Energy Conservation and Waste Heat Recovery
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Lecture – 33
Heat exchanger (Contd.)

Hello everyone, we were discussing regarding heat exchangers. So, far we have covered the base basic classification of heat exchangers and we have seen the techniques by which heat exchangers can be analyzed, mainly 2 techniques which are most commonly used that is logarithmic mean temperature difference technique or LMTD method and effectiveness NTU method. These 2 methods, we have seen, we have also taken up a problem to see how these methods can be actually used for simple calculations of heat exchanger.

Now, in this particular lecture I like to cover certain heat exchangers, which are specially suited for waste heat recovery though time to time, I have mentioned which heat exchangers are specially suited for waste heat recovery, but I think we should spend some more time look into different kind of heat exchangers, which are specially meant for waste heat recovery and of course, when it is waste heat recovery it is also for energy conservation.

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So, let us look into the slide. So, heat exchangers specially suited for energy conservation and waste heat recovery, first type of heat exchangers are regenerators, then there are certain special recuperators 1 or 2. I will discuss then heat pipes and then run around coils.

Out of this heat pipes are very special. They are used for different kind of industrial applications and; obviously, they are very good devices for waste heat recovery and energy conservation. I will not discuss this, the other instructor Professor Anandaroop Bhattacharya will talk about heat pipes in detail and you will see that, how this unique heat exchange devices can be utilized for waste heat recovery. So, we will start with regenerator. Now, regenerators are of different types. Regenerator means kind of heat exchangers in which the heat transfer is indirect; that means, the 2 fluid streams are not mixing with each other, but they are not also exchanging heat across some sort of a solid barrier continuously, what is the working principle of a regenerator.

First let us say there is a hot stream. The hot stream one I mean, we need to extract certain amount of heat from that hot stream. So, the hot stream is made to pass through some matrix or storage material. So, when the hot stream passes through this storage material, which is a solid material the storage material will pick up thermal energy and then cold stream will be made to pass through that storage material. So, that thermal energy which was stored will be taken by the cold stream again. Hot stream will pass through the storage material. So, this process will continue and we will get heat exchange from the hot stream to the cold stream via, a storage medium.

So, this is the working principle of regenerator and there are different kinds of regenerator. So, in a regenerator this storage material is very important and that is sometimes also called matrix. As I have mentioned the matrix could be stationary or we can have some sort of a rotation of the matrix.

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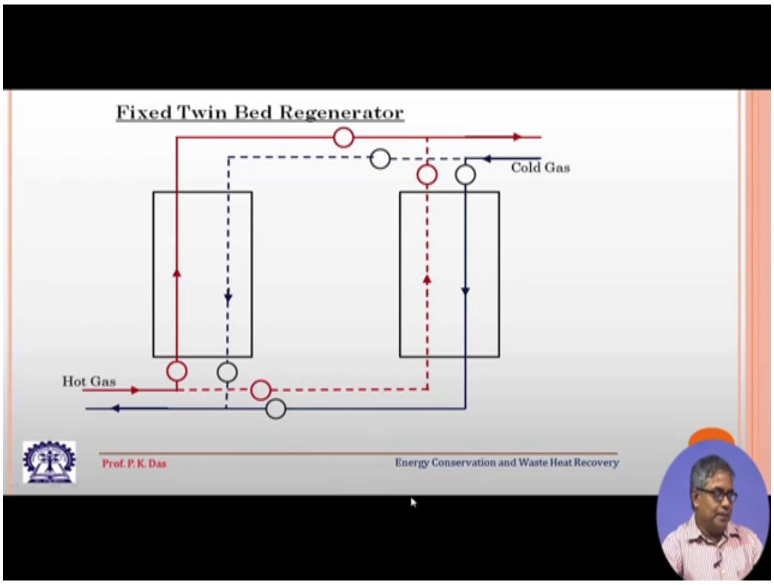

So, let us explain this with the help of some sort of diagram. So, first we can see fixed twin bed regenerator and in these 2 box kind of arrangement are called bed. In this bed, we have got storage material or matrix. So, generally these are porous material. So, they will have solid component, which can store thermal energy. They should be good in storing thermal energy.

