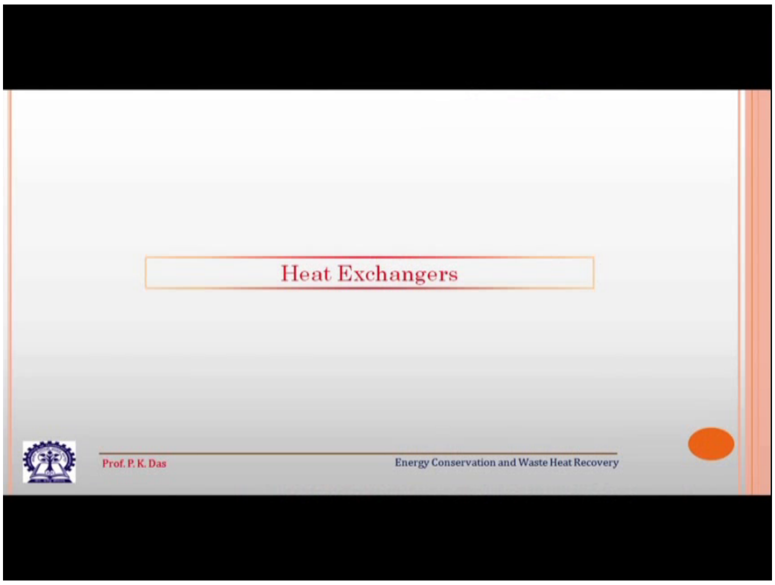
**Energy Conservation and Waste Heat Recovery**
**Prof. Prasanta Kumar Das**
**Department of Mechanical Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 29**
**Heat exchanger**

Hello everybody, today we are going to start a new topic for this particular course energy conservation and waste heat recovery.

(Refer Slide Time: 00:38)

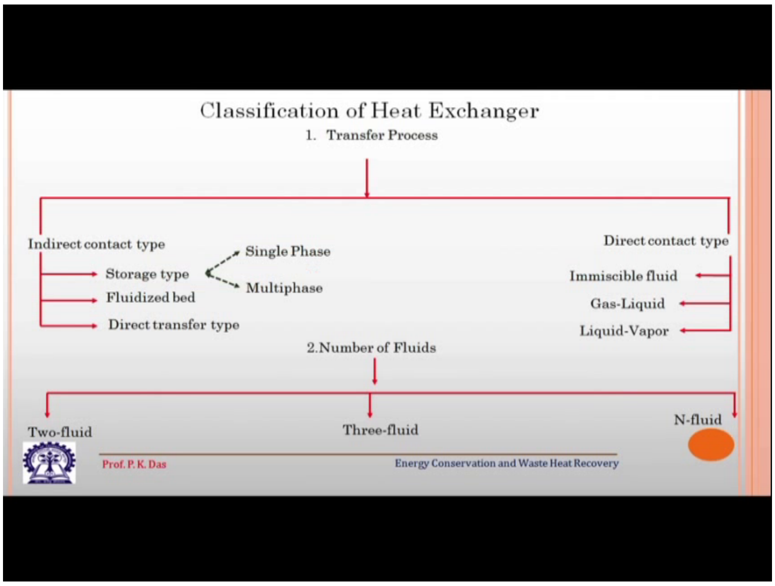



The topic which we are going to study is very important and it is heat exchangers, you know the subject which we are studying that is waste heat recovery. So, from the thermal energy which in other way; it could have been dumped to the ambient or the atmosphere. So, we want to learn principles how it can be recovered the different methods so; obviously, if we are trying to recover the thermal energy. So, the device which will be needed at the first place is called a heat exchanger, heat exchangers are very versatile devices it is very useful component and used in diverse industries.

One can think of a heat exchanger as a device in which two streams, two fluid streams they exchange thermal energy, one hot stream rejects heat and that heat or thermal energy is picked up by a cold stream, most of the cases these 2 streams of fluids they do not mix with each other. So, there is a barrier. So, across some sort of a solid wall the heat exchange or heat transfer takes place of course, there are certain heat exchangers where the fluids mix with each other and exchange heat without any intermediate solid wall, but those heat exchangers are few in number, most of the other heat exchangers they exchange heat or rather in most of the other heat exchangers.

