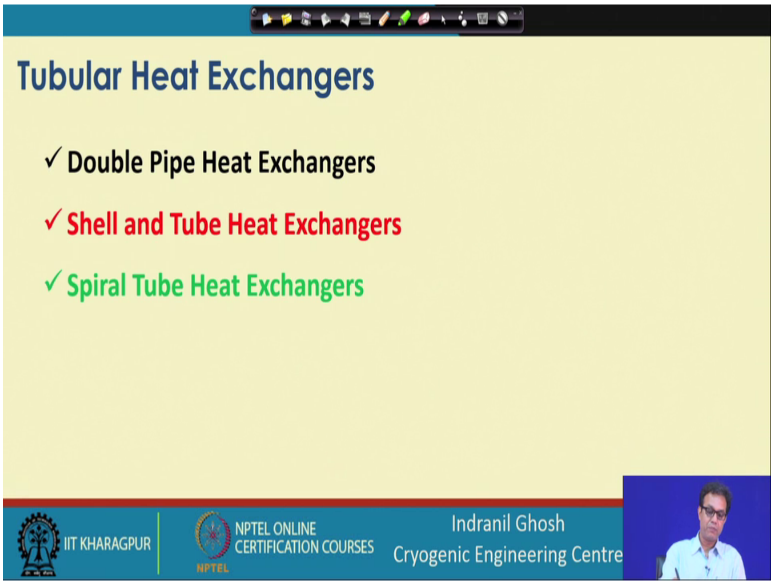
Heat Exchangers: Fundamentals and Design Analysis
Prof. Indranil Ghosh
Cryogenic Engineering Centre
Indian Institute of Technology, Kharagpur

Lecture – 10
Tubular Heat Exchangers Types

Welcome to this lecture where we are going to discuss about the Tubular Heat Exchanger and the various types of tubular heat exchanger those are present in the market.

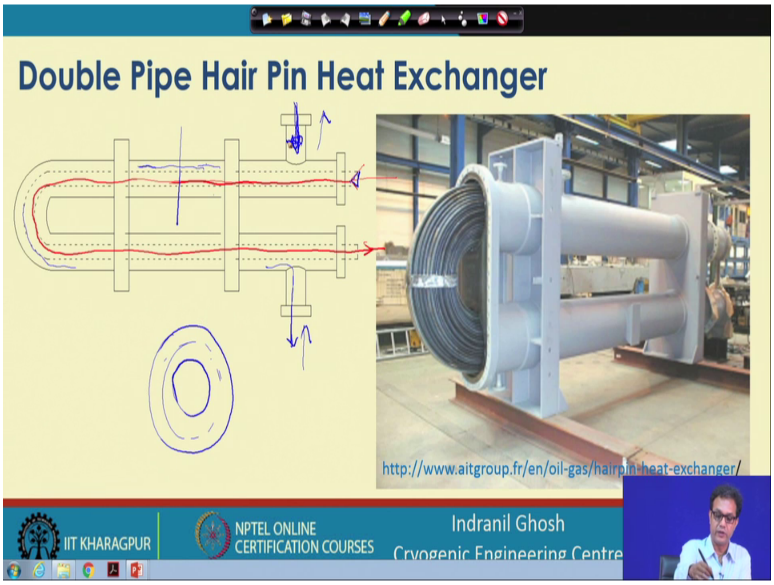
(Refer Slide Time: 00:30)



So, far we have talked about different heat exchangers, design methodology and analysis. And we have seen that most of the time we are taking the heat transfer coefficient of the fraction factor that is already given. But in reality we will find that those are the parameters which are to be determined and first of we will start with the geometry which are very simple and gradually we will go into the complicated one.

So, we will start with the tubular heat exchanger where the simplest geometry that we have already discussed about is tube in tube or more commonly known as double pipe heat exchangers. Then we will talk about the shell and tube heat exchangers and another variety of it is the spiral tube heat exchangers. So, before going into the details we will just try to have a look into this exchangers how it look like in reality.

(Refer Slide Time: 01:37)



So, the double pipe heat exchanger; if you look at this is a heat exchanger is a double pipe heat exchanger where you can see the you can understand the size of the exchanger from this diagram that and you will find that the tubes are coming or the fluid is coming from one end to the other end through this bunch up tubes.

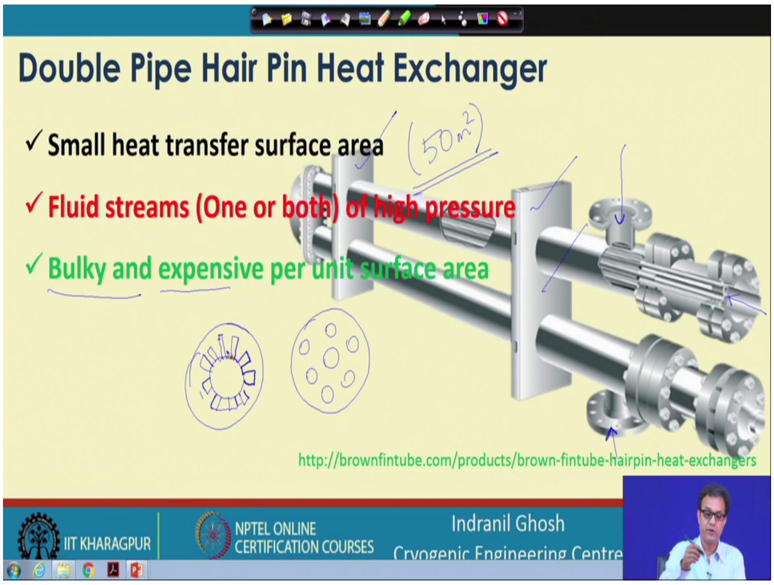
If we just try to look into it schematically, we will find that one fluid will be entering from this end and that fluid will be flowing through this inner tube from this end to this end and it will come out from this side. That is about the other fluid this is say one of the fluid streams, the other fluid stream will come from this end. So, it will end here; enter here into this heat exchanger then it will flow through this annular space.