But at this, at the same time these beds, they will have porosity or some sort of interconnected channels, through which the fluid stream can pass and in most of the application as fluid stream, we are having gas, some sort of a gas, we are having as fluid stream or we are having 2 fluid stream. So, 2 gas streams, we are having. Now, what is the advantage of using this storage material is that, the matrix construction is such that it will give very large residence time and very intimate contact between the solid and the between the solid and the flowing gas, which is not possible when there is a gas. There is a flow of 2 gas streams and they are separated by some solid valve, which is there in most of the other heat exchangers.

So, if I have to explain the working principle of this fixed twin bed regenerator. So, let us say this is a fixed bed. So, some hot gas is coming. So, in the gas stream; so, this red line is the hot gas line, in this line there are 2, there are number of valves. Let us say what we do; we close this valve and we open this valve. So, the gas stream is now, made to pass through this first bed, this is the first bed. So, it is made to pass through this first bed and then it is passing through this. Here, this valve is closed, this valve is opened. So, the gas stream is going out, but when the gas stream is going out, already we have extracted certain amount of heat and that is being stored, kept stored, within the storage material in the first bed.

Now, there is a cold stream, also the cold stream, once the gas stream has hot gas stream has passed through this first bed, the cold stream you follow this line, this dotted line. So, this valve has been opened, this valve has also been opened, but these 2 valves are closed. So, the cold stream is coming like this through this dotted line and it is passing through this first bed. Now, first bed when the cold stream passes through it, it is already very hot. So, the cold stream will pick up certain thermal energy and now, I have recovered certain amount of thermal energy which could have gone as exhaust with this hot gas by this cold stream and that can be utilized.

But when the cold stream is passing through this, through this, through, this first bed what the hot gas stream is doing? The hot gas stream is bypassing the first bet, but it is passing through the second bed. So, when the cold stream is passing through the first bed the first from the first bed. Heat is extracted by the cold stream, but at that time. The second bed is being heated and it is being, I mean it is in the process of being ready. So, that at the next instant, cold gas stream will pass through it and pick up certain amount of thermal energy. So, this goes on this, goes on by switching of these valves, directing the hot gas stream once through the first bed, next through the second bed and directing the cold gas, once through the second bed and next through the first bed.

So, this continues and there could be more number of beds. The simplest is the twin bed regenerator, but there could be more number of beds and by that we can get a good amount of heat exchange or good amount of thermal energy recovery from the hot stream to the cold stream. Now, this is one arrangement and here what we can see, that this valve operations are to be done. Generally, that is done automatically, one need to know, how much time one gas stream should pass through a particular bed and accordingly the valves are to be operated.

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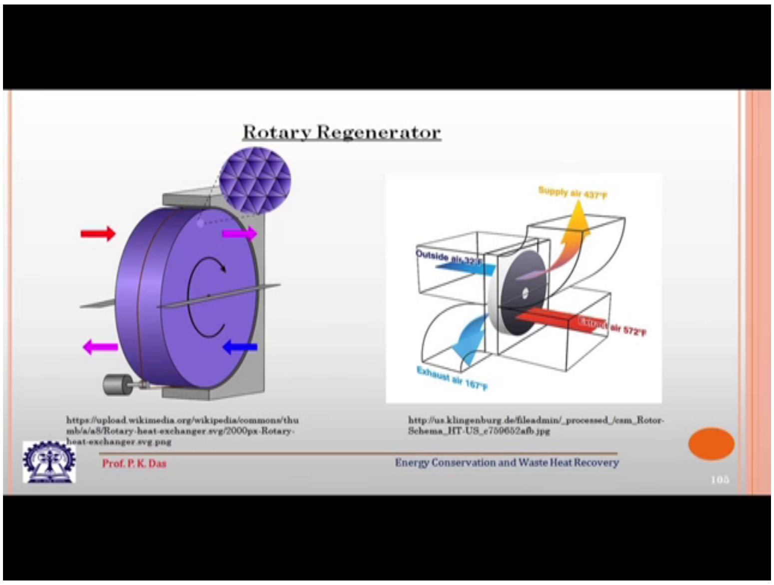

There could be a different kind of a design. In this design, we have got a rotary regenerator, rotary regenerators are very common, again as regenerated for extracting thermal energy from the hot stream and directing it or depositing it to the cold stream and there is a regenerator, this regenerator; obviously, as I have told, it is a matrix and it is a circular thing, but if we look closely, then the matrix will have passages. These are triangular passages. Triangular passages are very common. So, through these triangular passages, the any gas stream that will pass.

