Heat Exchangers: Fundamentals and Design Analysis
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Lecture – 52
Regenerators

Welcome to this lecture. In this lecture, today we are going to talk about a different type of heat exchanger called Regenerators. This is basically as storage type heat exchanger, which is in contrast to the recuperators, where we have seen two fluids are flowing either in counter current or in parallel flow at least to exchange their heat I mean hot fluid will be giving heat to the cold fluid. And either it will be a direct heat transferred or it will be separated by a plate or at least some I mean non-permeable medium, and fluids will be exchanging heat. Now, in this storage type of heat exchangers which we call as regenerators; this is in contrast to that recuperator, it is the storage type heat exchanger.

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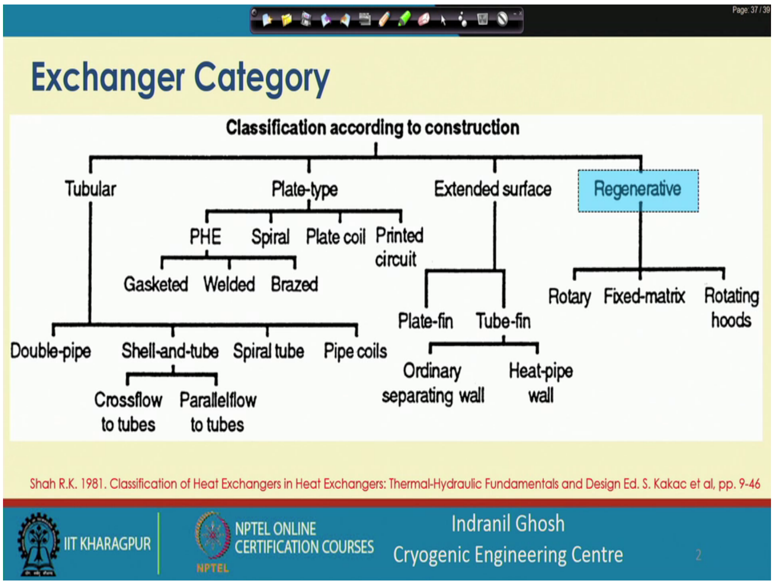

And here if we look into the classification back to our original, I mean original we have talked about it in some of the earlier classes, and we find that this belongs to I mean according to this we have here. This is the regional regenerative plate I mean heat exchangers this is where we have the all kinds of say the recuperative heat exchangers like tubular, plate-fin, extended tribes heat transfer.

And this is in contrary to that one we have this regenerator regenerative heat exchanger. And this is our different types we will talk about it in some of the later, I mean in later slides. Now, what is the basically the difference between this whole class of heat exchangers with this particular type of exchanges is that here we have a kind of, I mean same fluid will be occupying the space in different time.

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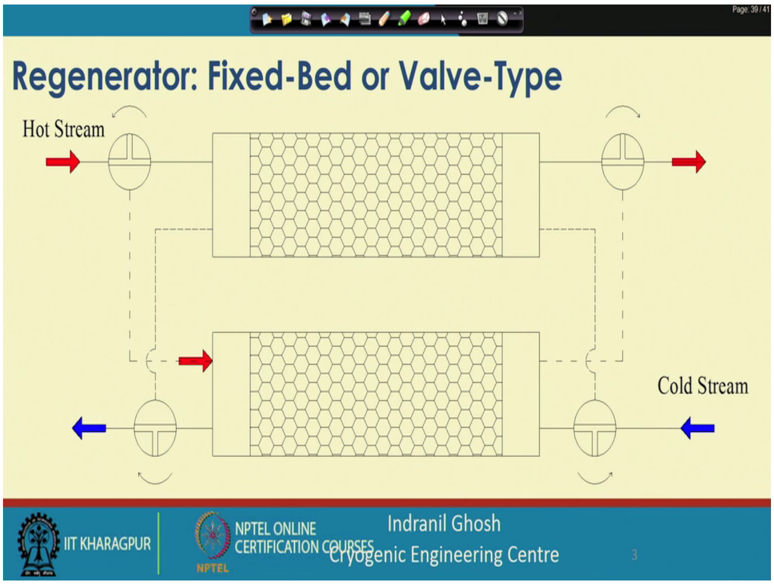