If I take a cross sectional view of this one we will find that there is an outer tube this is the inner tube and this is the annular space through which the this blue coloured fluid is flowing. And it will come like this and finally, it will move out through this end.

Now, depending on the direction of the flow it may enter from this side and it may come out from this side or it may enter from this end and finally, come out from this end. So, during the initial phase you can understand that if the fluid is entering from this end; this will be in parallel flow in combination to with respect to the second fluid. Whereas, if it is entering from this side you will find this will constitute a counter current configuration. Whereas, if it is entering from this end this will with this will be in parallel to this flow and that will make a parallel flow arrangement of the heat exchanger.

So, this is the simplest possible geometry where we find we call it double pipe heat exchanger or often it is called double pipe hair pin heat exchanger. We know the hair pin like it looks like pin like this and this is similar to that configuration; so, that is why we call it hair pin heat exchanger. So, this is one of the simplest geometry that is possible with the; this heat exchanger.

(Refer Slide Time: 04:38)



And then if we look at I mean this is another configuration, this is from the brown fin tube company. And this is another double pipe hair pin heat exchanger in reality how it looks like. And depending on the configuration what I mean is that say this is the some of the characteristics of this heat exchanger is that; the this type of exchangers are in use when we need a small heat transfer surface area.

Also the this particular type of heat exchanger is suitable for high pressure fluid streams, when both or one of fluid stream is bearing very high pressure and we can think of using this kind of exchanger. On the negative side what we have is it is bit bulky and it is bit expensive per unit surface area; typically it is having about a say 50 metre square of surface area. And about this when we need in a typically of this kind of surface area and high pressure fluid stream, we go for such kind of heat exchangers and it is have a I have said that it is bulky and it is bit expensive.

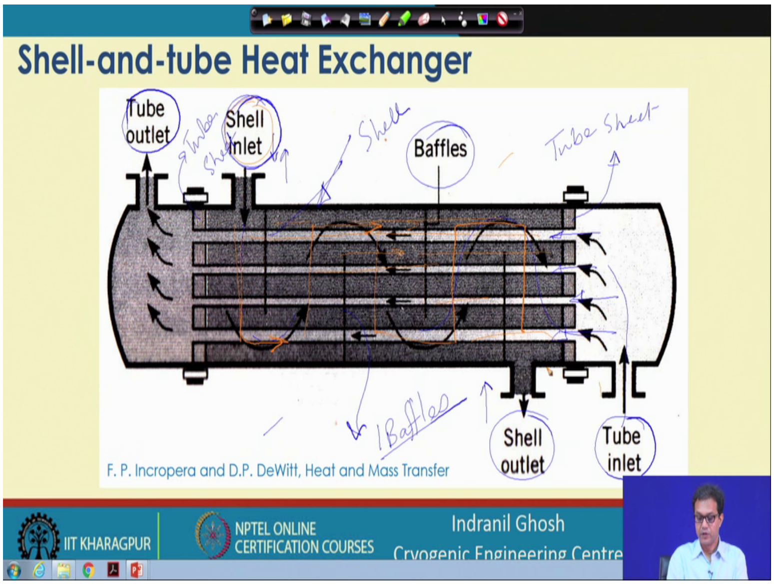
Otherwise it is very simple and this 2 are the supports which will keep it in horizontal opposition or in position. So, one fluid will be entering from this end and the other fluid will be entering from this end or it may also enter from this end depending on the counter current or the parallel flow arrangement that is to be made.

Now, here in this if we take a cross section from this end; you will find that it may so happen that this annular flow I mean annular passage may have a single tube or it may have a bunch of tubes like this. This is also possible I mean we may have depending on the configuration, we may have bunch of tubes or a single tube.

So, it is not a then double pipe it will have multiple tubes multiple pipe and it may also have depending on the heat transfer coefficient of this annular space; if we find that the heat transfer coefficient of this annular space is small, then we may have to use a extended heat transfer surface or fins on the this side on the outside of the inner tube; this is particularly for a single tube or multiple tubes.

So, this extended heat transfer surface will try to compensate that smaller heat transfer coefficient on the annular space. So, depending on the process requirement; we may go for an extended heat transfer or finned tube configuration, we may also go for multiple tube configuration of this a double pipe heat exchanger.

(Refer Slide Time: 08:11)



So, next is the shell and tube type heat exchanger it is one of the most common configuration; we commonly look in I mean get in the industries.

So, here you can see that we have a shell and we have the tube, we have bunch of tubes you know this is the tube inlet through which the fluid will enter to the heat exchanger I mean this is the tube side. And we have this is the tube sheet in the tube sheet we have the holes through which all this tubes will pass through, there is also another tube sheet on this side. So, this tube sheet will have holes through which this tube will pass through. And, in between you know this whole tubes sheet on both sides will be enclosed by the shell.