And when the gas stream will pass the triangular passages are very narrow. So, they have got valves which are made of special material which can store heat. So, that will store heat. So, when the hot gas stream passes they will store heat and when the cold gas stream passes they will relegate. So, this matrix or this wheel which contains this matrix that goes on rotating and you can see the arrangement by which it rotates. So, next figure if we see then you see there are 2 ducts and 2 ducts are in the counter flow kind of arrangement.

The flow is taking place in the opposite direction through these 2 ducts. So, hot gas is passing through this, it is passing through the a rotary regenerator or wheel which is also known as heat wheel and then when it is coming out, it has already deposited certain amount of thermal energy. So, it is cold, but this hot the heated up the portion which is heated up the portion of the matrix, which is heated up as it is rotating as the wheel is rotating it moves up and through that cold gas is passing. So, when the cold gas will pass through this, it will get this, it will pick up thermal energy and it will come out as hot air.

So, this is a very common device in many cases. It can be used in a large air conditioner air conditioning planed. It can be used for supply air and the air which is coming out from the room in a power plant, it can be used as air preheator, generally these rotary regenerators are suitable for gas to gas application and continuously this wheel will rotate and at the same time continuously these 2 flow of the gases will take place. In our earlier application, we have seen, when we have seen the fixed bed kind of regenerator we have seen that the beds are fixed and the fluid switches off from one bed to another bed. Here, the fluid flow path remains constant; there is no switching off for the path of the fluid streams.

But the regenerator is not fixed. Regenerator goes on moving and a circular geometry. So, it is goes on it, goes on rotating. So, this is for recovery of thermal energy there are designs, where this matrix material is coated with some sort of special kind of chemicals. So, some amount of latent heat also can be utilized, those special designs are possible. So, both sensible and latent heat transfer is possible with the design modification of this rotary regenerator, with this there is a small animation.

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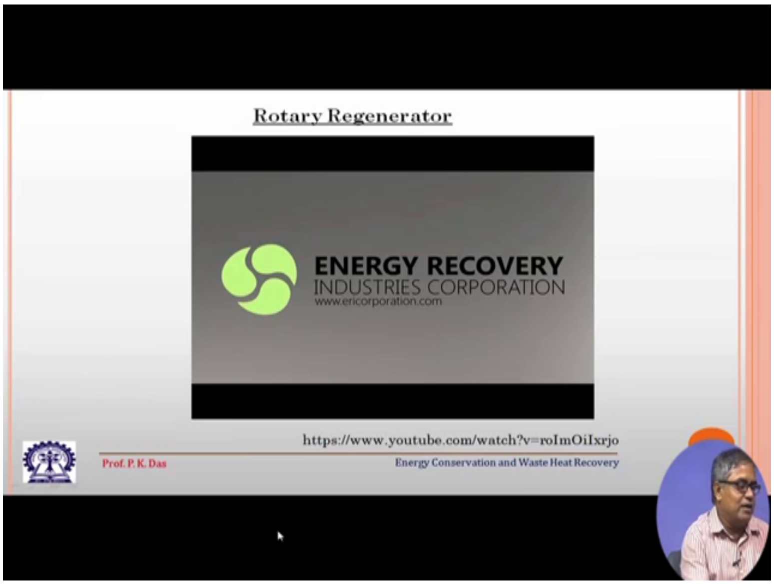

Which I like to run for you, it is self explanatory and you can see, what is the physical construction; how the material, sorry, the gas streams flows through it.

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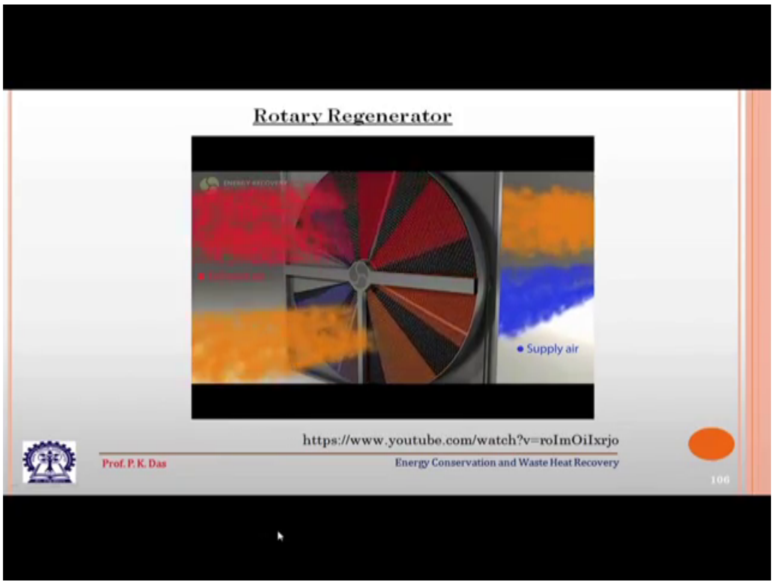

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So, this gives us some idea regarding the rotary regenerators.