What I mean is that by saying so; if you look at the regenerator, this is basically either a fixed-bed type or a valve-type and sometime we also have the rotary regenerator. So, here what we find that the hot stream and the cold stream, they are occupying the same bed in different time. So, here if you look into this diagram, this is called the fixed bed or valve type heat exchanger or generator. Here we find that this is the hot stream, which is flowing through this fixed bed, which is filled with what we call this space as the surfaces as the matrix. So, this matrix we will talk about the matrix in details, what are the type of matrix that is possible, I mean we generally employ for this type of regenerators.

And this hot fluid imagines that the valve is in this position. And in this position the fluid is directly flowing from here, and passing through this regenerator. So, it will come out from this, and it will go to the I mean process. And while going through this you know this will heat it up, this regenerator matrix will be heated up. Now, after sometime when this heat exchanger matrix is almost reaching to this hot stream temperature, we know that there would be any more heat transfer possible between this fluid stream and the matrix. So, during that time what we will try to do is that, we will allow this the valve to rotate. So, when we rotate this valve, so this configuration we will look like this.

And this hot stream will now flow through this bed, which is you know is occupied or rather this is the matrix, which is you know at a lower temperature. So, this will, now be cooled or rather this matrix will be heated up. And the fluid stream will, now flow or take this will be also you know having a changed position like this, and this will come out like this. So, now this hot stream, the role of this regenerator basically this complete arrangement is to make this hot stream colder. So, what will happen when it flows through this bed, which is at a lower temperature, so it will pick up the cold rather, and it will in turn make this regenerator hotter. So, it will, now pass through this configuration.

So, ultimately after sometime what will happen. Now, this bed was left hot just in the others previous cycle it was heated up. And then we started diverting the flow through this hot stream through this bed. Now, when it has been diverted I mean it has been left hot, we really did not put it ideal, but what did we do is that we put the cold stream, cold fluid stream through this bed. And this cold stream what happened this cold stream is flowing through this bed. And it is picking up that heat, which it has left that hot fluid left, and it heated up this regenerator in the earlier cycle.

So, now, this cold fluid stream is flowing through this, and it is picking up this one. So, during this cycle of course, you know its orientation would be like this and its orientation will be like this, so that this passage I mean this cold fluid usual path is diverted. And this flow is taking place like this, and it is picking up the heat from here and it is getting bond. And what is happening to the regenerator matrix, the matrix is getting colder, so because of this cold fluid stream we find that the matrix is getting colder, whereas that colder you know matrix, which was there earlier is, now being occupied by this hot stream.

So, when it is sufficiently cold, we find that there is no heat exchange between this cold fluid steam which is coming at a constant temperature. And it is no more able to pick up heat from this regenerator matrix. We will, now switch on or rather switch the valves you know in its original position. Now, it will keep on this hot stream will again keep on flowing through this bed, because this has been become sufficiently colder. And this bed has been sufficiently hot. So, the cold stream will follow this path usual path, and it will follow this way, but the hot, and the hot stream will be flowing through this usual path.

So, when it becomes you know again sufficiently hotter, this matrix become sufficiently hotter or this bed is sufficiently colder. And when there is no more heat being exchanged from this or exchanges possible from this regenerator, we will again switch it off, switch I mean switch over to the other configuration. I mean these valves will be changing them from this position to this position. And it will be flowing like this, whereas the hot fluid will be flowing through this bed.

So, in alternative cycle you can see this hot bed is I mean these beds are remaining fixed, but only is thing is that the valves are changing the flow from one regenerator to the other regenerator. So, this is the this timing, and all we have to find out depending on the flow rate or the matrix of the type of matrix we are using. And we will try to solve some numerical example at appropriate time.