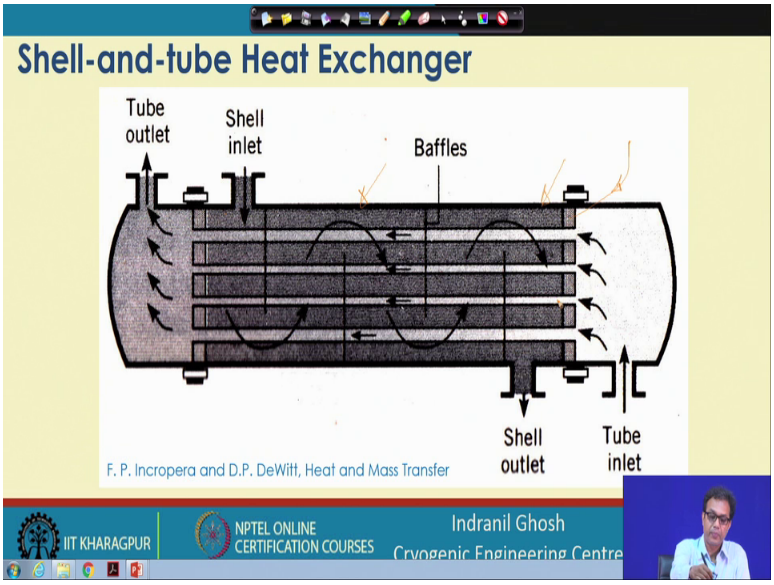
Now, the shell side fluid will enter from this end and it will come out from this end or it may also have a different configuration or it may I mean the, it is allowed that the fluid may you know enter from this side and it may come out from this side also depending on the configuration. Now, this is the tube side fluid going in and coming out and locally the shell side fluid this is a 2 fluid configuration where the shell side fluid is coming and passing over the tubes these are the baffles these are called the baffles. So, as we have written here this baffles will try to arrange the fluid or divert the fluid from one into the other like this it; it will be flowing like this from one end to the other end.

So, if we look into if this baffles are say not there; if we imagine that we have removed this baffle; so, what will happen? This shell side fluid will coming and it will flow like this in parallel or it is in the counter current a configuration, if it is entering from this end and this will be flowing on to this side through this annular space and it will come out.

So, it will be basically counter current or parallel current arrangement, but if we look at the stain time of this fluid it is very small. Whereas, on this side if we have baffles it is coming like, this it is cross flow. And then here this is a counter current arrangement then again it is flowing in cross flow, again it is in counter current arrangement then cross flow. So, this cross encounter current arrangement will allow the fluid to stay for longer time and have a larger heat transfer time.

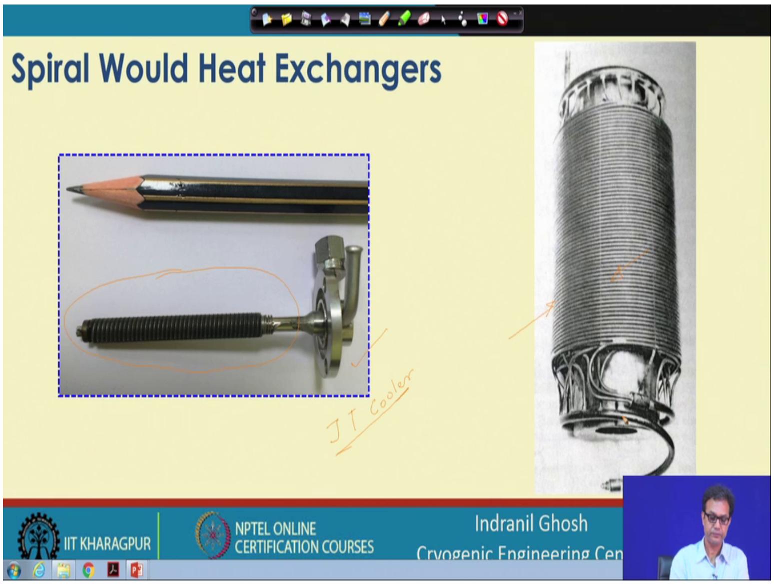
So, as a result what will happen? We will find that; obviously, the heat transfer will enhance, but at the same time we will find that the pressure drop penalty has also to be paid. So, this is what is in a nutshell about the shell and tube heat exchanger there are different kind of shell and tube configurations which we will be dealing later on.

(Refer Slide Time: 12:39)



As you can understand that if this you know these are the tube sides and this is the shell side. This tube sheets and the shell if they are welded together and if there is differential temperature I mean between; obviously, there will be differential temperature between the hot and the cold fluid.

But if that difference in is very large between the shell and the tube that may result in some kind of; I mean expansion which is or say the thermal stress may be generated and which if it is not designed properly that may be disasters. So, we may have to design it in such a way that the thermal contraction or thermal expansion due to differential temperature between the shell and the fluid type; I mean fluid flow has can be taken care and it is not I mean generating some kind of thermal stresses which is not good for the heat exchanger.

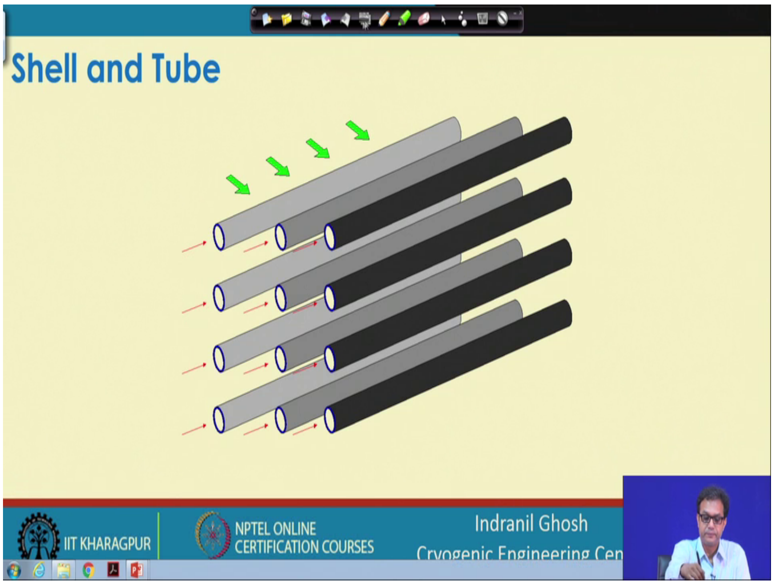


So, now we will try to move to the third one; this is spiral wound heat exchanger. You can look into the size of this particular exchanger it is just not you know larger than just a finger tip or a small finger.