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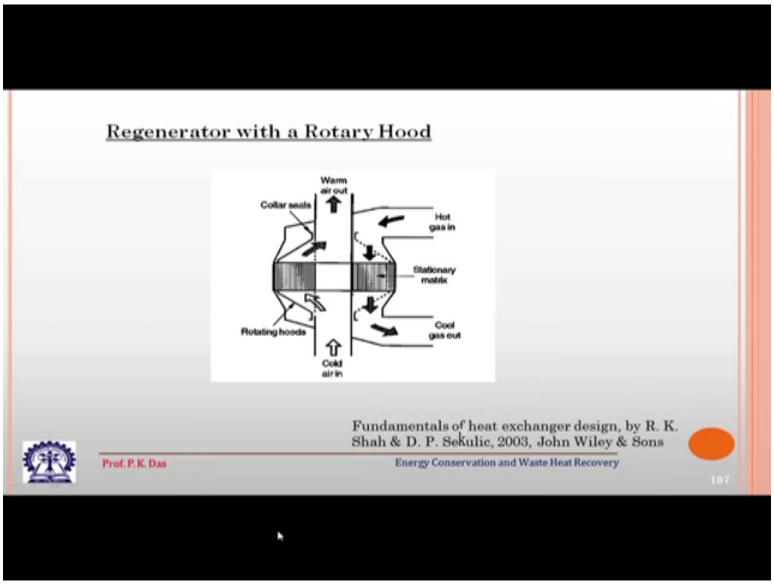

So, rotary regenerator has got a wheel, which rotates and that is why it is also called a heat wheel. Almost similar kind of construction, but a slightly different design is possible regenerator with a rotary hood here. Here, also we are having some sort of a wheel for a regenerator and this wheel will have matrix, we have got fixed, cold gas path and hot gas path. So, you can see this is the hot gas path and this is the cold gas path, but there will be a rotating hood or rotary hood. So, the rotary hood is shown like this.

So, this goes on rotating at one instant of time or for some duration. This will be on this side and for the rest of the duration it will be on the other side, when it is on this side let us say cold air is coming in and then the cold air has to go through this path and pass through the matrix material, which is already heated up by the hot gas. So, the cold air will get pickup certain amount of thermal energy. It is temperature will increase and one air will go out the rotary hood will be on the other side. So, that will make the hot gas to pass through this kind of is this one, I mean this part of the, this part of the wheel. So, that this matrix will get heated up and next time, this heat can be transferred to the cold gas.

So, this is the working principle of a regenerator with a rotary hood here, what is happening there is a switchover of the path of the hot gas and cold gas, but not by a valve, but with the help of a rotary hood. So, this is the difference, otherwise construction wise, otherwise if we see the construction. So, from the construction point of view, it is very close to a rotary wheel, kind of a regenerator. See for this kind of regenerator, the speed of rotation is very low, because there should be good amount of time given, for the heat exchange to take place between the flowing gas stream and the matrix material the wheels are very large, the gas velocity is also low. So, that good amount of heat exchange takes place.

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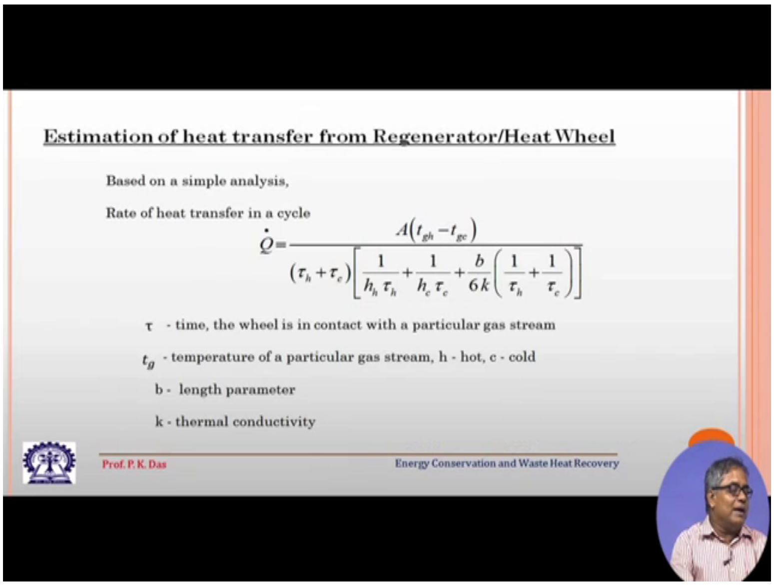

