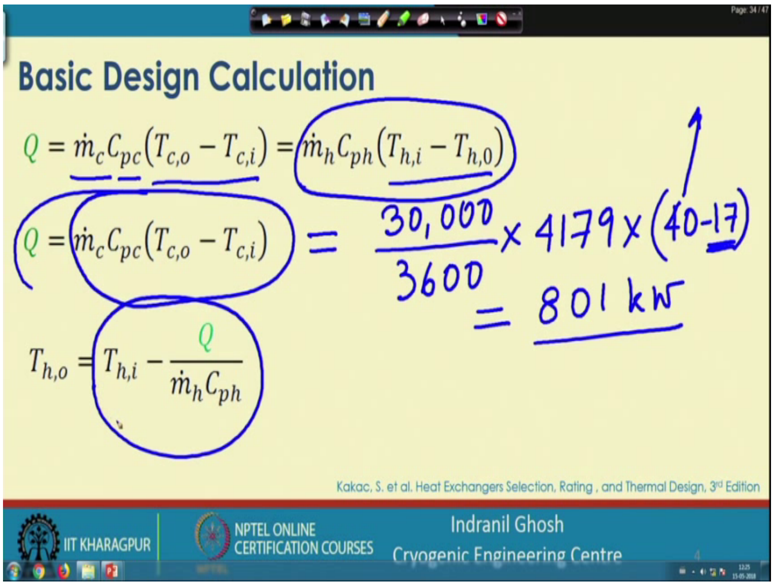
So, these are the specification, which is given now we have to look for the actual sizing of the shell and tube. So, how do we do? So, what we need to keep it in mind that we have to take an approach as we have discussed in the in the previous schematic this is the flow chart we have shown.

(Refer Slide Time: 14:37)



So, we will start with this is the problem definition has already been told. Now, we have to already it is also selected now you will try to make an rough estimation of the design parameters like we will try to find out what would be the number of tubes on the shelled side what will be the diameter of the shell side. And once we know that we will come back to this rating problem. So, let us try to look into that and we have this kind of heat exchanger.

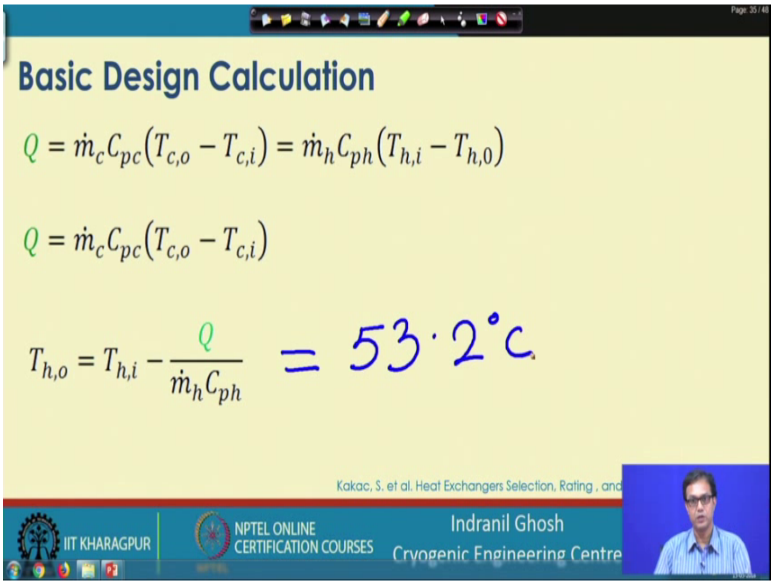
(Refer Slide Time: 15:08)



So now we will start the calculation. So, we know that the heat transfer the flow rate of the cold fluid, C pc the specific heat of the cold fluid multiplied by the difference in temperature. So, if we look at all this temperature all these parameters are known on the right hand side; so, that we would be able to find out the amount of heat transferred.