And, this kind of exchangers are in use particularly in cryogenic both this examples have been taken from the cryogenics. This is typically a Jock Hampson heat exchanger, this is a spiral tube heat exchanger. Whereas, this is a; this particular Jock Hampson tube heat exchanger I mean it is a tube exchanger or tubular exchanger without any fin; whereas, this particular spirally wound heat exchanger it is having integral a finned tube.

So, this is spirally wounded on a mandrel as well as that is having integral fin on top of it, we call typically this is called J T cooler heat exchanger; this is a J T cooler and this is called Jock Hampson heat exchanger.

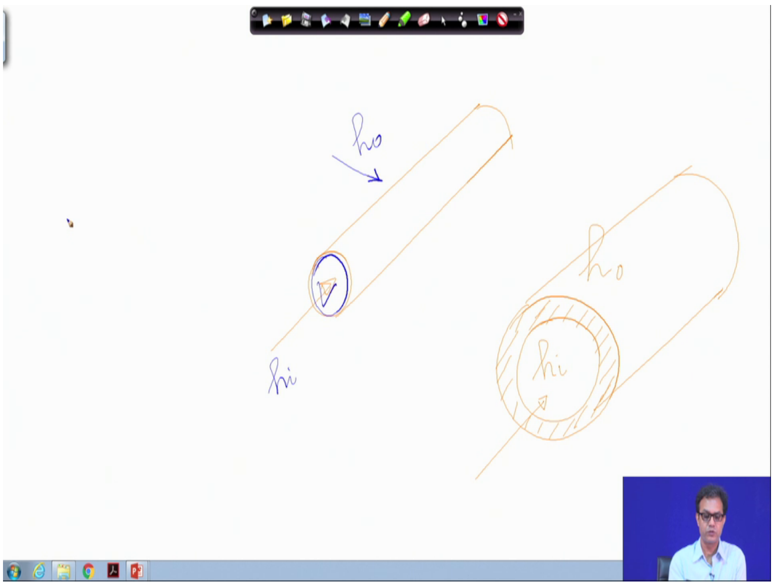
(Refer Slide Time: 15:37)



So, we will not go into details of this one at this moment; here we will rather look into the as we have said that we will try to find out what is the heat transfer coefficient I mean available for both the both the shell side or the tube side.

So, first of all if we look into this all this tubular heat exchanger configuration; we will find that one of the fluids is passing through the tube whereas, the other tube is passing through the shell side.

(Refer Slide Time: 16:21)

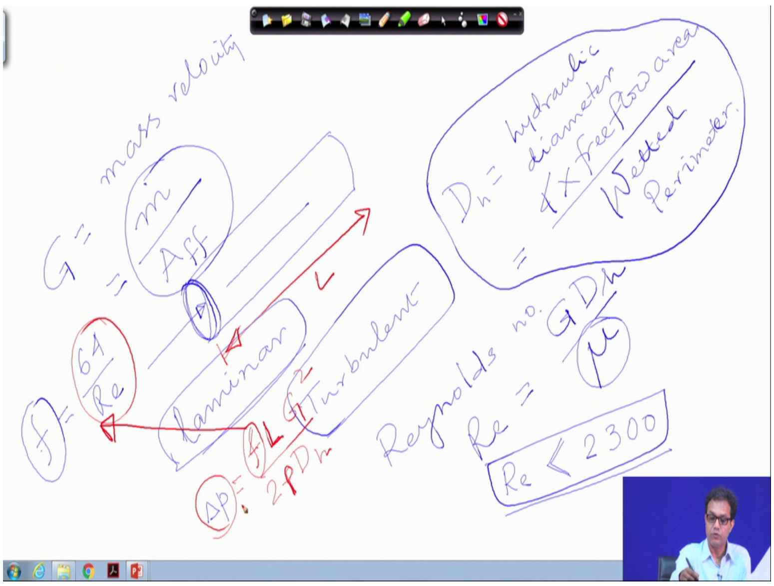


So, what we need to look into is; what we need to look into is the internal flow and sometime we also need to look into the external flow. So, one fluid is flowing inside this tube; so, when we talk about we talk about the internal heat transfer coefficient. And also this is the wall most of the time we neglect the resistance offered by the metal of this wall and we also have the external heat transfer coefficient.

So, far in our analysis we have assumed that this heat transfer coefficient has already been given to us. But this time we are trying to find out how this heat transfer coefficients are known or how this have these are to be estimated? So, here for the internal flow; we have some kind of correlation, for the external flow depending on the type of fluid flow; we will have a different type of heat transfer coefficient and for the internal flow we have different type of heat transfer coefficient correlations.

So, first of all we will try to look into the internal heat transfer coefficient. And there are different types of correlations available in the; I mean different textbooks, you will be able to follow in, I mean you can follow any one of them.

(Refer Slide Time: 18:02)



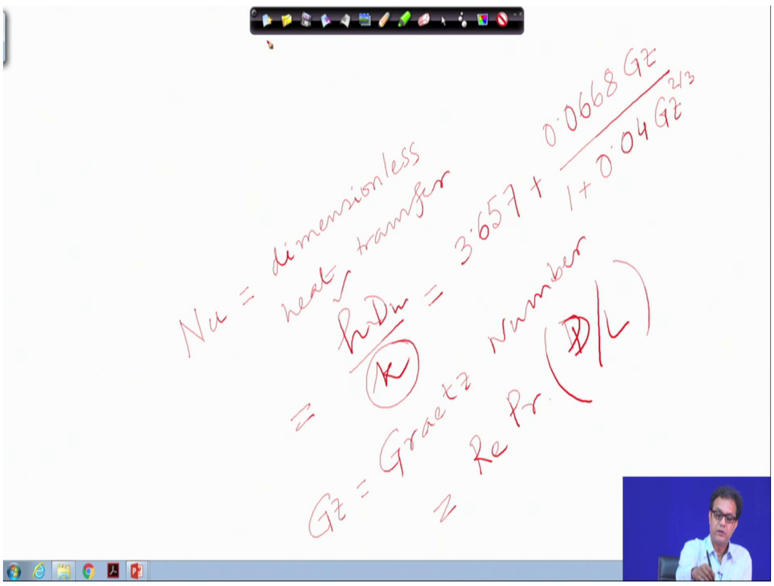
Now, when we talk about the internal flow through a circular tube; what we need to know also how is the flow condition. Whether this flow is laminar or the flow is turbulent; depending on that the heat transfer coefficient will change.