The fluid streams exchange heat across some sort of a solid wall or solid boundary. So, as heat exchangers are being used in different industries for diverse application for centuries. So, we will see that there are many kinds of heat exchangers and for the sake of convenience so that we can design them, we can analyze them easily. So, heat exchangers are classified or categorized, there are different ways of classifications of heat exchangers, first we will spend some time on the classification of heat exchanger, very quickly we will see what are the different classifications of heat exchanger.

(Refer Slide Time: 03:19)



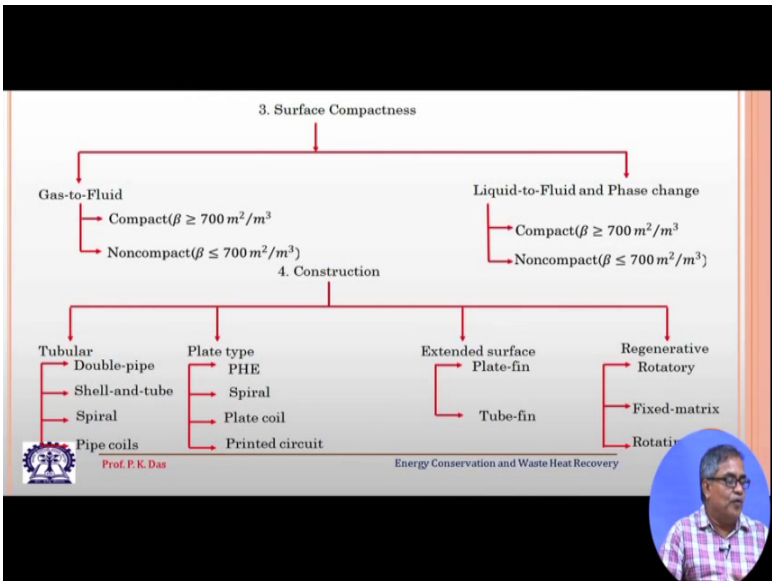

So, depending on transfer processes heat exchanger can be classified and most of the heat exchangers are in direct contact type; that means, 2 fluid they will not contact each other they will thermally contact or thermally interact with each other through some sort of a solid wall.

These are called indirect contact type there is storage type heat exchanger, thermal energy from a from the hot stream will be stored temporarily in some sort of a matrix or body and then that stored thermal energy will be passed on to the cold steam, to the cold stream or to the low temperature stream. So, that is that is your storage type heat exchanger and it could be single phase and multi, ma or multi phase then fluidized bed heat exchanger and then there could be direct transfer type; that means, there is no intermediate body to store thermal energy. Thermal energy will directly pass on from the hot stream to the cold stream only it will pass through some sort of a solid wall or solid body.

So, this is your direct transfer type, sorry indirect transfer type. So, there is direct transfer type where the 2 fluid streams mix with each other or they come in contact with each other and transfer the and exchange the thermal energy. So, there could be 2 immiscible fluids transferring thermal energy between each other, there could be a gas stream and a liquid stream or there could be a liquid and the vapour stream.

Then number of fluids most of the heat exchanger handles 2 fluid streams, but there are quite a few heat exchangers they handle 3 fluid streams and there are special heat exchangers which handle, which handles more than 3 fluid streams more number of fluid streams. But our discussion will be mainly on 2 fluid exchanger which is the most common device and is also very relevant for the purpose of waste heat recovery and energy conservation.

(Refer Slide Time: 05:55)




Then if we go for surface compactness, surface compactness we have to understand this thing bit carefully it is like this the heat exchanger has got a volume, but volume does not give its capacity directly. The volume does not directly gives it capacity for transferring heat, heat transfer is a surface phenomena and the rate of heat transfer that depends on the surface area available for heat exchange. Now, a heat exchanger will be very effective that when within a small volume when it occupies a small volume, but has got a very large amount of heat transfer area and this property that means having a large amount of heat transfer area within a small volume is called the compactness of the heat exchanger.

The heat exchanger is very compact when it has got large amount of heat transfer area within a small volume. So, it depending on that the compactness is defined by some sort of a number which is beta, when beta is greater than 700 meter square per meter cube then this heat exchanger is called a compact heat exchanger. When it is less than this number, when beta is less than this quantity or this number then it is not a compact heat exchanger. This is some sort of loose definition of compact heat exchanger, but it is widely accepted that when the area to volume ratio is 700 meter square per meter cube then the heat exchanger can be taken as a compact heat exchanger.