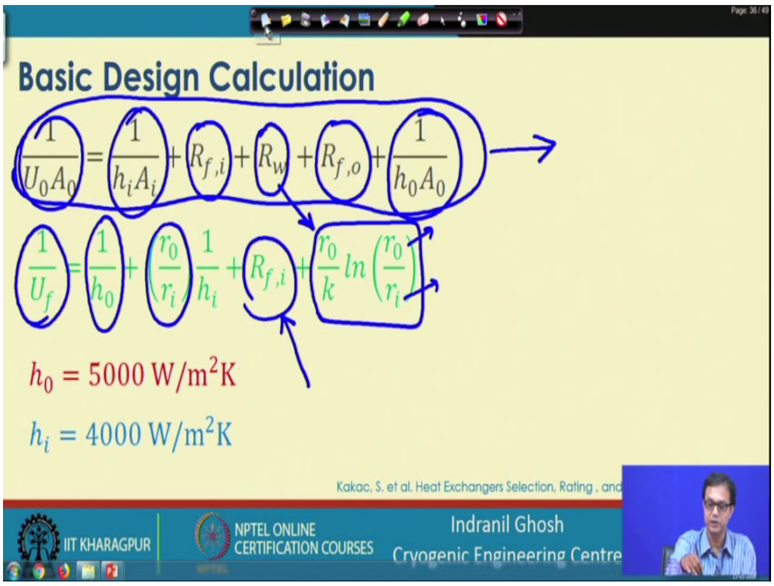
So, this is just nothing but if you try to calculate this is 30,000 divided by 3600 multiplied by 4179 is the C p and then you have the difference in temperature 14 minus 40 minus 17; 40 is the desired temperature, and this is 17 is the inlet temperature of the cold fluid. So, it is coming to be 801 kilowatt amount of heat that is going to be transferred and this is equal to; obviously, m dot h C ph T hi minus T h 0. So, here this equation will be used to find out the exit temperature of the hot fluid.

(Refer Slide Time: 16:37)



And, if we look at this will come out to be because, already we have calculated Q equals to 801, and if we put that value we will be able to estimate it to be 53.2 degree centigrade. So now, you see already we know the all inlet and exit temperature of the heat exchanger. So now, at this point, we have to make some kind of assumption regarding the heat transfer coefficient and so, that we can try to estimate the overall heat transfer coefficient on the shell side. So, how do we do that?

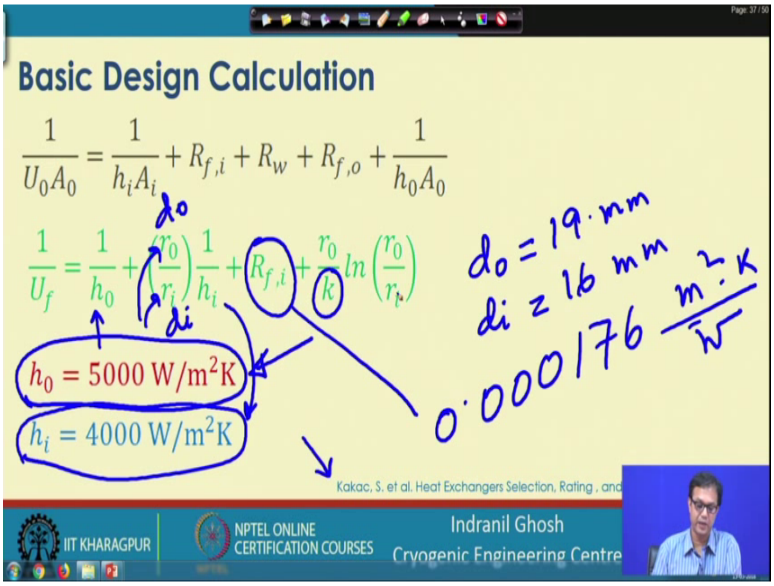
(Refer Slide Time: 17:23)



In order to do that, we have to depend on certain realistic values of the internal and the external heat transfer coefficient. So, this is the overall heat transfer coefficient, where we find this is the wall resistance. This is the fouling resistance inside and at the outside. Then we have the overall resistance of the external one and this is the overall heat transfer coefficient on the inverse of the overall heat transfer coefficient this is 1 by 1 by U 0 A 0.

So, this is what we get in general. And for the specific case where we have r 0 and r i as the radius of the 2 tubes, we have 1 by h 0 then we have r 0 by r i. This is defined in terms of the external heat transfer area. So, this is the what is called the fouling resistance. This is already been given this is this takes account of the heat transfer resistance offered by the wall of the tube and here this is we have taken a rough.

