Heat Exchanger: Fundamentals and Design Analysis
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Lecture - 28
Plate fin heat exchanger: Pressure drop

Welcome to the lecture we are talking about the Plate fin type heat exchangers and as we know that pressure drop is equally important parameter in case of any heat exchanger. So, how do we estimate the Pressure drop in Plate fin type heat exchangers that we are going to study in this lecture.

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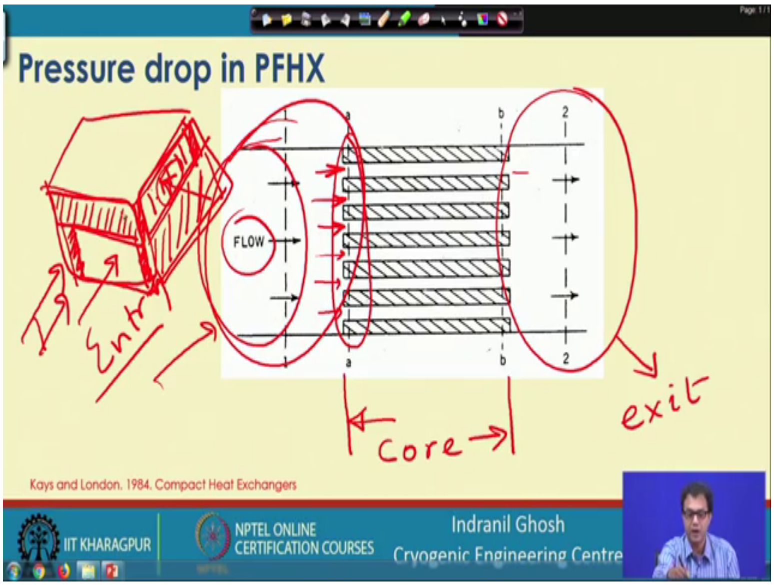

And say if we look into typical plate fin type heat exchanger this has been taken from Kays and London's Compact Heat Exchanger text book, you can also have a look into the fundamentals of heat exchangers by Shah and Sekulic, there you will have the detail description or the derivation of this equations of the pressure drop we will only look at I mean the final expression of the pressure drop in this lecture.

So, here if we look at we have a this is a cross sectional view; we will find that some of the passages are blocked, where some of the passages are open and through which the flow will take place. And these are the places through which the flow is taking place and it will again come out. So, this is what is the heat exchanger core you can say; so, this is the heat exchanger core and we have this is the entry region where it is the header and this is the other exit region. So, this is where the fluid is moving out this is the entry.

So, as you can understand that this flow when it is coming and reaching to this surface or this core; it will find certainly there is some kind of reduction in the heat transfer flow area. Earlier it was flowing through this area now it has some reduced area because some of the passages are blocked. You may remember that we have talked about the when we talked about the construction of the plate fin type heat exchanger; we have alternative hot and fluid layer.

And when this fluid is flowing through this direction; if we look into this you know the 3 D view; so if it is a plate fin type exchanger cross flow type and this is the side bar for this fluid flow. And similarly for this side you can see that this is the side bar. So, this is when this flow is taking place from this end; you will find that is it this side bar is blocked for this flow.

So, this flow can take place only if take this is as the frontal area; we will find that almost all a part of a 50 percent or you know some portion of the fluid flow area is blocked for this fluid. Similarly when this fluid is flowing from this end to this end, it finds that only it this passage is available for it, but it was coming from this end it was having this much frontal area.

But only this much flow free flow area it is having of course, the fins are there; fins will also block the passages and. So, we can say that there is some kind of contraction in the flow area and on the other hand what will happen on the on the exit end.

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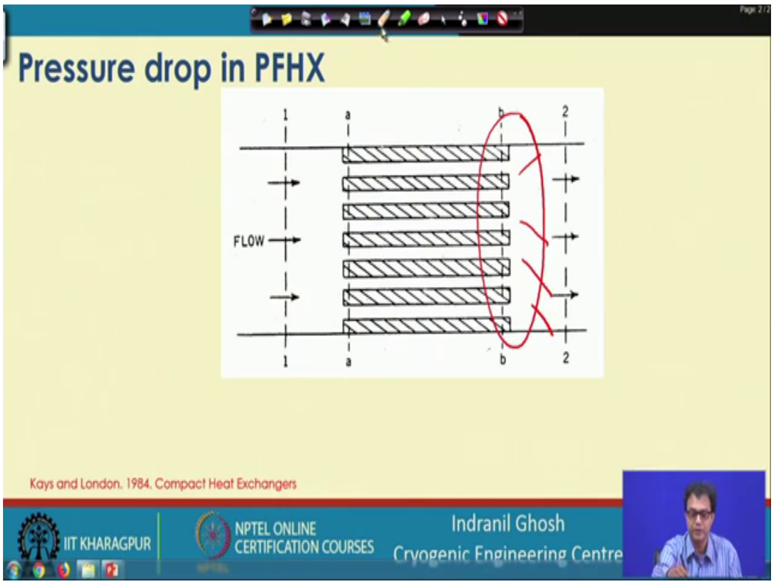

We will find that the flow is suddenly you know getting expanded. So, as a result; we can say that we have 3 components in this pressure drop.