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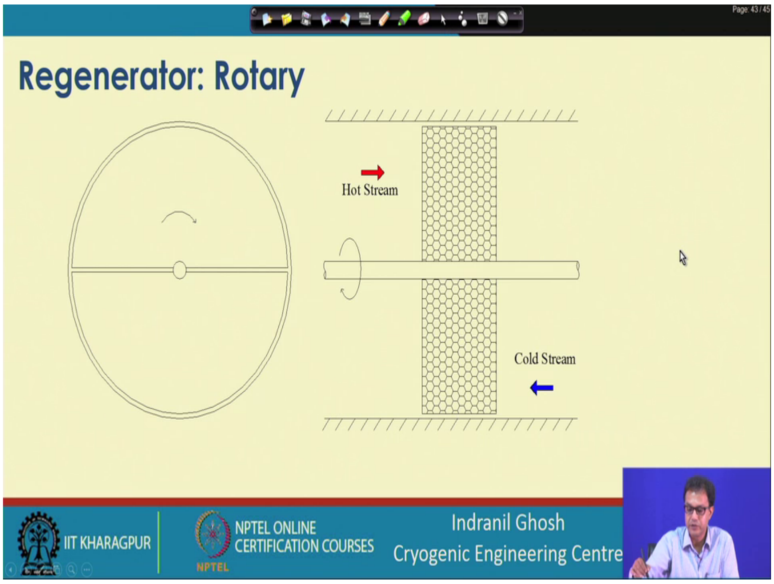

Now, looking into the other type of regenerators this is called rotary regenerator, where this is the bed is not, the regenerated matrix is not I mean in a fixed position rather it is rotating. So, here we see this is the matrix. And the other part of the matrix is this one. And we see this is the continuously it is you know on a shaft, and this shaft is the allowing it to rotate like in this direction.

So, here we have the cold stream and this is the hot stream. They are flowing through this passages I mean this passage is meant for the hot stream and the this is for the cold stream. So, usually they are flowing in this direction or in this direction. Generally, there in mostly in counter current configuration here also we can see that there in forming a kind of counter current configuration. So, this is the matrix, and this matrix is located on this shaft.

So, when this shaft is rotating, we find that this matrix, which was earlier exposed to the hot fluid will, now come in contact when it is rotating, this will come in contact to the cold fluid and it will, I mean the cold fluid will be heated up, and the regenerator matrix will become colder. So, when it goes again you know it is continuously rotating, so it is coming up, and it is in contact with the hot fluid. And again you know it is transferring the hot, I mean taking that heat from the hot fluid and then in the next I mean it is continuously rotating, so it will come in contact to the cold stream periodically. So, this is the periodically hot it is this matrix by rotation it is coming in contact to the hot and cold fluid streams. So, this is in contrary to the fixed-bed one, where we have used a valve in the set of valves to divert the flow, where the matrix remains constant or it was remain fixed, whereas in contrast to this one.

Here matrix you know, the fluid stream remains you know stationery they are not changing its position, whereas the matrix will you know continuously rotate between the hot and the cold fluid stream to exchange the energy from one fluid to the other fluid. So, these are the basically two primary type of regenerator, which we come across in case of rotary, I mean in terms of the regenerators.

Originally or historically this regenerator has started in 1816 by in an air by Stirling air engine hot air engine. And gradually it has been adopted in different refrigeration, and systems. Particularly in cryogenic we find plenty of application of this regenerative type of heat exchangers I mean heat exchangers. In particular, we have seen that there are stirling tricolours, there are GM tricolour, there is a pulse strip tricolours.

And all this type of tricolours are basically the regenerative tricolours, but we mainly use the fixed-bed type heat regenerators in those kind of cooling systems, but otherwise in large scale engineering also, in I mean the rotary type heat exchangers are in use.