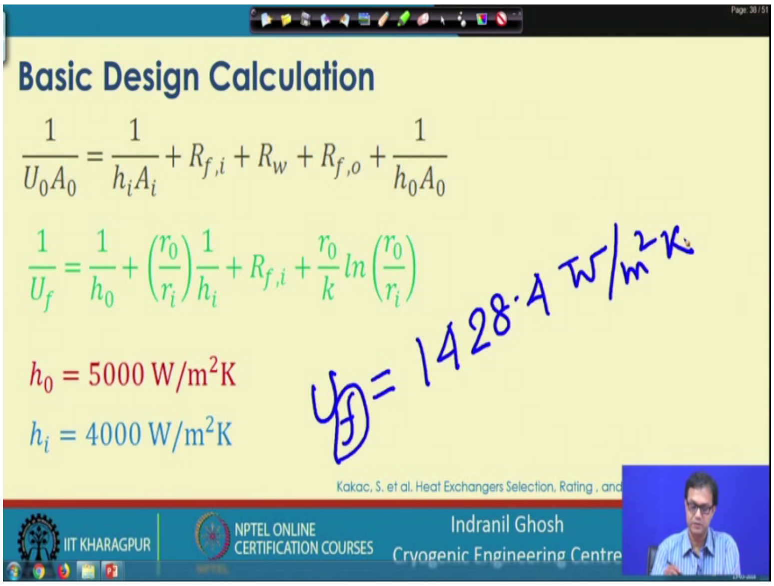
(Refer Slide Time: 18:54)



Estimate of this shell side heat transfer coefficient to be 500 watt per meter square Kelvin and we have taken it as 4000 watt per meter square Kelvin. This has been given from taken from the heat exchanger selection by S. Kakac et al.

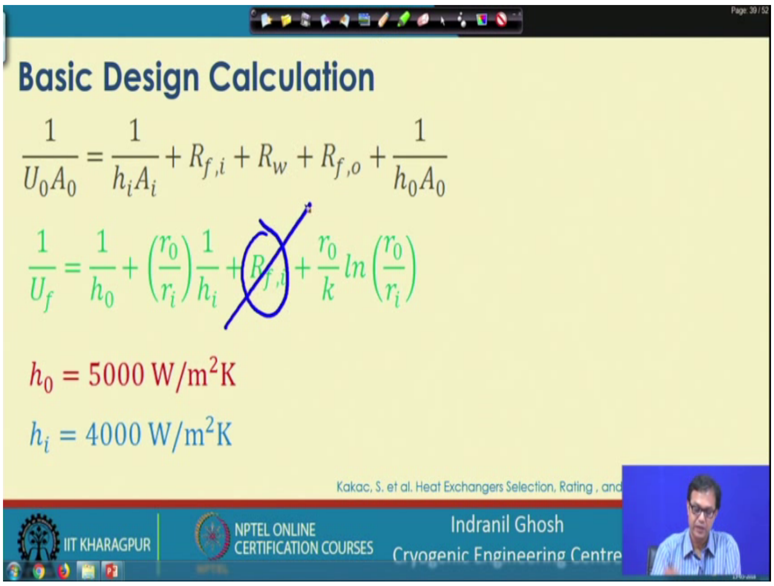
So, they have given a chart of these values, which are typically which can be considered for different kind of fluids and different kind of heat exchanger configuration. So, based on this value, if we now estimate we will find that already we know h 0. If we can substitute r 0 already we have talked about, r 0 is already known to us this is and this is r 0 is say, if we define it in terms of this can also be d 0 by d i. So, d 0 is basically d 0 is equals to 19 mm and di is 16 mm, h I is already given, rf I is already known that is equals to 0.000176 meter squared Kelvin per watt and we have d 0 or sorry r 0, and you have to put the value of k and r 0 by r i and l n.