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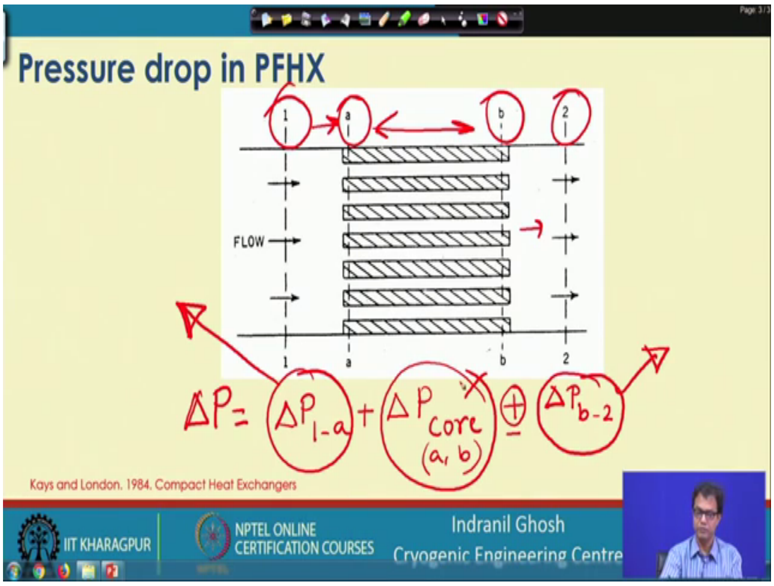

One is the core pressure drop; between this is the core pressure drop between a and b and this is if we divided it into a b and this is between a and b and this is between 1 and 2. So, we have some kind of delta P between 1 and a and then we have some kind of pressure drop in the core which will consist of we will come into that part. And there is another delta P actually here this will be a negative one and this will be minus b by b to

2. So, we have 3 components in this pressure drop one is the due to sudden contraction; then we have the core pressure drop then we have certain expansion and there it will give some pressure rise in this region.

So, here we have pressure drop; here we have pressure drop and here there is some kind of pressure rise; so, that is what is the total pressure drop in case of plate fin type heat exchanger. So, we have you know some means to estimate this certain contraction and certain expansion of this one. And finally, this core pressure drop we will have 2 terms for those core pressure drop.

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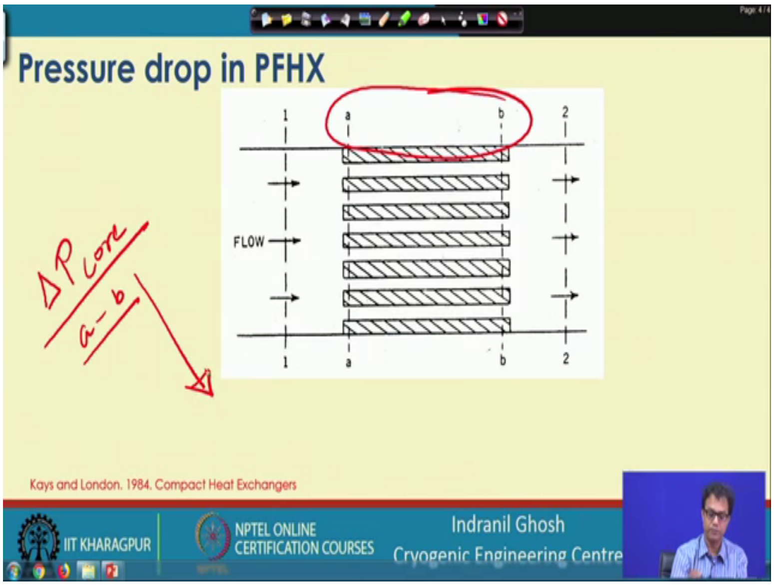

This pressure drop that is between core in the core where it is between a and b region this between the region a and b we have this core pressure it will consist of 2 parts.

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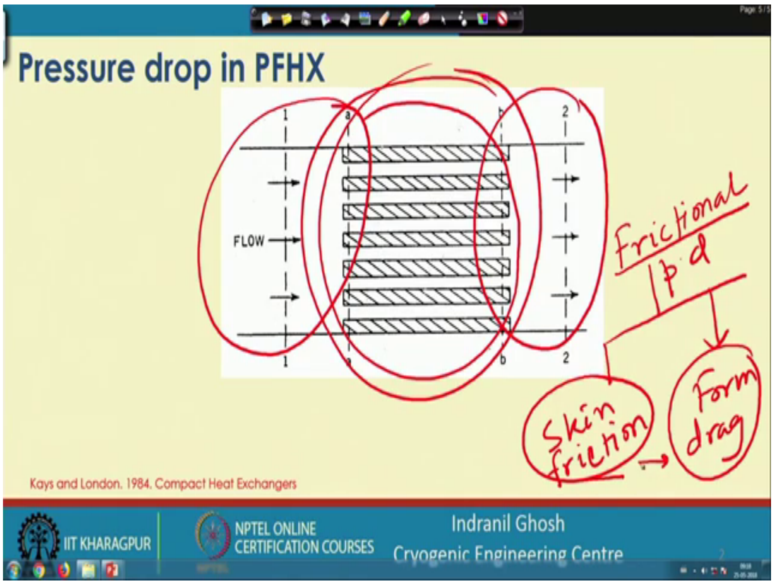

One part what we call it as the friction frictional pressure drop. This frictional pressure drop will have a 2 components one is the skin friction and skin friction and then you will have also the form dragged.