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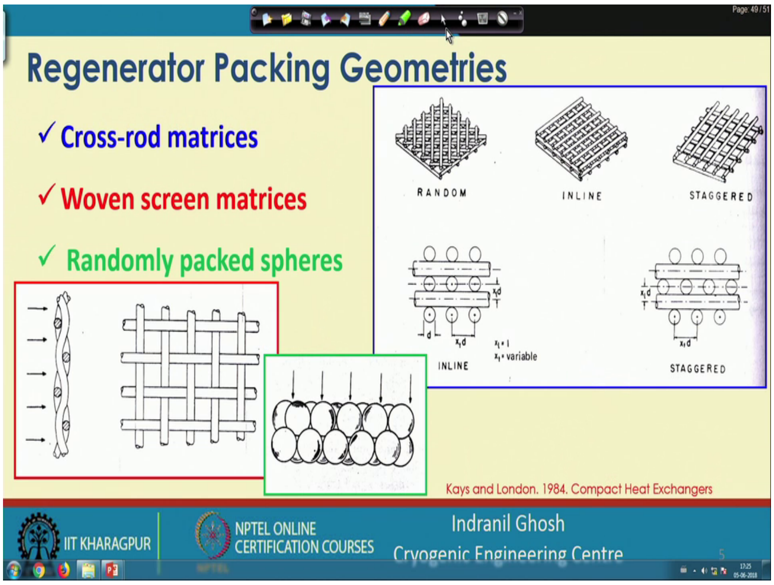

So, now if we look into the particularly to the surfaces that are used in this is the regenerator, particularly we call it as the matrix or the packing geometries. Those are used in such kind of regenerators are like this. We can have the cross-rod matrices. So, this has been I mean this is the one of the very old I mean type of a packing materials where the random the these are cross rods or the rods randomly oriented.

And they can also be put in inline configuration or they can also be put in staggered configuration as we have seen. This has been taken from the Kays and London's compact heat exchanger book. So, these are some of the primitive type of the you know, packing materials or packing geometries meant for this regenerators. Other than that we have also this is the woven screen matrices or this is also used I mean as regularly we used this type of woven screen for the matrix or regenerated material the packing material.

So, the next is another a commonly used material is randomly packed spheres or loosely packed spheres. I mean we have the led or copper shorts of particular diameter depending on the application we can use it say from 2 to 3 mm diameter shorts will be there to as randomly it will be packed in a pipe inside the pipe. And through which the fluid will be flowing.

So, usually what we look for is a basically I mean the large heat transfer surface area per unit volume I mean low pressure drop, and obviously high heat transfer coefficient between the fluid and the material. And of course, we need list to say that you should have a large heat capacity or the cp should be high. So, mcp is the heat capacitive of this material. So, it should have mass of this I mean of this cp. Though we have we do not have any problem with the mass of this material, but as we know that the cp being function of temperature.

So, we have to see or we look, we have to be careful particularly in case of cryogenic applications that. It is having considerable amount of specific heat at low temperatures, because we know that the cp of the material varies with the temperature particularly at low temperature cp becomes considerably low. So, we have to take, I mean make a notice or take a notice of that one while designing the regenerator part particularly for the cryogenic applications.

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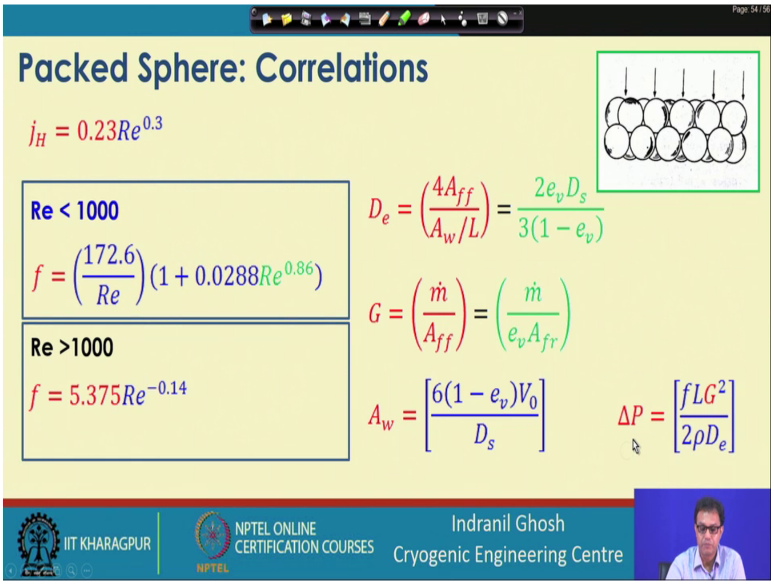

So, if you know go to the I mean what are the formulas or like what are the correlations that we should use for the packed-bed, here we have I mean bed spheres we have given the correlations. So, here the heat transfer coefficient as we know that we need to have a high heat transfer coefficient as well as low friction or the low pressure drop. So, it is important to have high heat transfer coefficient and low pressure drops. So, we at least to know what are the heat transfer and pressure drop characteristics. Here in this case, in case of packed bed we have these correlations for the cold it is given in terms of the cold one j factor, and it is related to the Reynolds number.