(Refer Slide Time: 20:37)



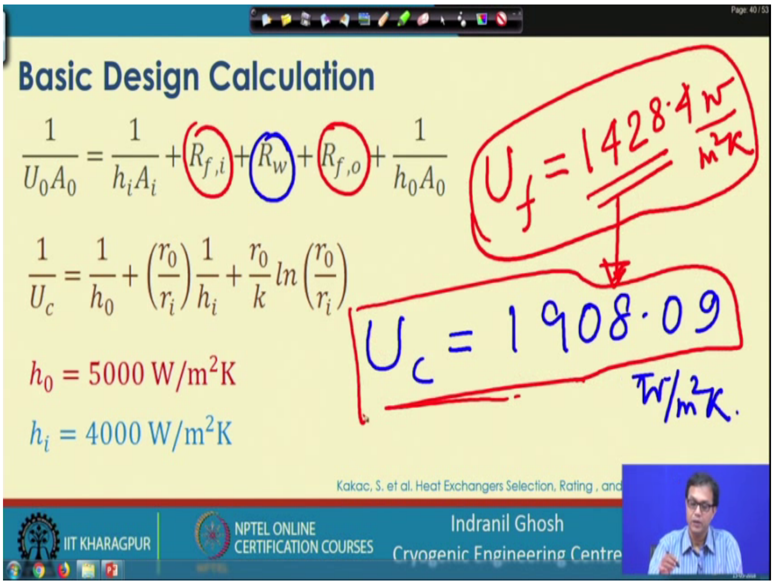
So, if we put all these values we will find U f; this U f where we consider the fouling resistance. This comes out to be 1428.4 watt per meter square Kelvin. Now, we also try to find out if it is a clean surface; that means, if there is no resistance given or offered by the fouling.

(Refer Slide Time: 21:06)



So, in that case what will happen? We will find that this term is not there in that case we define it let us look into that condition.

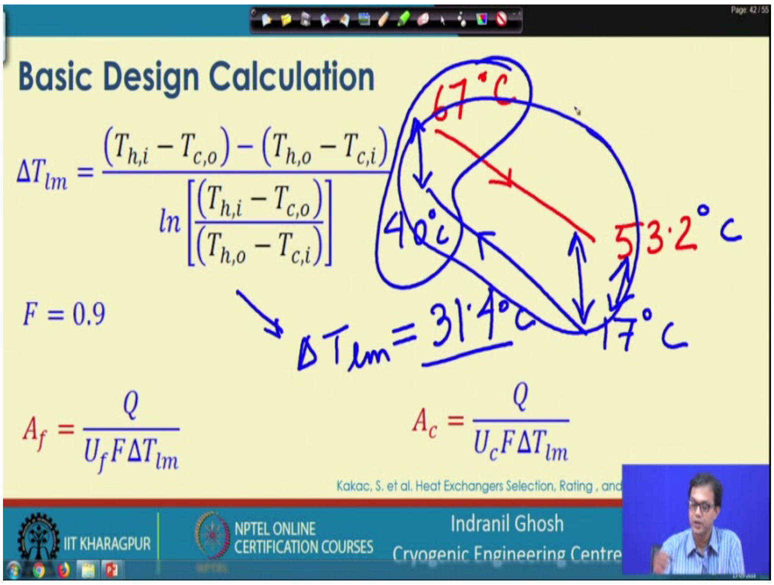
(Refer Slide Time: 21:23)



Here in this case as you can see that this part is not there. So, when this part is not that corresponding r value is not appearing here. And in this case all the other parameters being known we can try to find out U c and this will come out to be 1908.09 watt per meter square Kelvin. So, you can understand that this is in contrary to or in contrast to our earlier value where we were considering the fouling resistance and that was appearing 1428.4 watt per meter square Kelvin.

So, this resistance oh I am sorry not this is the fouling resistance. This fouling resistance contribute I mean we are considering when we are considering the fouling resistance, we are finding that the heat transfer overall heat transfer coefficient is substantially small as compared to the clean heat exchanger. So now we will try to find out based on this information, we have already have the knowledge about the overall heat transfer coefficient.