So, what is the transition? I mean how we will we know whether it is in the laminar flow or in the turbulent flow? So, first of all what we need to find out is the Reynolds number, it is a dimensional wise number we often call it Re; the Reynolds number. And we define it by G D by mu, where this D h is the hydraulic diameter; it is called the hydraulic diameter. And we define it as 4 times the free flow area divided by weighted perimeter.

So, this is how we define the hydraulic diameter; what is G? G is known as the mass velocity, this is mass flow rate per unit free flow area. So, this is how we define the mass velocity and mu is the viscosity of the fluid. So, if this Reynolds number is less than 2300; 2300 then for a circular small circular pipe we assume that the flow is a laminar.

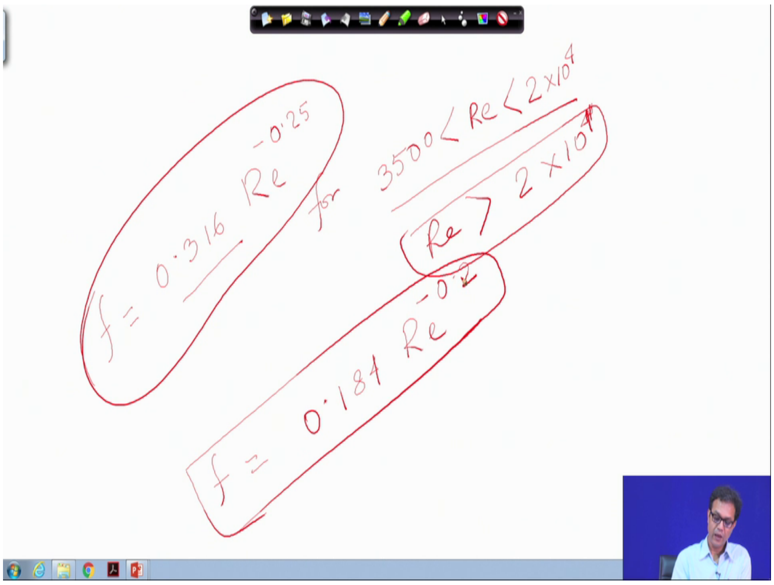
So, if it is having a laminar flow through this circular pipe or circular tube; we will assume that it is laminar and the friction factor will be given by 64 by Re, where Re is the Reynolds number. And why do we need this friction factor? Because in any heat exchanger design one of our concern is the pressure drop and we define this pressure drop as f L G square by 2 rho and then the hydraulic diameter that we have defined. So, this f in case of laminar flow configuration through a circular pipe, we will be using 64 by Re. We have the G as the mass velocity, L is the length of the tube and this rho is the density of the fluid. So, this is how we calculate the pressure drop across the length of the tube. So, now let us look into the Nusselt number; this is again a dimensionless heat transfer coefficient.

(Refer Slide Time: 22:04)



This is a dimensionless heat transfer coefficient and we define it by h D by k, where h is the heat transfer coefficient, D is the hydraulic diameter and k is the thermal conductivity of the fluid. So, this is given by 3.657 plus 0.0668 Graetz number divided by 1 plus 0.04 Gz to the power 2 third where this Gz is called Graetz number. And we define it as Re into P r and D by L; sorry this is D by L, this is what is the Graetz number.

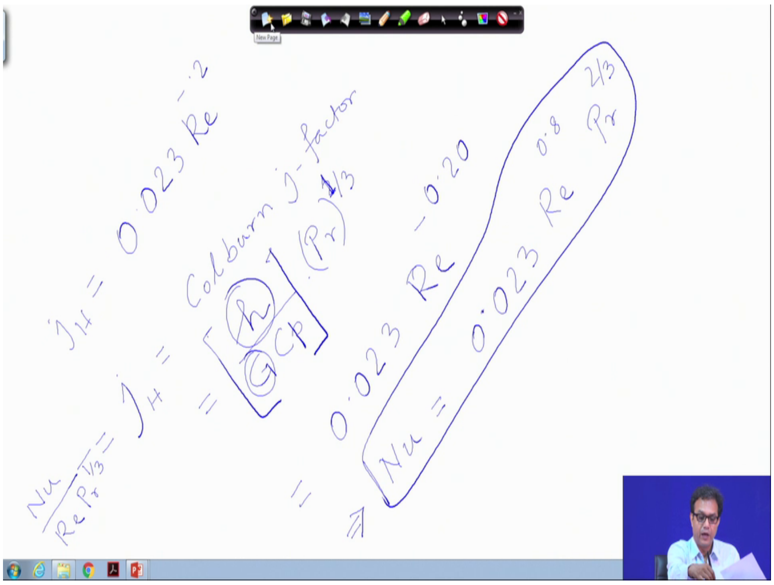
(Refer Slide Time: 23:49)



So, this is about the laminar flow region and when we have the turbulent flow in that case this fraction factor will be 0.316 Re to the power minus 0.25. And this is for the Reynolds number range between 3500 Re less than 2 into 10 to the power 4. And for Re greater than 2 into 10 to the power 4; we have this f equals to 0.184 into Re to the power minus 0.2.

So, these are the correlation for the turbulent flow where we understand that the friction factor values are like this. So, if the Re range is between 3500 and 2 into 10 to the power 4; we have this kind of the friction factor. And similarly we have when the Re is on the higher side more than 2 into 10 to the power 4, we have 0.184 Re to the power point minus 0.2. And what is about the friction fact, what is about the heat transfer coefficient?