Now, this is very important because in waste heat recovery we want to recover thermal energy and in many of the cases the delta t or the temperature difference which is the driving force for heat transfer is low in case of waste heat application and we need to have a compact heat exchanger, only in that case within a given volume we will be able to extract good amount of thermal energy. So, compactness is very important as far as waste heat recovery is concerned.

But at the same time when the heat exchanger becomes compact; that means, generally the fluid flow passages becomes narrow or they become very intricate and there is always a problem of fouling or deposition on these intricate passages and surface features which is used for the compactness of heat exchanger.

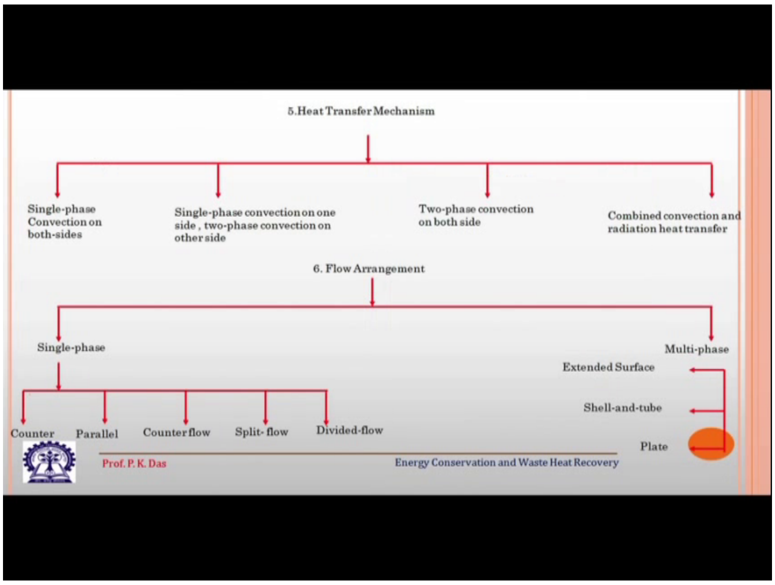
So, again if we are considering some sort of waste heat recovery action where we are handling with dirty fluid, dirty affluent then we have to really judge whether we can use a compact heat exchanger or some such, some other design will be suitable for that particular purpose. Then depending on construction heat exchanger can be divided into several categories, tubular geometry is very common it is a very common geometry for any industry. So, there could be double pipe or pipe in pipe kind of heat exchanger, there could be shell and tube heat exchanger I am not going to describe them in detail now because I am going to show them to you some sort of photographs etcetera.

Then there could be spiral heat exchanger then there could be pipe coil heat exchanger. So, this is if the main construction is tubular type and again many of them are relevant for waste heat recovery purpose, plate type that there could be plate heat exchanger sometimes this is all called cascaded plate heat exchanger or plate and frame heat exchanger. There could be spiral plate heat exchanger, there could be plate coil and there could be printed circuit heat exchanger. Both of plate and frame heat exchanger or phe and spiral plate heat exchangers are very relevant for waste heat recovery purpose because they give good amount of heat exchange within a small volume, then extended surface.

Extended surfaces are heat transfer augmentation devices commonly they are known as fins, we have seen our many of us, we have many of us we have seen the radiator of a car. So, in the radiator of a car you will find these fins or extended surfaces are there if you look into the heat exchanger which is what is there in a room air conditioner you will find fins. So, fins are devices for augmenting the rate of heat transfer and there are different kind of heat exchanger with fin, there could be tube fin and there could be plate fin heat exchanger, both of which I am going to show you some sort of photograph or figure.

Then regenerative heat exchanger again this is very important for waste heat recovery purpose there could be rotary regenerator, there could be fixed matrix regenerator and there could be rotating hood regenerator we are going to discuss some of them in detail.