This 2 type of pressure drop we form dragged; these are the 2 type of friction type we will have in the this is the frictional pressure drop, which we will have within this one. Along with this frictional pressure drop we may have a pressure drop due to that change in rate of momentum and that will be taken into account. So, we finally, obtain that there are 3 components one is the entrance, one is the exit effect, one is the core pressure drop and this core pressure drop consist of 2 part one is the skin fraction friction and the other one is the form dragged.

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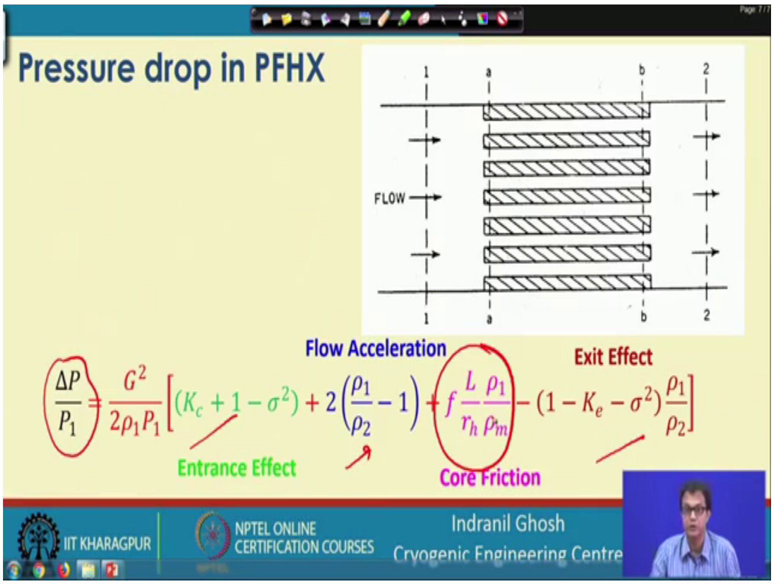

So, altogether what we find it is that we have a final expression given by this one this you will find from any heat exchanger book or by Kays and London or by Shah and Sekulic and others. So, where we have this delta P; ratio delta P divided by P 1 here this is the P 1 and on this side it is P 2.

So, it consists of so many factors here we will try to find out one by one. This is the entrance effect where we have K c plus 1 minus sigma square. So, we got 2 new term here one is the K c 1 is the sigma. Now this sigma is basically we will find that this is the ratio between the free flow area divided by the frontal area.

And this is the coefficient K c which takes account of the sudden contraction. And then we have another term is the, this is the rate of change in the momentum or we call it flow acceleration. Then we have the core friction as I told you that it will have both the skin friction and the form dragged associated and that will be included within the fraction friction factor f. So, we will not separately look into the form dragged or the skin fraction; both will be taken inside the friction factor f.

And we have r h; r h is the hydraulic radius and rho 1 and rho 2 are the density at the entrance and the exit end. Then we have the exit effect where we again find 2 more terms one is the sigma and another one is the K e. This K e takes care of the; exit effect or the coefficient of coefficient of sudden expansion.

So, we have now then 4 terms in the pressure drop correlation delta P by P 1. Earlier we were looking only into this part we have not taken care of the flow acceleration not the entrance effect or the exit effect or this flow acceleration; we have not encountered I mean in our earlier equation only we were talking about this delta P by P 1 is equals to this.

But if we want to have a accurate estimation of the pressure drop then we will have to take account of all this entrance exit effect. But you will find that this effects are very small in a in I mean as compared to the core friction; this entrance exit effects are very small. So, now, we will look into this.

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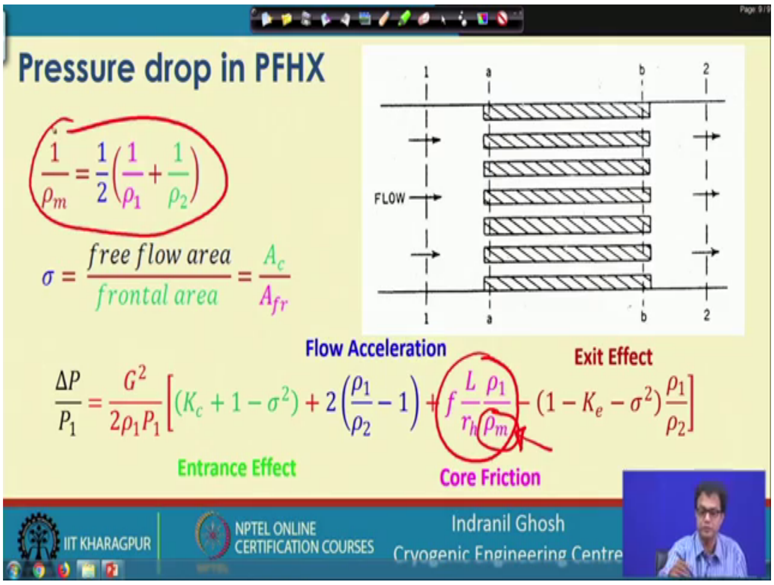

As we have told you that this sigma is the ratio between the free flow area and the frontal area and we defined it as A c by a frontal A f r. And so, most of the time we have an idea about the what is the frontal area of the heat exchanger. And we also know sometimes it is specified you will find that the sigma value will be given and from there we may have to calculate the free flow area or sometime we have the idea about the free flow area and that 2 ratio gives us the sigma value.