(Refer Slide Time: 25:21)

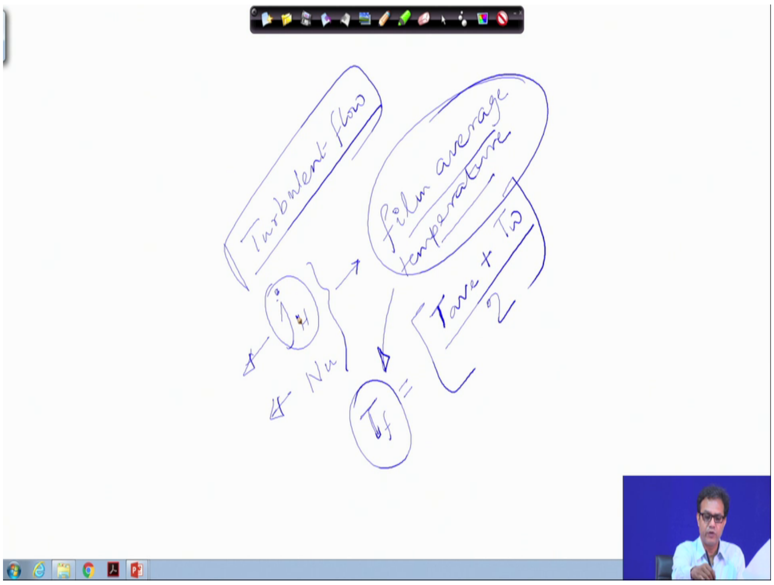


The heat transfer coefficient we can generally it is either defined in terms of the Nusselt number or it is often it is defined in terms of the Colburn j factor; it is given by h by G C p, where h is the heat transfer coefficient G is the mass velocity C p is the Stanton number this is nothing, but Stanton number into Prandtl number to the power 2 third Colburn j factor.

So, I am sorry this is Prandtl number to the power one third. So, this is what we will find as 0.023 into Re to the power minus 0.20. So, this will become if we express it this j is also this j can also be written as the Nusselt number divided by Re to the power P r to the power one third.

So, this becomes if we want to express it in terms of the Nusselt number then the Nusselt number becomes 0.023 Re; it becomes Re to the power 0.8 and P r one third and P r one third, it becomes P r 2 third. So, this is in terms of the Nusselt number or in terms of the Colburn j factor, this is just j H equals to as we have said 0.023 into Re to the power minus 0.2.

(Refer Slide Time: 28:06)



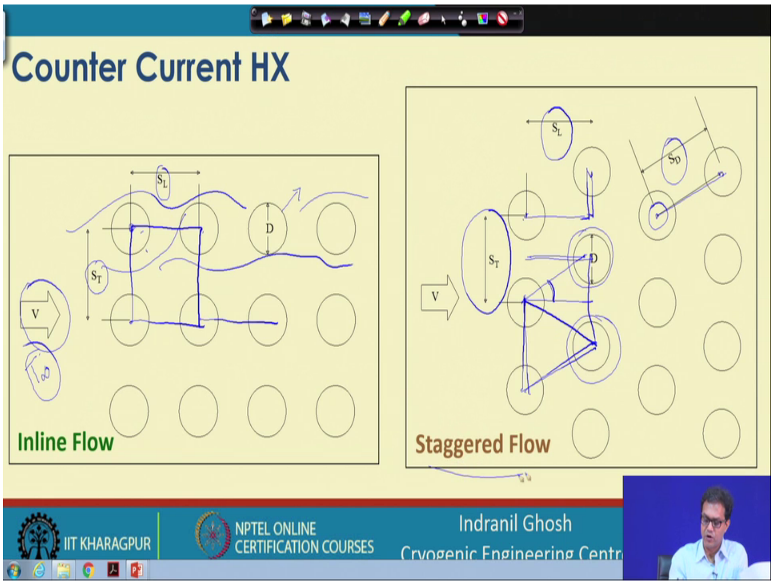
Now, on this j H or say the Nusselt number as we have written for the turbulent flow, all the fluid properties are evaluated at the film average temperature; what is film average temperature? It is the average fluid temperature, this is T f is average fluid temperature plus T wall temperature divided by 2.

So, this is how we evaluate this film average temperature and all the fluid properties have been evaluated at this film average temperature while calculating the cold burn j factor or the Nusselt number. So, this is very important so far as the estimation of this fluid properties are concerned. And we should deviate from that film average temperature or for evaluating the fluid properties, otherwise we may have you know a possibility that we will be calculating a wrong cold burn j factor or the Nusselt number; so, this we have to keep it in mind.

Now, if we go back to our discussion here, we will find that this is when we talked about the internal flow; whether it is laminar or turbulent we have the internal heat transfer coefficient in terms of the Nusselt number or the j factor. And from there we would be able to calculate the heat transfer coefficient H that will give you the internal heat transfer coefficient.

Now, if we have a bunch of a tubes and over which the fluid is flowing on top of it then we may have to I mean; if we have to calculate the heat transfer coefficient on the external flow, then how do we do that?

(Refer Slide Time: 30:44)



So, depending on the configuration we may find that this these are the 2 possibilities I mean in which in one of the flow configuration, we will find that this fluid is flowing on a band cup tube this is the cross sectional view. And this are the, I mean fluid flow direction this is the internal flow through which fluid is flowing and this is the external flow; this is how it is flowing through this over the tubes, over the tube bands.