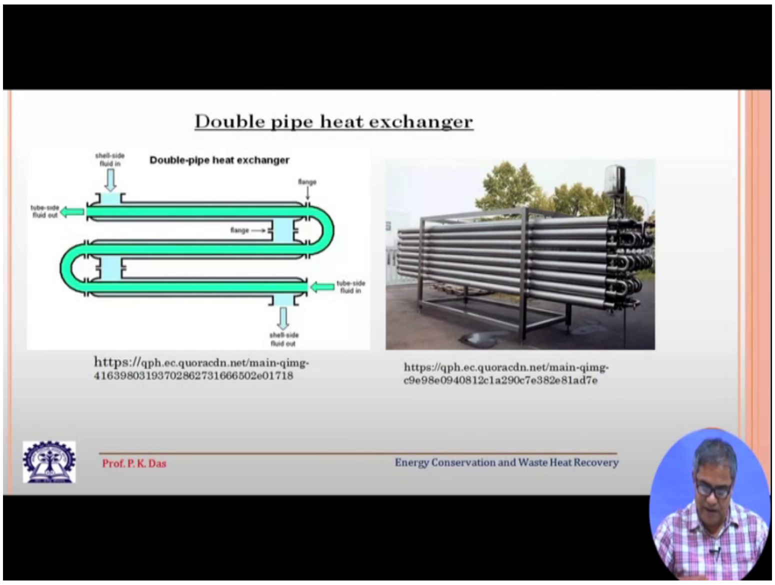
(Refer Slide Time: 12:10)




Next classification if we see the next classification is based on heat transfer mechanism, it could be single phase if there is no phase transfer both the fluid streams they are exchanging heat, but both of them are in the original phase itself there is no phase then it is single phase. Then single phase convection on one side, 2 phase convection on the other side, then 2 phase convection on both the side combined convection and radiation which can be there in kind of a in a boiler.

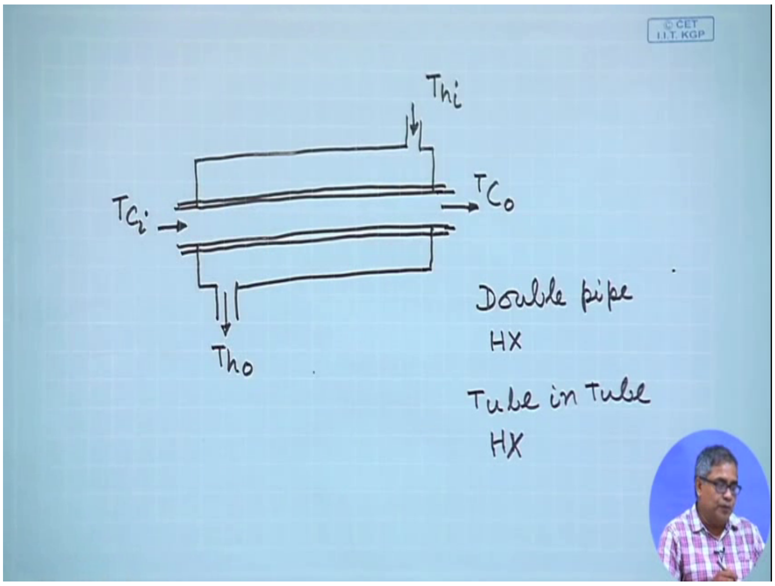
So, this kind of different mechanism of heat transfer could be there, then flow arrangement. Flow arrangement again depending on whether it is single phase or multi phase we can have different kind of flow arrangement, in case of single phase we can have counter flow, parallel flow, cross flow, split flow, double divided flow etcetera and in case of multi phase we can have extended surface, shell and tube, and plate heat exchanger so these are the heat exchanger which can be used for multi phase flow. Now there are 3 main arrangement based on flow that is your counter flow and parallel, parallel flow counter flow and cross current flow or cross flow. So, these we will see in details as we proceed.

(Refer Slide Time: 13:45)




Now, as I have told that I will show you some photographs and schematics of heat exchangers. So, that you can form an idea how does it look, the basic heat exchanger arrangement could be something like this.

(Refer Slide Time: 14:10)