So, we have another term here we have encountered that is equals to the rho m; this is we have not, I mean this is a mean value this is an harmonic mean of say one by rho I mean rho 1 and rho 2. And this is given by rho m how this is there are related to each other.

So, that is what it this friction factor I mean when we are talking about the core friction; we are supposed to take this rho value the density of that fluid at mean value of the density. And that is basically an harmonic mean given by 1 by 2 in this equation given in this relation.

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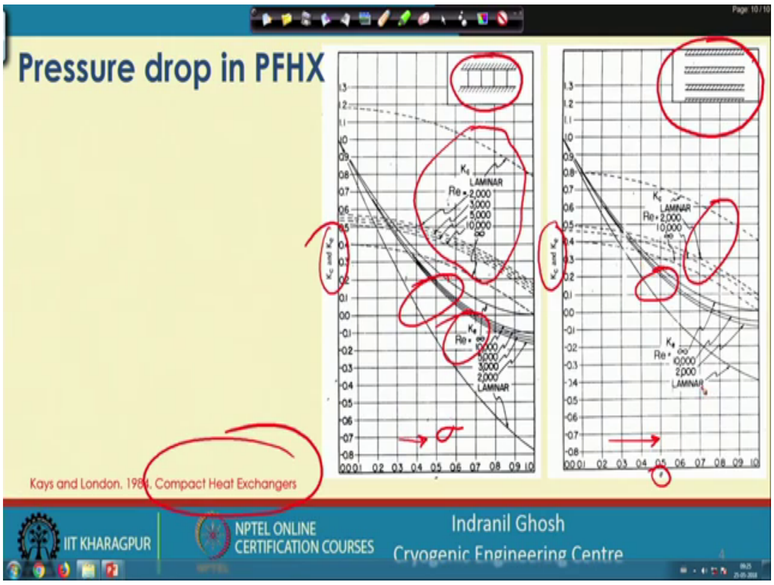

So, with this information now we will try look into particular problem where, but before going into that problem we need to look into the an estimate of this K e and K c; that is the coefficient of entrance and the exit. So, this is this has been taken from the Kay's and London's Compact Heat Exchanger book you can have a look into that.

So, here you can see that for a different kind of flow channels this is like channel, this is another channel where we have the flat tubes and this is a closed cell. And we have say for different this is where we have the sigma value on this side we have sigma it is not shown here. This is where we have the sigma value sigma value for different sigma value we have different K e and K c values.

So, we can see that this whole bunch is for K e the exit effect and this other I mean dotted lines takes account of the contraction coefficient of certain contraction. Similarly on this side we have for the certain contraction and this is for the K e. So, as you can see also that we have the coefficients for I mean this K e as a function of R e also we have for different R e values.

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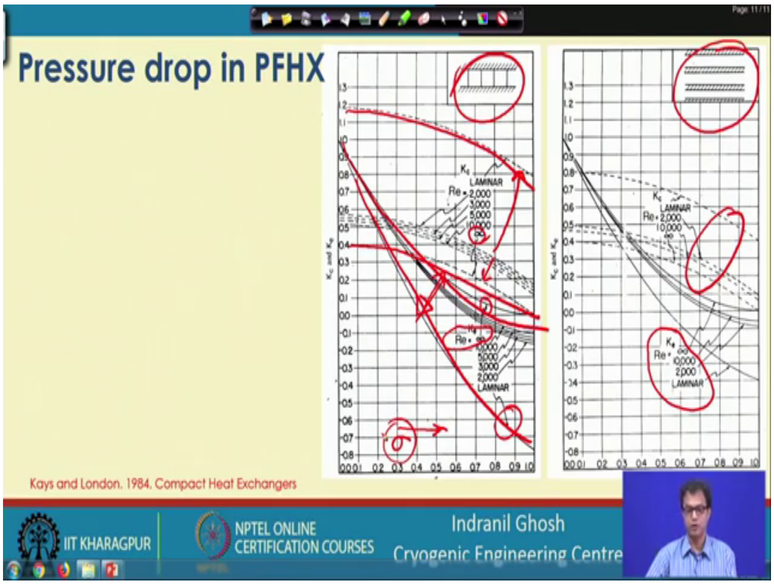

We have different K e and K c. So, not only that we have the sigma on the side we have the K e; K c values for different R e. So, depending on whether it is laminar or very turbulent where you I mean R e is infinite. So, between this limit we have the values of K e and K c; similarly we have for R e infinity at this one and the other end is the laminar one. So, between this limit this K c will vary and between this 2 limits the K c will varies for this kind of closed.

So, and this is for the flat tube where we have this is the K e K c and K e values. So, if we know about the sigma value and if we have an idea about the R e values then we can try to find out the K e and K c from this graph and try to estimate how much is the pressure drop due to sudden contraction and sudden expansion. But again as I told you that these constitute or give a very small percentage of the total pressure drop ok.