One can estimate the heat transfer from regenerator or heat wheel the analysis is made up, a made with a lot of simplification. We are not going through the analysis, but I like to give you the relationship, which is approximate, but it gives you some idea on which parameters, the rate of heat transfer depends, this is the rate of heat transfer; obviously, there are 2 streams and temperature of the 2 streams in steady state operation. The 2 streams are coming with constant temperature and these 2 temperatures are very important.

The area of the of heat transfer that is also very important. So, we have got area then, we have got these 2 temperature, the hot gas temperature and cold gas temperature, the temperature difference that is important. So, if the area is more heat transfer will be more. If the temperature difference is more than the heat transfer will more, will be more and on which it will depend, the other parameters are given over here. So, this is the time the hot fluid stream is in contact with the matrix. This is the time, the cold fluid is in contact with the matrix. So, this is the total amount of time; obviously, if the total amount of time is large then the rate of heat transfer will be less and then this is the hot side convective heat transfer coefficient and this is the time of hot fluid in contact, with the wheel as I have told or in contact with the matrix as I have told.

This is the cold side convective heat transfer coefficient. This is the corresponding time for the cold fluid, this is some sort of a length parameter, this could not may not be the physical length, but this is, I mean this is related to the physical length and then this is the thermal conductivity of the matrix material and these are again, these 2 times already I have defined. So, you see the time has got, some sort of a conflicting effects, the more the time; obviously, the there will be a more opportunity between the gas to exchange heat for exchange heat with the matrix material. So, that way, we need certain amount of time.

But at the same time the full cycle, because there will be heating and cooling that should be, if it is very, if it is taking place over a very large period of time then; obviously, we will not have a good amount of heat exchange, a during the cycle, because the heat transfer rate will be divided by total amount of heat transfer divided by the time of cycle. So, there should be, this is a design parameter, how to decide the total time of the cycle and how to decide the cycle, I mean the time of contact between the hot gas stream and the matrix material and the time of contact between the cold gas stream and the matrix material.

So, this is kind of a design, this is kind of a design parameter. So, with this, we have got some idea, regarding the regenerator, which could be fixed bed type or which could be a rotating bed type. So, there are the other kind of design also. We have seen with that let us go to special type of recuperator.

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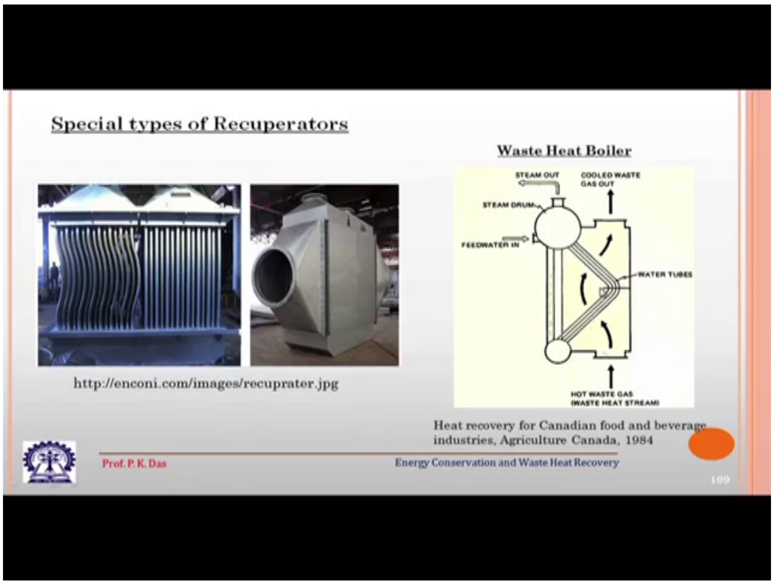

Now, if we see heat exchangers, heat exchangers. There are different ways of classifying heat exchanger, one way of classifying heat exchanger is that that we can classify the heat exchanger as Recuperators and regenerators; recuperators means continuously, there will be heat exchange between the cold fluid and the hot fluid without having any intermediate storage material medium.