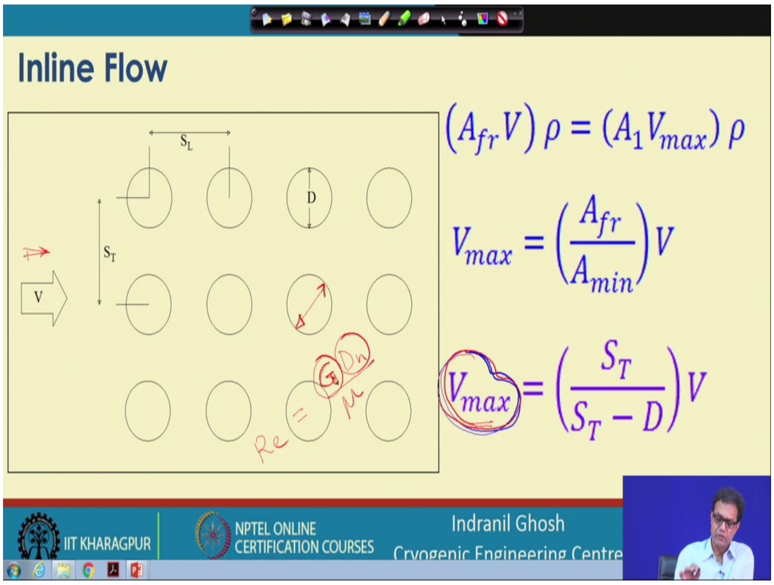
This is called this distance between the centre line distance is called the transverse pitch and this distance between the 2 consecutive tubes in the flow direction is called the longitudinal pitch. And, D is the external diameter of the tube and the frontal velocity or the first stream velocity is V and let this be flowing at a temperature; T infinity.

So, if it so this is the inline flow where the fluid I mean the tubes are arranged in line to the; I mean one is just after the other or it is all of them are in line. So, this is called the inline configuration, we may also have a configuration like this where they adjust offset this second row of tube is offset and it is just in between the 2 fluids. I mean though 2 tubes there is the third one or the second row tube is just in between the this 2 tubes this tube and this tube and this is the third one; so, they are forming like a triangle.

So, here they were forming a this 4 were forming a kind of rectangle and this is a forming a kind of triangle. And depending on this angle I mean we may have a different flow arrangement and here I mean the heat transfer coefficient is possible. So, we have the transfers pitch, we have the longitudinal pitch for this is the longitudinal pitch; the centre line distance between 2 consecutive tips tubes in the flow direction. We also have another length this is the diagonal length called S D and this is also important in case of this staggered flow configuration or staggered configuration.

So, here what we now consider that depending on this inline or the staggered flow configuration, we may have different heat transfer coefficient possible.

(Refer Slide Time: 34:04)



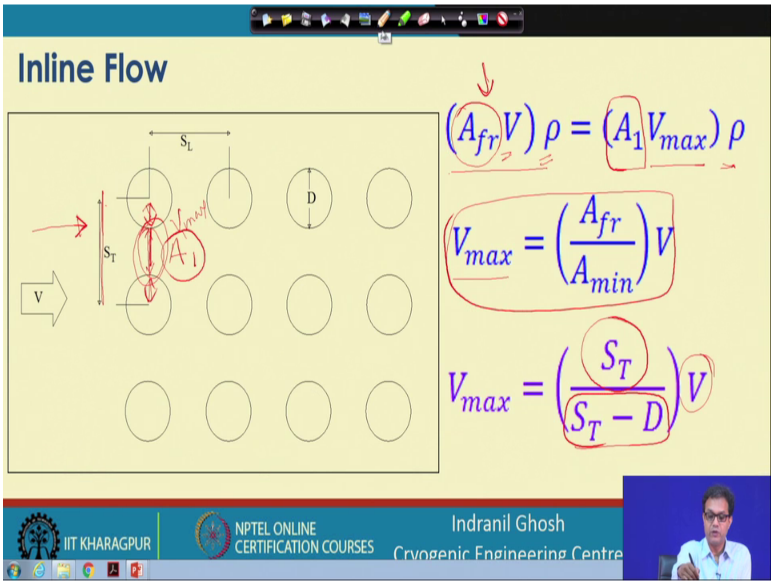
So, let us first try to find out what is the; what is there in the inline flow configuration? So, before going into the heat transfer coefficient; we will find that it is important to know what is the maximum velocity because that will be used to calculate the Reynolds number. And if you look at this Reynolds number where if it is either in terms of say as we have said that we define it; the Reynolds number we have defined it as G D h by mu.

And here this D h is the external diameter of this tube and what is the G? G is the mass velocity, so here the velocity of the fluid is V and it is flowing over a bank of tubes. And, we need to find out what is the free flow area or if we look at we need to we need to find out what is the maximum velocity that it is given; what is the maximum velocity we will how will we find?

So, whether it is occurring as you can understand that this maximum velocity in this particular configuration is suppose to occur at this location, where we have the minimum gap. So, the velocity of the fluid is taking place from this direction and here we have the minimum free flow area. So, that will constitute the maximum velocity at that point and how do we find out the maximum velocity?

We know that the total mass flow remains constant; so, if we write it in terms of this A f r; A f r is just nothing, but the frontal area multiplied by the velocity and the density this is just nothing, but the mass flow of the incoming fluid and if it is the flow rate is remaining constant.