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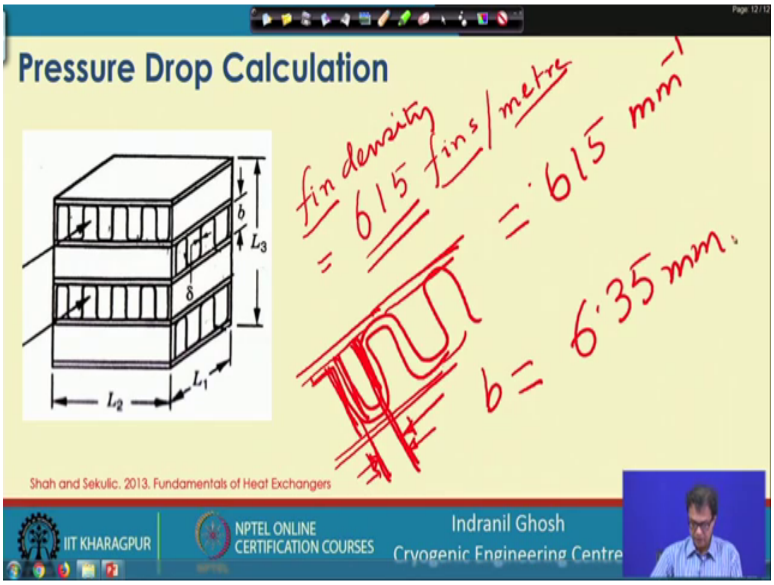

So, next we will go to numerical problem; here we try to numerically estimate the pressure drop. This example I have taken from the Shah and Sekulic's the Fundamentals of Heat Exchangers. And there are certain parameters or the specifications given and we will first note them down and then try to calculate the pressure drop or try to estimate the pressure drop. First of all for estimating the pressure drop what we need to know; what is the I mean the fins specification of the geometric specification.

Then we need to know; what are the operating conditions like what is the flow rate and etcetera. So, the geometric specification I mean that what are the fin types, what are the fin details and then what we need to know is the frontal area or the length and the width or the height of the heat exchanger then only we would be able to estimate the pressure drop.

So, the general idea is that we need first of all the geometric specification of the heat exchanger. Then we need to look for the we need look for the operating conditions. So, here for this particular one the fin density is given the fin density is given; the fin density what is mean by fin density? We have already talked about it and this is having 615 fins per meter fins per meter. So, if we have 615 fins per meter; that means, we have this kind of a fin say this is the separating plate, these are the separating 2 separating plates and we have this kind of fin and like this we have.

So, between how frequently they are appearing. So, that is what is the fin frequency. So, from this end to this end this is what is the fin spacing or this is the fin spacing or this will be I mean how many number of fins we have in 1 inch or 1 meter. So, we have 615 number of fins in 1 meter and thereby we can tell that 1 fin; how much is the distance between this fin to this fin; so, that is what we get an idea about of the fin spacing.

So, here we have the fin density that is 600 fins per 15. So, we have 615 power millimeter per millimeter we have this one. Then we have the plate spacing that plate spacing b that is equals to 6.35 millimeter. So, we have 6.35 millimeter at the; plate spacing then we have the fin offset length. So, as we can now understand that is an offset.

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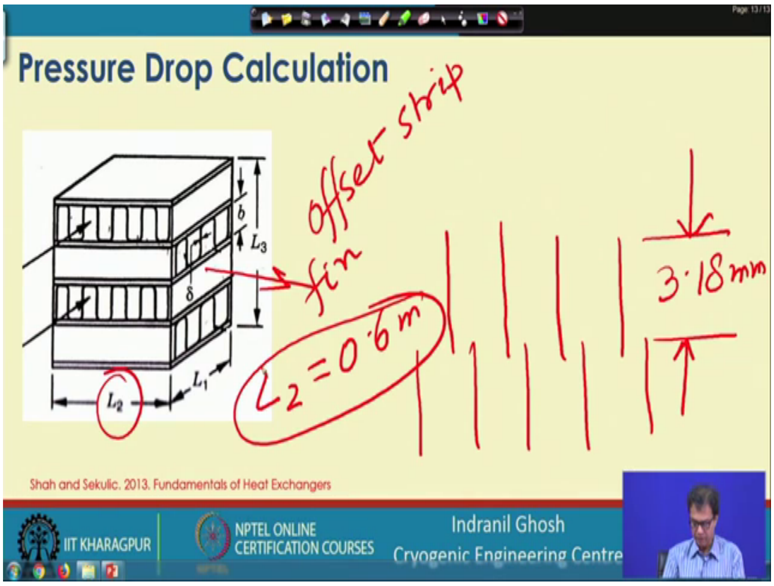

This has been given as offset strip fin and for offset strip fin we have one; if we look at this is you know this is the top view if we say. This is like we have the fin arrangement and this is what we call it as the lance length or the fin offset length; this is equals to 3.18 millimeter. And air flow length; so the air flow length L 1 this is L; L 1 or sorry this is L 2 this is L 2 this L 2 is equals to 0.6 meter.

So, the air is flowing in this direction and we have it is traversing a length of 0.6 meter and we have to find out the pressure drop due to this air flow through 0.6 meter of air flow length. Then we have the hydraulic diameter for this passage is given as 0.02383 meter this is what is the hydraulic diameter; this was already been given.