There could be a intermediates solid medium through which heat transfer is taking place, because we cannot allow in most of the cases, the 2 fluid streams to mix. So, there could be a solid barrier between them through which heat transfer is taking place, but this heat transfer is not via a storage medium. So, this type of heat exchangers are called this type of heat exchangers are called recuperators. So, all the salient heat exchanger, the example we have picked up the plate type heat exchanger. The example I have shown all the plate fin heat exchanger. These are all recuperators.

There could be a another kind of heat exchanger which just. Now, we have discussed that is the regenerator. So, the regenerators are heat exchangers, where there is a storage medium heat transfer is from the hot fluid to the cold fluid via a storage medium; so, for the time being for some time. There will be for some time, there will be heat storage from a fluid steam to the storage medium or matrix and then for some time, the stored heat will be transferred to the cold stream. So, regenerators we have seen more or less different kind of regenerators, we have seen recuperators we have discussed, but some special recuperators for waste heat recovery purpose that I like to show to you.

If we go to this particular slide, here if we go to this particular slide then, here we can see certain recuperators, which are special for waste, heat recovery purpose. So, these recuperators, you can see these are tubes, through this tube, generally hot gas passes and across the tube, the cold gas or cold air passes through this. So, from the furnace, from the incinerator, the hot gas will come and pass through this tube and outside. There will be the cold gas, that will pass. These are bare tube, sometimes, they could have some pins depending on the type of gas, we are using and these are specially used for a waste heat recovery.

This is one typical waste heat boiler, which is also kind of a recuperator, but though we are calling it a waste heat boiler, we are it is not fired. So, hot waste gas is coming from some sort of resource and then it passes through these cubes, these are the riser tube of the boiler. So, here the steam generation will take place and then it will go to the steam drum, steam will be taken out here. One can give the feed water and this is the down comer through which cold water will come out.

So, to make the contact time between the hot gas and the riser tubes, we have got bend tube and you can see that there are number of riser tubes, but there is only one down commodity though the mass flow rate is same for the entire circuit. So, here we increase the surface area also, because here we need to have the heat transfer here, we increase the surface area by bending the tube, we are increasing the contact time between the hot gas and the, a fluid which is flowing through, these tubes and then the waste gas is coming out. So, this is also one special kind of heat exchanger, which is a recuperator, basically a recuperator for waste heat recovery purpose.

There are many such examples, economizers used in steam power plant. They are, they are again special kind of recuperators, which are used for waste heat recovery purpose, the gas to gas waste heat recovery purpose, the recuperator will not have fins on the hot gas side, because that side the fouling takes place, but they may have fins on the colder side. So, economizers, we will have again this tubular structure whereas, air preheator in many cases, it can have a tubular structure or it can have some sort of a regenerative kind of principle for extracting waste heat.

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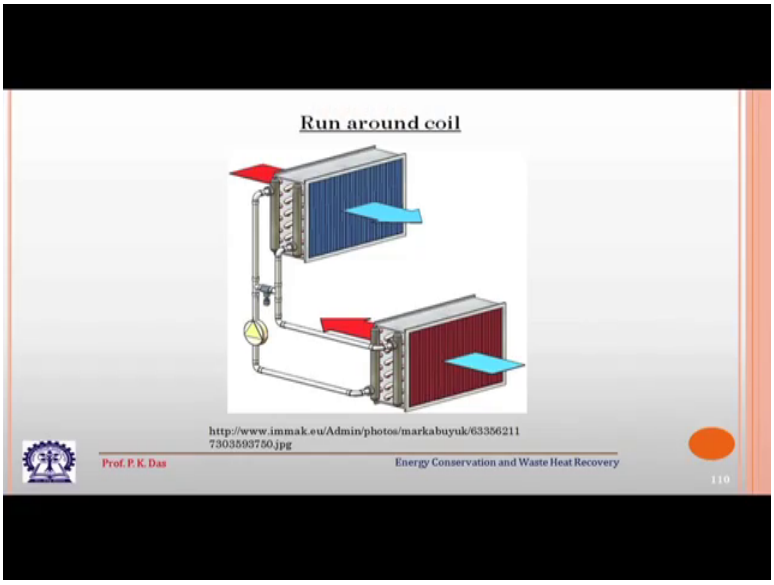

Now, let us go or let us see a another kind of heat exchanger, which is called runaround coil or sometimes, it is called a fluid coupled, heat exchanger let us say in a plant, there are 2 stream, one is a hot stream and another is a cold stream. So, we have shown a hot stream, here this hot stream is coming and we have also shown a cold stream that is coming, but the hot stream and cold stream in the plant they are not side by side, they are far apart.