We will come to the definition of this Reynolds number, all the characteristic dimension of this, I mean sphere packed spheres later on. So, here for the Reynolds number, you we get Re for Re less than 1000. And also we have correlations available for Re greater than 100 than 1000. So, we have these two correlations depending on the Re values we have to use either this one or we have to use this correlation for the friction factor, and that is as we know that it is important for the calculation of the pressure drop.

So, now when we go for the, I mean heat transfer or the pressure drop calculation, we understand that we have to calculate the Reynolds number. And for the Reynolds number, what is important is the characteristic dimension of the system. And here in this case the equivalent diameter for this packed bed spheres is basically given by D e or I mean the equivalent diameter. It is defined as the free flow heat transfer 4 times free flow heat transfer divided by the heat transfer area per unit length.

And it is you know finally correlated to this a correlation I mean this is where this e v is basically the void available inside this you know packed sphere. And then D s is the mean diameter or the average diameter of the spheres. So, this is the average diameter I mean there are it is not possible that all this packed spheres will be of similar dimension. So, we take the average diameter of this packed spheres. And then we calculate the, I mean this void and we correlated it to this equivalent I mean the diameter of this packed sphere regenerated bed.

So, next is the when we know the equivalent diameter, we can try to calculate the mass velocity as you have learned in our in case of the heat exchangers also that it is it depends on the mass flow rate the fluid that is flowing through this packed bed. And the free flow area again it is appearing here. This free flow area now can be correlated to the frontal area and the void. So, this e v is void and A f r is the frontal area of this packed bed say if it is like tube, which is filled with this packed you know this spheres randomly the packed spheres.

And this is this becomes the frontal area this cross sectional area becomes the frontal area of this regenerator. And the mass that is flowing in or out that is the basically the mass flow rate associated with this one. So, we have the mass velocity we have the equivalent diameter. So, we can easily calculate the Reynolds number for this system. So, now once we have the mass velocity we can calculate the pressure drop in terms of the Reynolds number, because the Reynolds number can be easily defines on the basis of this mass velocity and D e.

And another parameter which will be of our importance that is the surface area. So, the surface area is basically related to this D s or the average diameter of the or the mean diameter of the sphere. And this is again correlated to this is the void and the V 0 is the volume associated with this is regenerator. So, all this you will be the finally, correlated or can be used in appropriate time, when we design or simulate these regenerators.

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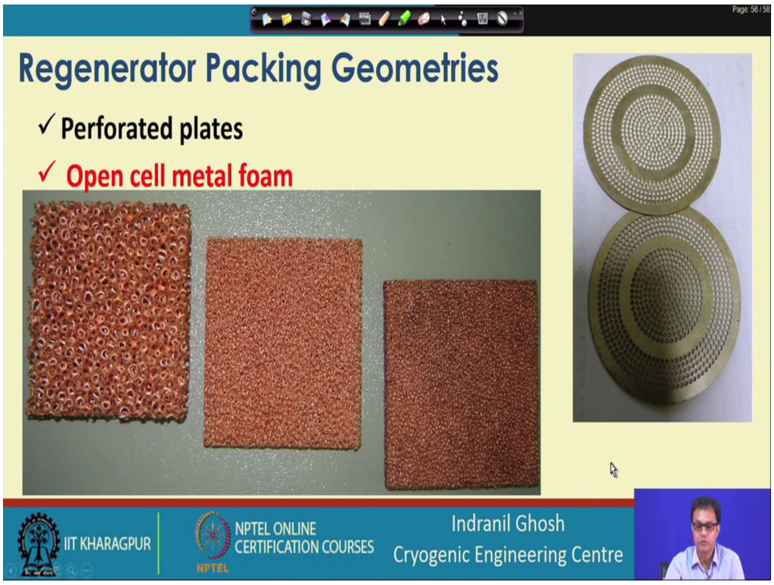

So, now with this information we will now proceed to the other some of the, I mean recent or the geometries, which are regularly in use high performance. This is perforated plate actually this is some of the perforated plates, but in case of this is regenerator. We will have only this much it is particularly this particular perforated plates are meant for two fluid stream heat exchangers. But if we remove this portion or if we remove this outer section, this can also be used as a regenerator with appropriate spacers in between the plates.