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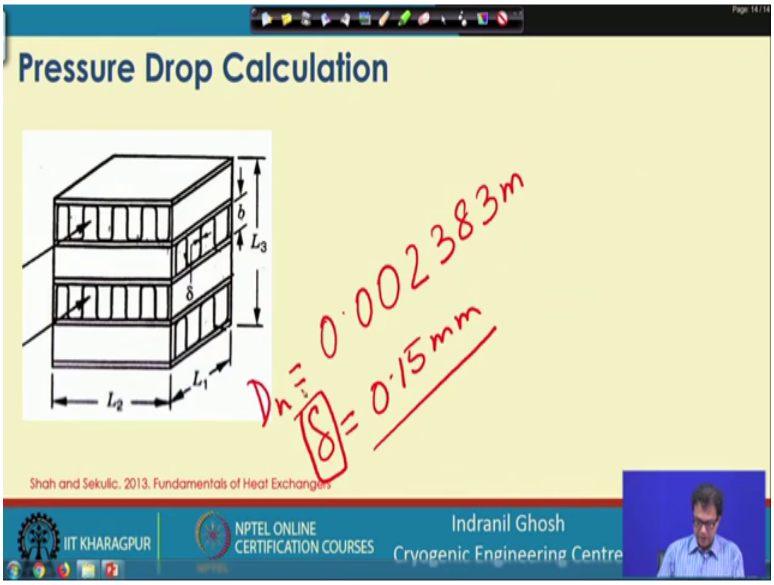

And the fin metal thickness that is delta that is equals to 0.15 meter sorry millimeter. And as you can understand that if we are using thicker fin; the pressure drop is going to be higher. And we have also be given the free flow area as well as the frontal area I mean we have already learnt about that.

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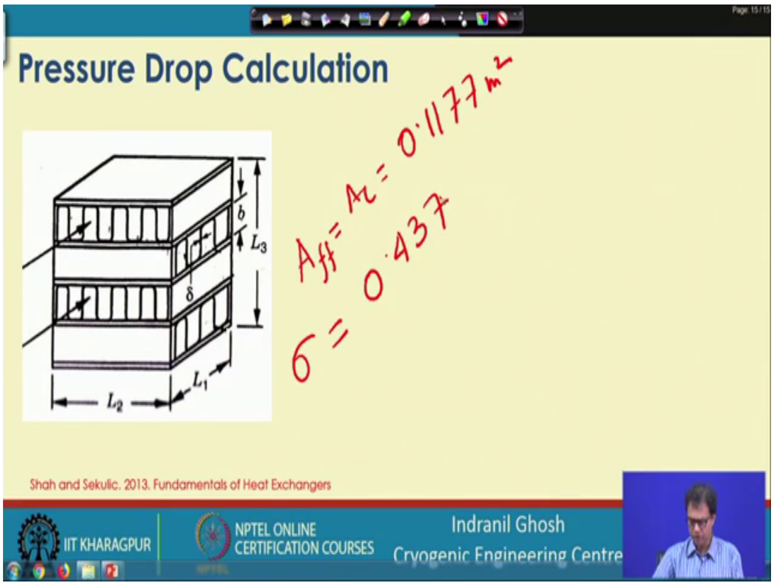

The minimum free flow area A f f or here in this one we have defined is as A f f or A c that is equals to 0.1177 then meter square. And the free flow area by the frontal area that is sigma is equals to 0.437; we have these values given for the contraction of the geometrical properties. Now we need to look into the operating conditions.

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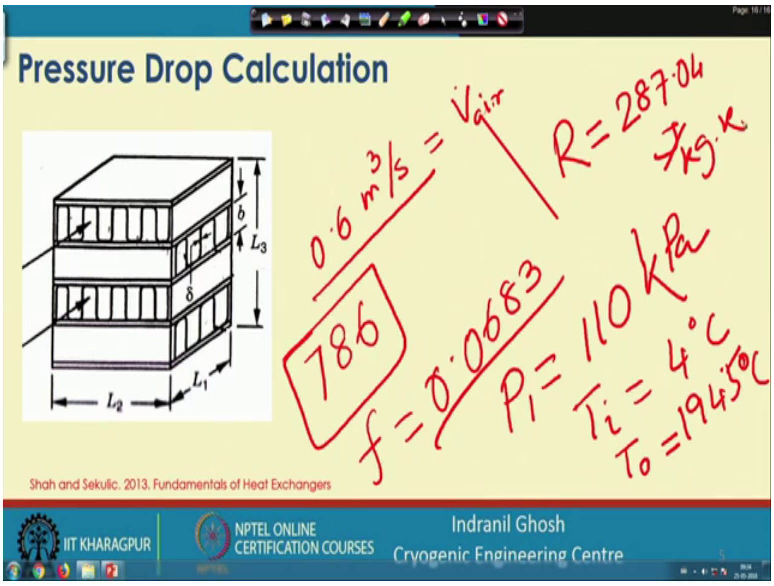

So, in the operating conditions we find that the volumetric rate is given as 0.6 meter cube per second; this is the volumetric flow rate V dot of air; V dot I am sorry V dot of air is given as 0.6 meter cube per second. Then we have it has already been estimated for us the Reynolds number 786; otherwise you know we have to calculate this one from the geometry. And the fanning friction factor that f has already been estimated for us 0.0683. This is the fanning friction factor the inlet pressure P 1 is known as it is 110 K P a kilo Pascal.

Then we have the inlet temperature t in is 4 degree centigrade; whereas, the exit temperature this is equals to 194.5 degree centigrade; 0.5 degree centigrade. And the gas constant the R; the gas constant for air has been given as 287 0.04 joule per kg Kelvin; so, these are the parameters what are given for us. So, based on this information now we have to calculate the pressure drop; so first of all what we need to do is that as you can understand if you look into our pressure drop expression we have both K e K c, then sigma then we have the different densities rho 1 rho 2 and P 1 is already given. So, if you now then try to; I mean in our hand we have all the parameters known to us we have to calculate them the one by one.