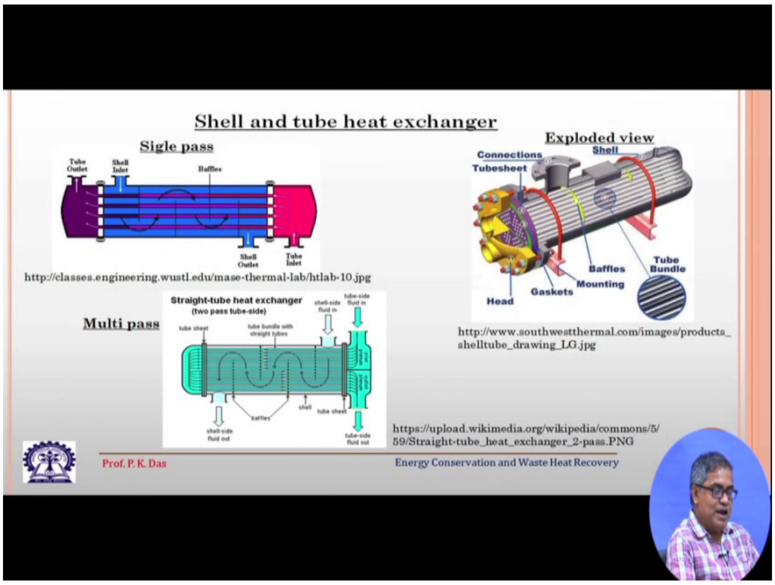

Let us say we have got a tube and this tube is concentrically placed within another tube which is larger in diameter and this one constitute the most simple or basic heat exchanger, this heat exchanger is called double pipe heat exchanger or tube in tube heat exchange. So, I think the names are quite obvious and then you see in through the central tube let us say the fluid is flowing like this and through the peripheral tube let us say the tube fluid is flowing like this and when the fluid is flowing like this, in between the solid wall is there.

So, there will be heat transfer between these 2 fluids, let us say the central fluid is a cold fluid. So, it will enter with tc i and it will go out with tc o. So, it will go out with at warmer condition and let us say this is the hot fluid which is coming out th i and it will go out with th o; that means, when it will go out its temperature will be less than the temperature it, less than its temperature at the entry . So, if we now switch to the ppt. So, this is a tube in tube heat exchanger or double pipe heat exchanger. So, you see through the central tube fluid is entering over here and fluid is passing through like this and through the peripheral tube fluid is entering like this and it is going out like this and here you see it is kept in some sort of a hairpin like of arrangement and there are number of term.

So, it is kind of a the flow direction it changes from here it is like this and then again it is taking a turn and there could be quite a few turn, now why it is done because to have some sort of heat exchange we need certain length and for a tube in tube heat exchanger if that length is very large it cannot be accommodated in the site of the factory and for other convenience. What we do that we do it like this we take a turn over here hairpin bend like this and there are several bends. So, within a small footprint probably the vertical height of this heat exchanger will increase, but within a small footprint we can have this heat exchanger instead of increasing its height.

So, on the right hand side there is a photograph of such heat exchanger.

(Refer Slide Time: 17:45)




But; obviously, the problem you have seen that a tube in tube heat exchanger will have a will have large length or otherwise we have to go for some sort of a design modification if we want to have certain amount of heat duty or certain amount of heat transfer. So, what is most commonly done that we have a shell and tube heat exchanger, in shell and tube heat exchanger here also here also the construction or the geometry is mainly tubular. So, instead of one tube at the centre we have got number of tubes through which a particular fluid passes and these numbers of tubes are arranged in a shell which is another tube we can take it another tube with a large diameter.

So, basic design of shell and tube heat exchanger is shown here, the there are 2 fluids as I have told that there is a sell side fluid and there is a tube side fluid. The shell side fluid is entering from here this is shell inlet and shell side fluid is going out from here this is shell outlet, then this is the tube inlet tube side fluid is entering over here and tube side fluid is going out of here. The colours have been selected in such a way that it indicates tube side fluid is hot and as it passes its temperature falls and it leaves the shell and tube heat exchanger in colder condition, the shell side fluid is cold, but it comes out here; obviously, it will gain some amount of, some amount of temperature.

Now, there are quite a few things to which I like to draw your attention, the tubes are held these tubes are held between tube seats over here and we want that there is a good contact between of course; it is in direct contact good contact between the shell side fluid and the tube side fluid. So, for that what we do, we try to ensure that these 2 fluid remain in contact for a larger time, this is called the residence time. The residence time of the fluid that we try to increase, particularly shell side there is having I mean we are having larger area. So, in the shell side we want to use we want to increase the residence time. So, for that what we do we provide some sort of baffles? So, these are baffles you see here there is one baffle, here there is another baffle, here there is another baffle like this.