If they are far apart then, what will happen, we cannot exchange the heat with the help of a heat exchanger directly from the hot stream to the cold stream and their distance is. So, large that we cannot have also a regenerative kind of heat exchanger for this hot stream and cold stream, which are physically not close, but what we can have for the hot stream, we can have a heat exchanger and here the heat given by the hot stream will be picked up by some fluid preferably by a liquid and then that hot liquid will give heat to the cold stream and then certain amount of heat exchange is possible between the hot stream and the cold stream.

So, there is a coil running around from the hot stream to the cold stream. So, that is why it is called a runaround coil and for circulation of fluid; obviously, we need a pump over here and a heat transfer is through some sort of a fluid medium. So, that is why it is called a fluid coupled, heat exchanger also. So, basically, we are having 2 heat exchanger, not a single heat exchanger, both of them are recuperator. They are coupled by a fluid stream.

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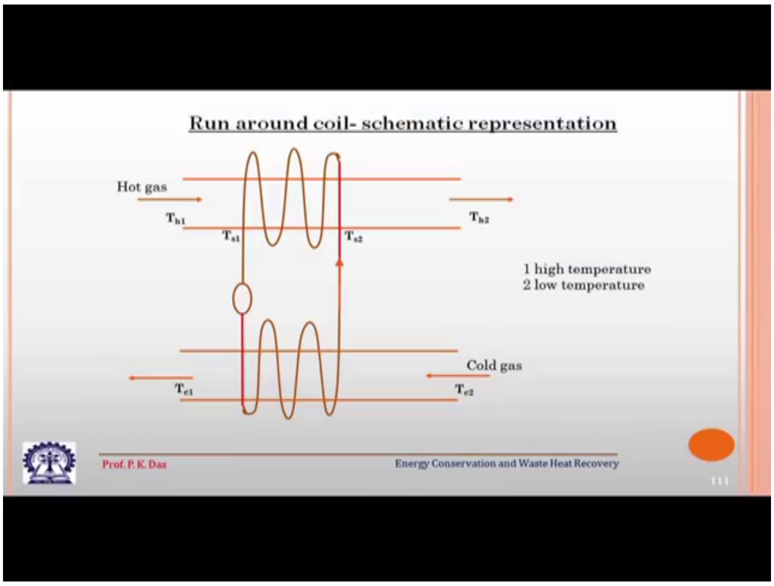

Now, if we see, this is a schematic arrangement of the fluid coupled heat exchanger hot gas is coming. Here, with a temperature TH 1, it is going out with a temperature TH 2, the cold gas, that is coming in with a temperature TC 2 mind, it we have written TC 2 not TC 1.

And it is coming out with TC 1, then the fluid which is moving through this coil and it is some sort of a loop, then it is entering with. So, this is called a secondary fluid. So, this can be called a secondary fluid. So, it is entering the hot heat exchanger hot side heat exchanger with TS 2 coming out in heated condition, with a temperature TS 1. So, it is entering the cold side heat exchanger with a temperature TS 1 and coming out with a temperature TS 2 from the cold side heat exchanger.

So, what nomenclature, the take I mean methodology or norm for nomenclature, we have followed that we have used this subscript one for high temperature and 2 for the low temperature. Now, this kind of; so, 2 heat exchangers are involved and in between a moving fluid in a loop that is involved. So, what we can do that what we can do that we can go for some sort of analysis and assuming steady state operation, we can go for some sort of analysis and we can have some idea of course, the analysis will be simplified and we can have some idea regarding the performance of this kind of heat exchanger.