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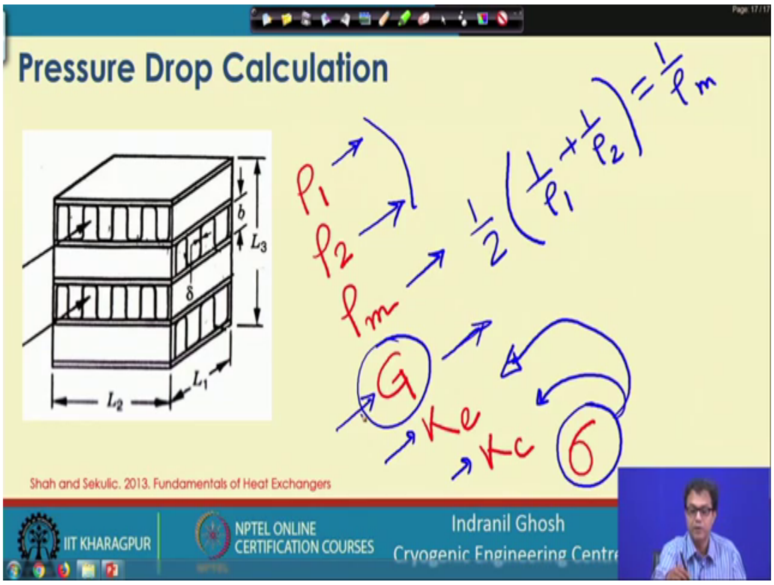

So, if we look into this we have rho 1 we have to estimate we have to estimate the rho 2, then we have to estimate rho m; then we need to look at the G or the mass velocity then we need to have an look into the K e, then we have K c and this sigma. So, now, as you can understand that we have already been told about this sigma it has already been given K c K e; we have to estimate based on this sigma values.

So, depending on the sigma values and the R e value we have to estimate this K e and K c. And then we have to estimate rho 1 and rho 2 and based on this rho 1 and rho 2; we will estimate this 1 by rho m as 1 by rho 1 plus 1 by rho 2 is equals to 1 by rho m. So, from there we will calculate the rho m.

And then we have to estimate G we have been given about the mass flow rate the volumetric flow rate is given. So, from the volumetric flow rate we will multiply it with the density appropriate density to get the mass flow rate. And we also know we have already been told about the; fluid flow free area. So, we can estimate the value of G and then we can calculate the total pressure drop.

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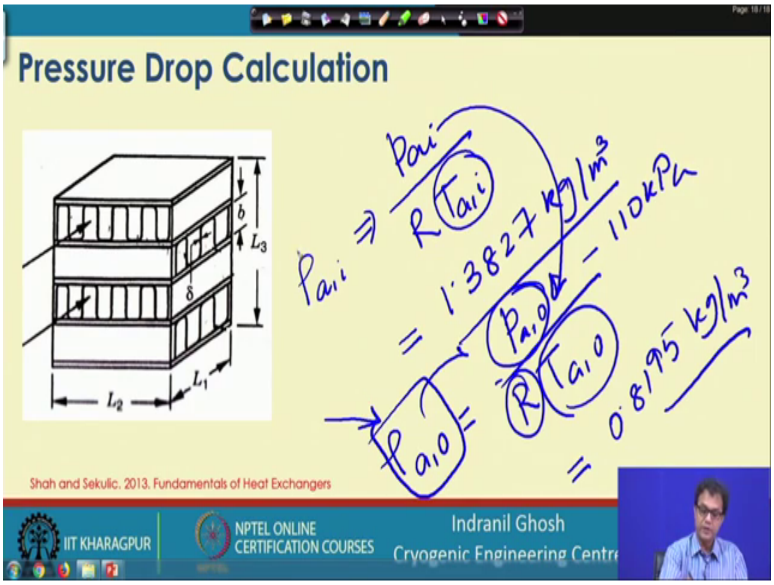

So, if we look one by one into those parameters now, if we you will find that rho of the inlet can be estimated as a function of I mean; if we assume it to be an ideal gas we can use the P v n r t relation. So, this is P air in the by R T a inlet. So, you have to convert this a into the Kelvin and accordingly this will come out as 1.3827 kg per meter cube. So, this will be the density of the air at the entry.

Then we can similarly calculate the density of air at the exit and we will have to assume some kind of pressure drop, but we do not have the pressure drop idea, but it is a I mean we need an assumption at this point and we will assume that the pressure drop is not substantial. So, that you know we will use the same pressure drop relation I mean that 110 kilo Pascal and then later on we have to rectify ourselves if we are getting really a large pressure drop. So, we will put this value of 110 kilo Pascal here and this R value already we told the temperature is already known. So, accordingly we will be able to find this is coming as 0.8195 kg per meter cube for the density of the exit air.