So, this is basically meant out of copper and it is finally it has been coated with the silver. So, there is a recent development in the materials science, where which allows us to which allows to you know use this metal form as the regenerator material. Here we have this is often called the metal sponge.

And this metal sponge is basically a open porous or it can also be closed cell. So, basically for regenerative publication we used it for I mean the open cells that used. And it has different kind of porosity and pore density. So, this is basically by porosity what do you mean that gives the relative density of this material. And the pores you can understand that these are having larger pores as compared to this one and these are having still smaller number of pores. So, these are basically this is this pores are defined as the PPI - pores per inch. And this is nearly about say 5 to 10 pores per inch, whereas this is about 20 PPI. And this is nearly 30 PPI these are copper foams.

So, porosity is, porosity can be varied between the wide range and typically of the order of 60 to 65 percent porosity is look for the regenerated materials for this when a metal foam is used as the a regenerated material. So, these are some of the recent edition into this regenerator material packing geometries.

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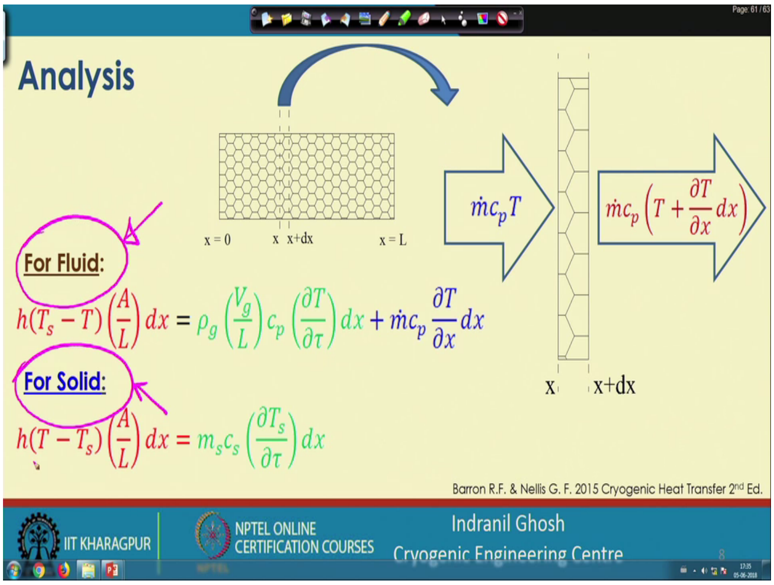

But we will, now with this basic information go to the analysis part, where we will find that the same matrix is usually you know I mean the fluid is flowing say in one cycle from this direction to this direction. So, the hot fluid will be flowing from say this direction to this direction. And this hot fluid will in turn heat it up this matrix.

And in the next cycle we will find that the cold fluid is flowing through this direction. So, this cold fluid will pick up that heat it has left in the earlier cycle. So, this regenerator is now hot and the cold fluid is passing through this one and picking up that heat while moving out from this to this direction. So, the same fluid is you know going in one cycle living its heat over here. And in the next cycle it is moving from this direction to this direction picking up that heat. So, basically that is how the storage type of heat exchanger works, I mean it is basically allows the fluid to stored its energy here.

And then in the other cycle it picks up that heat it has left in the earlier cycle, so that is how it works, but while writing the governing equations we I mean make it into two parts I mean for one for the fluid and one for the solid. So, in the solid part, we will write this equation; and for the fluid part we write this equation. So, detailed discussion of this equation will be taken up in the next class.

Thank you for your attention.