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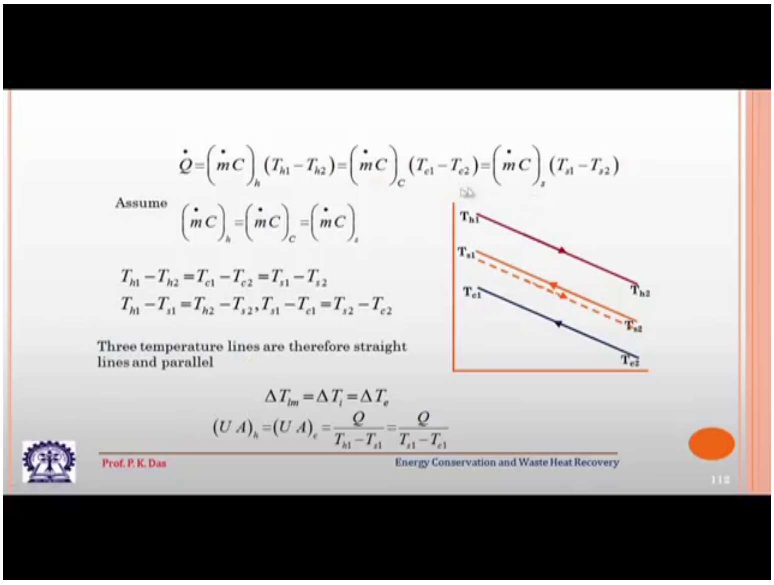

So, let us say, this is what we will get from energy balance Q dot that is the rate of heat transfer. If we consider the hot side fluid, we will have MCP M dot CPH multiplied by the temperature difference TH 1 minus TH 2 mind that what I have told that for any fluid stream, hot side fluid will be denoted by some subscript one that is for the sake of convenience and the course like side fluid, that will be denoted by subscript two, for the sake of convenience, there is no other reason. So, inlet outlet we are not generally in a, in the other cases. We have done this one and 2 based on inlet and outlet. Here, we are trying to do based on the temperature value high, temperature value is one subscript one and low temperature value that is subscript 2.

So, we get this is the rate of heat transfer as far as the hot fluid stream is concerned. This is the rate of heat transfer as far as clod fluid stream is concerned and this is the rate of heat transfer as far as the intermediate fluid stream is concerned and then we have assumed that, they are operating under steady state, there is no energy storage and at the same time, we have also assumed that there is no heat loss, whatever heat exchange is there, that is between the hot stream and the secondary fluid and again there is heat exchange between the secondary fluid and the cold stream.

So, with the ambient there is no heat exchange. So, if I do that, then all this thing can be equated, all the 3 rate of heat transfer can be equated and we can also assume. This is an assumption for simplified analysis, this assumption may not be true at all for the actual practice, but this assumption is done to have some simplified analysis, which will give us at least some idea regarding the operation of this of this special kind of heat exchanger. So, we assume M dot CH is equal to M dot CC that is equal to M dot CS; that means, heat capacity rate of the 3 fluid, stream, hot stream, secondary fluid stream and the cold fluid stream, all are equal.

So, if that is. So, then we will get TH 1 minus TH 2, that is equal to TC 1 minus TC 2 and TS 1 minus TS 2. You mind that again, I like to remind you that one subscript indicates high temperature and subscript, 2 indicates the low temperature. So, this is the temperature difference. If we assume this then, if we assume counter current flow one can also do the analysis for parallel flow. If we assume counter current flow, if we go back to our previous figure, then you see, it is a counter current flow or gas passes like this and the secondary fluid passes like this.

So, if we assume counter current flow, then we get the temperature change along the length of the heat exchanger, that is a linear temperature change, not only that the for hot gas stream, it will be a line straight line for cold clod gas stream. This will be a straight line and for the intermediate fluid, that will be another straight line. So, all the 3 straight lines, should be parallel, what we have done, let me explain it, these first 2 streams, these 2 are same color; this orange color, this is your intermediate fluid.

So, this red one and the orange one, with solid line that constitute the hot end heat exchanger and the orange line, with a broken line and the blue solid line, that constitute another heat exchanger, that is at the cold end. So, both of them are counter current heat exchangers and the temperature change that is linear in both the heat exchangers and for all the 3 fluids. So, with this we will get also, we can make some sort of a simplification, TH 1 minus TS 1 is equal to TH 2 minus TS 2; that means, this end and this end delta T are the same, that is what I wanted to explain so far. So, 3 temperature lines are therefore, straight lines and parallel. So, let us stop over here and we will continue with this analysis in our next class.

Thank you.