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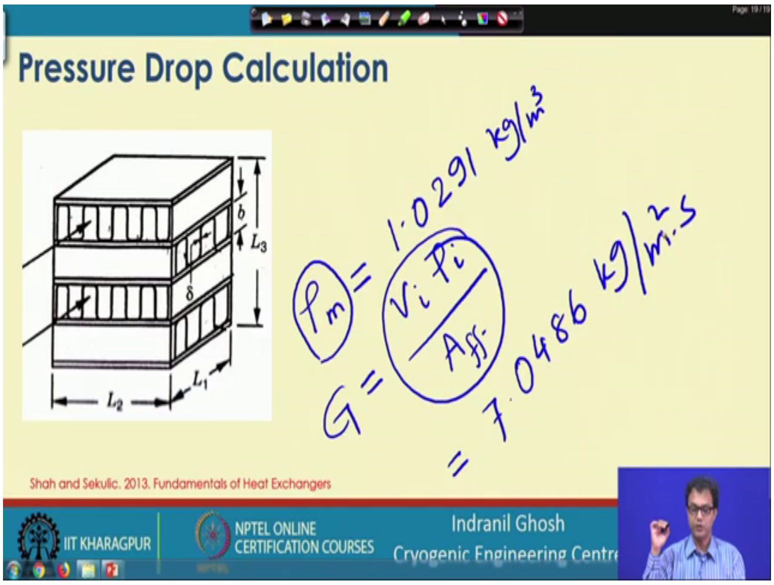

So, based on these 2 values of rho inlet and rho exit we can then calculate the rho m this will come out as 1.0291 kg per meter cube. So, this will be the main density and then we have the G; G can be estimated from the volumetric flow rate, multiplied by rho at the entry and then we have the free flow area as we have estimated that already it is given.

So, from here we would be able to calculate the G value of the mass velocity 7.086 kg per meter square per second. So, that is the unit and for the; Reynolds number given we can try to estimate the calculation I mean we can estimate K e and K c.

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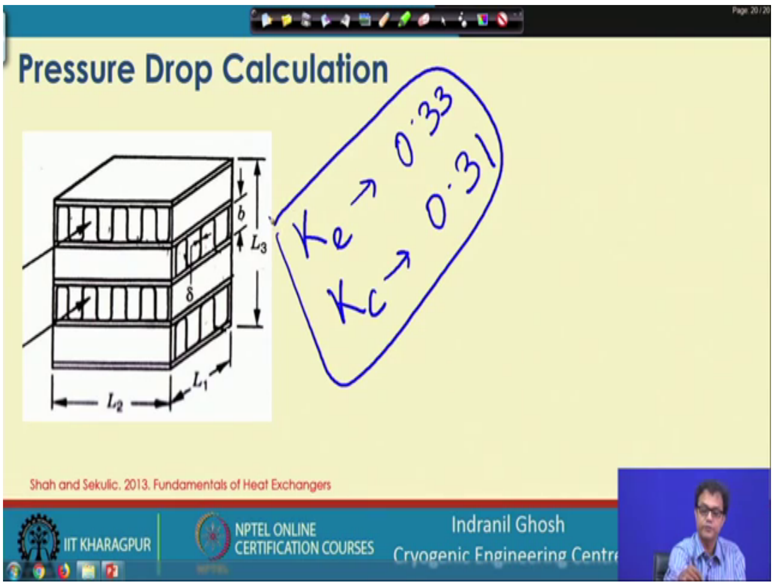

So, the figures that we have given or shown there; from there you would be able to find out that that K e is coming as 0.33 and this is K c is given as 0.31. So, then put this all this parameters now are known to us; so, accordingly we can try to find out that delta P by P 1.

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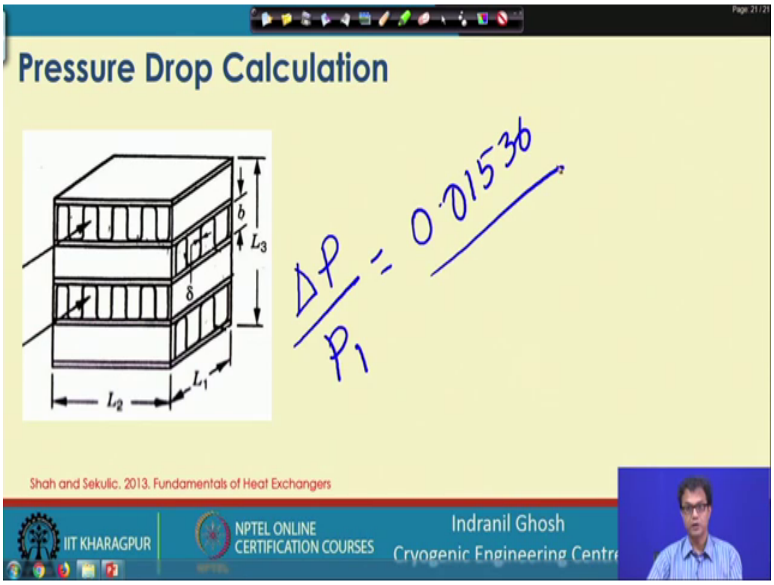

And this will come out as 0.01536. So, we can find that the pressure drop is 1.69 kilo Pascal and that is not really a very I mean it is not it is only about 1.5 percent of that total inlet pressure. So, that the assumption that has been made in our calculation that the exit pressure is not really very different from the inlet one is valid and we can.

I mean use the that assumption for we do not need any separate iterative calculations to repeat this one or to estimate the exit pressure drop. So, this is how we calculate the pressure drop in a plate fin type heat exchanger. So, we have already talked about it.

Thank you for your attention.