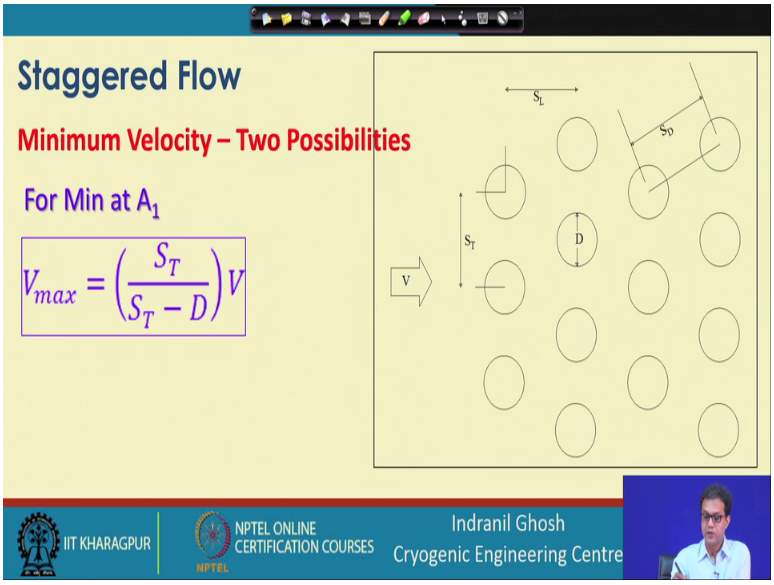
(Refer Slide Time: 36:41)



So, here this A 1; that is the area at this point and here you have the velocity say V max and corresponding the density is rho. So, we have a relation for the V max related to the frontal area and the minimum free flow area.

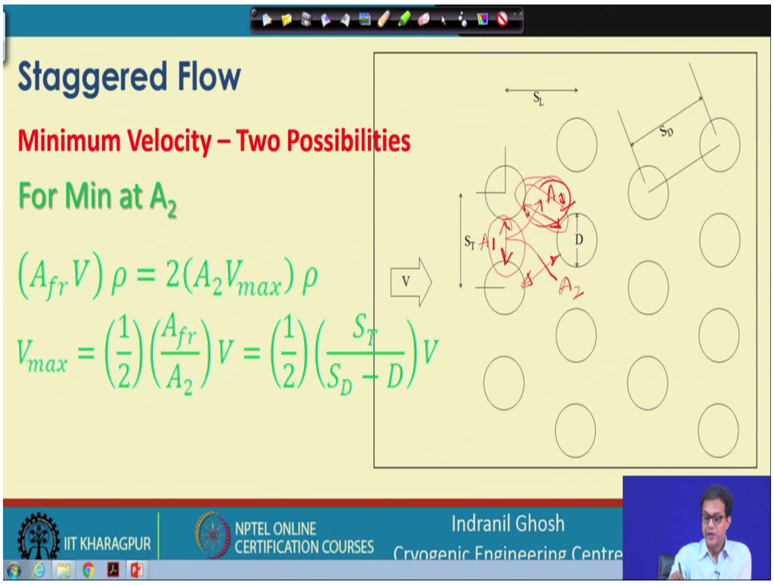
So, minimum area is if you look at the in terms of the pitch; we have S T that is corresponding to the frontal area and the minimum area is just nothing, but S T minus this length and this length. So, that will constitute D; so, S T minus D is the in the denominator and multiplied by V. So, Vmax is becoming S T by S T minus D into the frontal velocity or first stream velocity.

(Refer Slide Time: 37:44)



Similarly, now if we look into the standard configuration we have 2 possibilities.

(Refer Slide Time: 37:50)



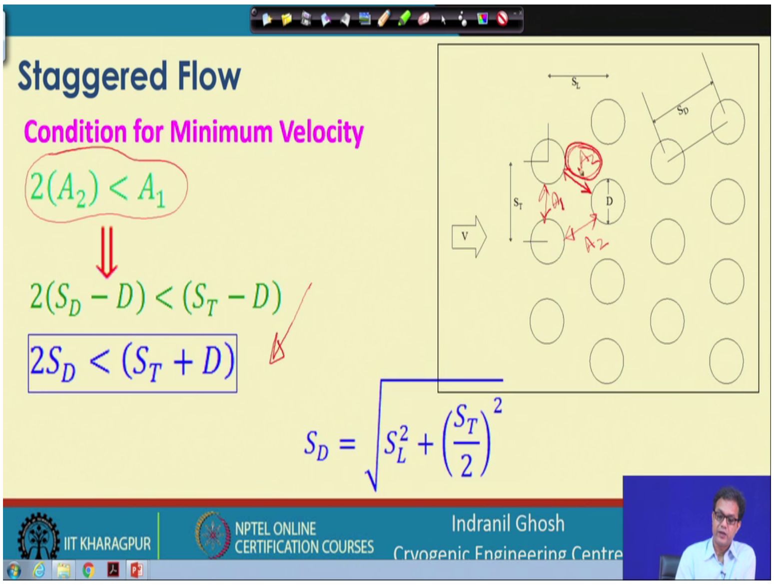
The free flow the free flow may occur at this point or depending on the configuration there is a possibility that the flow the minimum free flow can also be at this location. So, we have to look for this 2 possibilities; I mean one is already that we have seen that if it is A 1 and this is the other possibility A 2; if we have a free flow area depending on the configuration; if A 2 is the area where we are finding the minimum area and the maximum velocity.

So, in that case how the velocity looks like; so, if it is for the, if we go back to our previous slide this is if we have the minimum at say I am sorry; if we have the minimum flow flee free flow area or the maximum velocity occurring at this point then we have already looked into this configuration that A 1; if it is at A 1 then we have the V max equals to S T by S T minus D.

The other possibility is as we are talking about that if we have the free flow area occurring at this point; then this flow is getting coming here and this flow is coming over here. So, it is getting divided into 2 parts; so if we write that same equation, we now have V max is equals to half of frontal area divided by A 2, where A 2 is this particular area.

And this is; obviously, related to S D and this S D you will find, you will be able to relate it with the S L and S T. So, we have V max is equals to half of S T minus S T by S D minus D into V; so, and when will it happen? What is the condition?

(Refer Slide Time: 40:20)



Now, if this area A 2 or this is A 2, this is also A 2 and if twice A 2 is smaller than A 1, then only this is nothing, but A 1; then only we have this maximum velocity occurring at this location. So, if we just solve this one we will find that this is constituting a condition that 2 S D less than S T plus D that will give you minimum flow area at this A 2 or maximum velocity at A 2.

Thank you.