So, a shell side fluid it enters, but it cannot directly go to the outlet from the inlet. So, this has to take a circuitous route like this and; obviously, when it is taking a route like this the residence time increases. The residence time increases means we get more heat transfer, more scope of heat exchange between the shell side fluid and the tube side fluid. So, baffles could be of different designs the most simple design of baffle has been shown here and this also gives another advantage the flow of the shell type fluid is now cross flow, it passes the passes pass the tube in a cross flow direction.

That means the tube side flow is in this direction and the shell side flow is perpendicular to that and this cross flow arrangement gives a good amount of heat transfer between these 2 fluids. Now, you see this is the simplest arrangement of shell and tube heat exchanger, now if we want more heat transfer as we have provided the baffles on the sell side. So, that sell side fluid has got more residence time before it leaves the heat exchanger, the tubes the tube side fluid can be made to pass this shell length more number of times. So, then what will happen the tube side fluid will also have more residence time. So, for that below what we the top one the shell and tube heat exchanger can be called a single pass shell side.

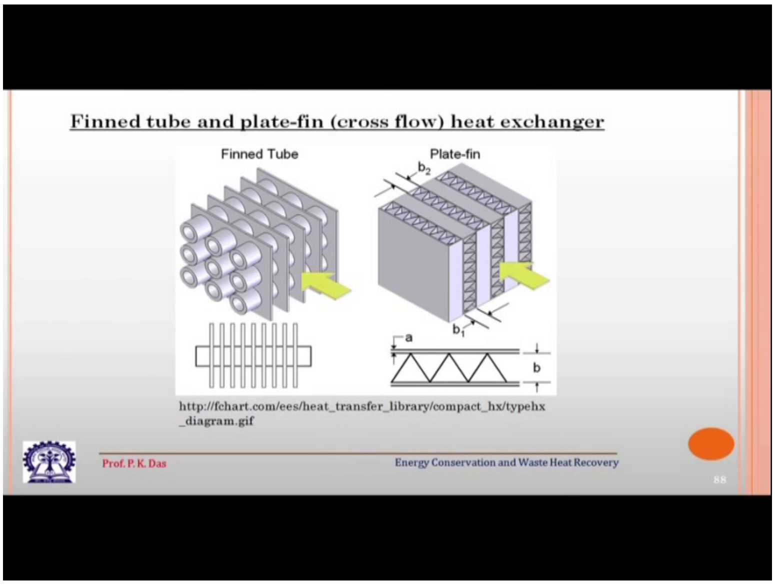
There is only one pass tube side also there is one pass, but below we have got multi pass more or directly speaking we have got 2 passes on the tube side. So, tube side fluid enters here, it moves like this and then it changes its direction, it changes its direction by 180 degree it again traverses the entire shell length in the opposite direction and comes out like this. So, you see a fluid particle starting from here to here it has to traverse the total shell length 2 times it will have more opportunity to be in contact of course, in directly with the shell side fluid and we will have a good amount of heat exchange. So, this is one arrangement where I have shown 2 pass arrangement there could be more than 2 passes there could be more number of passes on the shell side and on the tube side.

And here what I have shown here we have shown a shell and tube heat exchanger, the cutaway view or the exploded view whatever one may call it and then you see the tubes one can see the baffle one can see this is called tube seat where the tubes are held and they are gasket for the prevention of leakage then this is the head through which of course, there could be a liquid entry or exit point shell and tube you can see separately. So, this is the arrangement there could be many variations and this is the arrangement we take for shell and tube type of heat exchanger, let me tell you shell and tube heat exchangers are most extensively used.

They have got diverse applications starting from power industries, refrigeration, air conditioning and process plant petrochemical plants. So, they have got diverse applications and their design has been standardized over the year, they are very suitable for liquid-liquid if both these streams are liquid, liquid streams and there is heat exchange between the liquid streams. So, they are very suitable for liquid-liquid stream heat exchange operations and they are generally easy to clean and in as far as waste heat recovery is concerned. So, there are many applications of shell and tube heat exchanger, if we have to extract heat from a liquid stream and that heat has to be passed on to another liquid stream. So, we go for shell tube heat exchanger.

Very rarely it is used for gas and liquid heat exchange and of course, these kind of heat exchangers are used for multi phase heat exchange, heat as multi phase heat exchanges; that means, where one of the stream goes through some sort of a phase change process. So, this is your shell tube heat exchanger which is very important and relevant for your waste heat recovery purpose also.