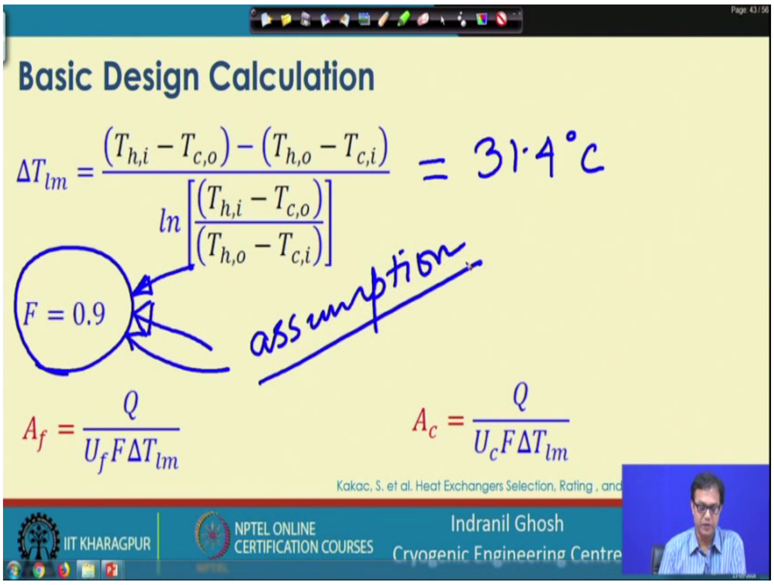
(Refer Slide Time: 22:58)



Then we have the knowledge about the heat transfer. So, next is we have the knowledge of the overall temperature profile or rather the exit and inlet temperatures. So, we will be able to find out what is the log mean temperature difference, if the fluids are arranged in a counter current exchanger configuration. So, if we look into it, we will find that the hot fluid is coming from 67 degree centigrade and it is coming degree centigrade it is coming to 53.2 whereas, the cold fluid is entering from 17 degree centigrade and it is coming out at 40 degree centigrade.

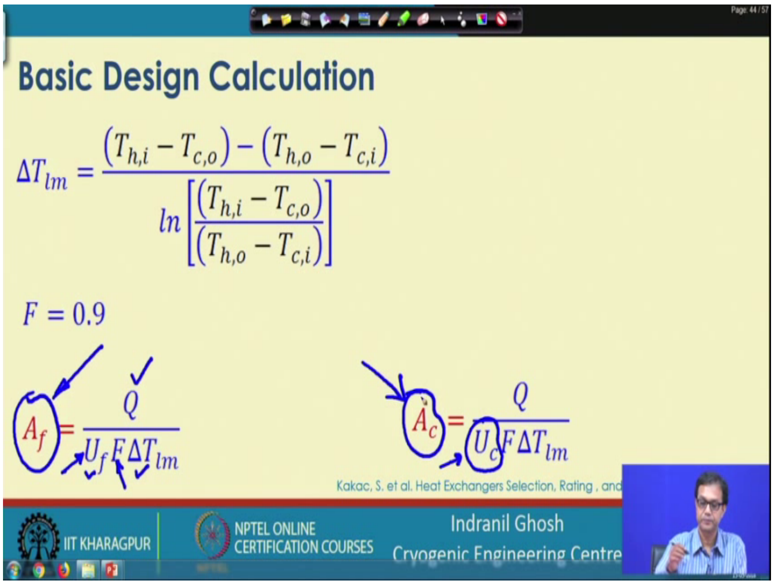
So now, we can find out the delta T 1 and delta T 2. And we will find that this difference and this difference will be appearing in this expression to give us a delta T lm of we will be able to find out this one, this will come out if you put all these values you will find that this is coming as 31.4 degree centigrade as the delta T log mean. So, in reality this is this is true only for the purely counter current exchanger, but in reality it is not.

(Refer Slide Time: 24:23)



So, this is 31.4 degree centigrade and we are assuming a correction factor of 0.9. So, this we have already learned that for a cross flow type or if I mean when we have a single pass single tube heat exchanger single cell what would be the corresponding correction factor, but we are just assuming it at this moment this assumption has to be later on you know rectified. So, this is an assumption and based on that assumption, we are now trying to find out the, if we now look we have the knowledge of Q.