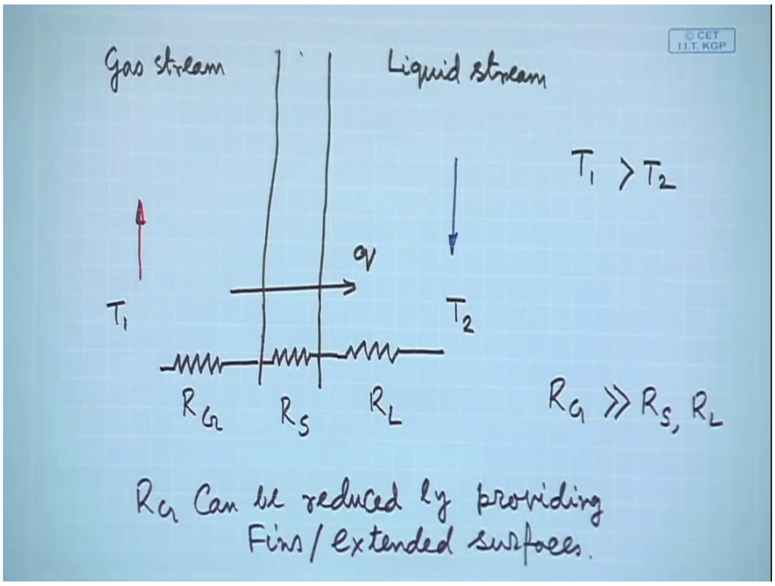
(Refer Slide Time: 26:29)




This is your fin tube heat exchanger or rather this is this there are two2 heat exchangers shown both uses extended surfaces or fins for augmenting heat transfer. Let me tell you that if we consider that there are 2 streams one is a liquid streams another is a gas stream.

So, generally in the liquid side the heat transfer coefficient is very high, on the gas side the heat transfer coefficient is low and in general it is like this lets say we have got a gas stream and then a liquid stream and they have got different temperatures and in between there is some sort of a solid wall.

(Refer Slide Time: 27:16)



Schematically the solid wall is shown like this, let us say the gas stream is hot it is moving in this direction in the upward direction and the liquid stream is cold it is moving in the opposite direction and then the temperatures are let us say this temperature is T 1 locally at some point and this temperature is T 2 and where T 1 is greater than T 2. So, heat transfer will take place. So, q will move from gas stream to liquid stream, but there are 2 resistances gas stream side there is one resistance. There is one resistance in this solid body which in most of the cases is a metallic wall and then there is another resistant resistance on the liquid stream shell. So, let us say this is R G lets say this is R solid and this is R L. So, what we will find the solid conductivity is very high. So, solid side resistance is low, heat transfer coefficient in the liquid side that is also very high. So, that resistance is low on the liquid-liquid side, but R G is very very large compared to both R S and R L. So, that is a common feature or common scenario.

So, if we have to have effective heat transfer then somehow we have to reduce the heat transfer resistance in the gas side and one way one very convenient way of doing this is by providing. So, R G can be reduced by providing fins or extended surfaces. So, there are many heat exchangers, this is a very common device for increasing the gas side heat transfer rate of heat transfer and we can have in tubular geometry the fin tube type of heat exchanger and in plain geometry we can have plate fin type of heat exchanger and you can I can very click quickly describe them. So, tube side heat exchanger the fluid passes like this from here to here and the gas passes in this direction.

So, this is basically a cross flow type of heat exchanger and plate fin heat exchanger this is one plate, this is another plate and there is number of fins like this they could be of different geometry, different design and one fluid passes like this another fluid passes from the top to bottom or from bottom to top. So, here also it is in cross flow kind of arrangement, though in plate fin heat exchanger we can have different kind of arrangement both this heat exchanger or both these type of heat exchangers are very relevant for waste heat recovery purposes.

We can think of that a car radiator from there if we have to recover waste heat this kind of heat exchanger is used, in many process plant and even in air conditioning plant if we want to recover heat. So, one can take this kind of a heat exchanger where both these streams are gas streams, here one stream is a liquid stream another stream is a gas stream here generally both these streams are a gas stream or one side one can take a stream which is changing its face. So, with this I like to stop with our description of heat exchanger for the time being in our next lecture we will find some other interesting designs and construction of heat exchanger.

Thank you.