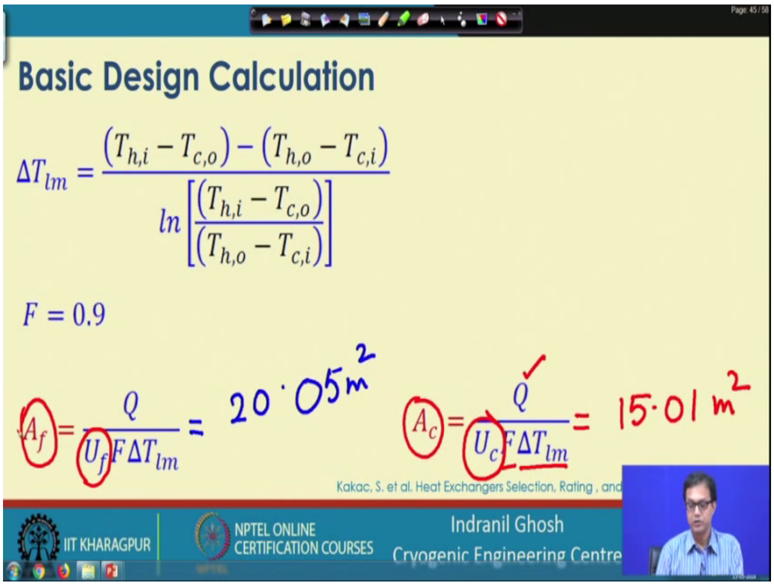
(Refer Slide Time: 25:35)



We have the knowledge of delta tm we have the knowledge of U f and we have assumed correction factor. So, accordingly we would be able to calculate the A f, A f corresponding to the overall heat transfer coefficient, where this is considering the fouling and here this is where we have not considered the fouling and this is basically a clean heat exchanger.

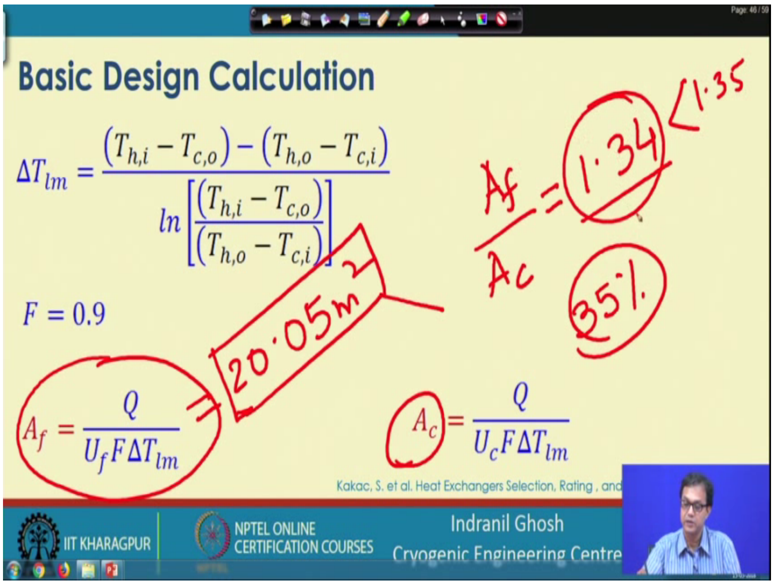
So, accordingly, we will be able to find out another heat transfer surface area and; obviously, as you can understand that this will be higher than this one. So now, we will try to estimate this one.

(Refer Slide Time: 26:26)



And you will find that this is coming to be 20.05 meter squared, whereas, the other one will come to be 15 point if you put all these values meter square. So, the Q remains same. The delta T lm F remains same and only thing is changing is U f and Uc that is giving rise to different kind of overall area, which is to be taken into consideration for the heat exchanger calculation. Now, once we know this heat transfer surface area, which is necessary and obviously.

(Refer Slide Time: 27:27)



We will be going by this surface area which corresponds to 20.05-meter square. So, our calculation will be based upon this one because eventually we find that the fouling is going to occur. And this fouling is going to be there. So, that if we do not take that extra area, the desired performance of the exchanger is cannot be expected after certain time.

So now, if we look into the area of this A f by A c. So, this is what is the clean surface area and this is anticipating some kind of fouling, what is this ratio this comes out to be 1.34. So now, if you look at that we have been told that the over design should be less than 35 percent. So, as we can understand that this is less than one point 3 5. So, this design is or this over sizing is within the limit.

Thank you.