Heat and Mass Transfer
Prof. S. P. Sukhatme
Department of Mechanical Engineering
Indian Institute of Technology, Bombay
Lecture No. 25
Heat Exchangers-1

So far we have studied the modes of heat transfer; we have studied heat conduction in solids, we have studied thermal radiation and we have also studied convection. In convection, we have looked at forced convection and natural convection. Now today we start with the topic of heat exchangers. The first thing we ask ourselves is, the first thing we will do rather is to describe various types of heat exchangers. Before that, let me just restate again the textbooks and the reference books which we are following.

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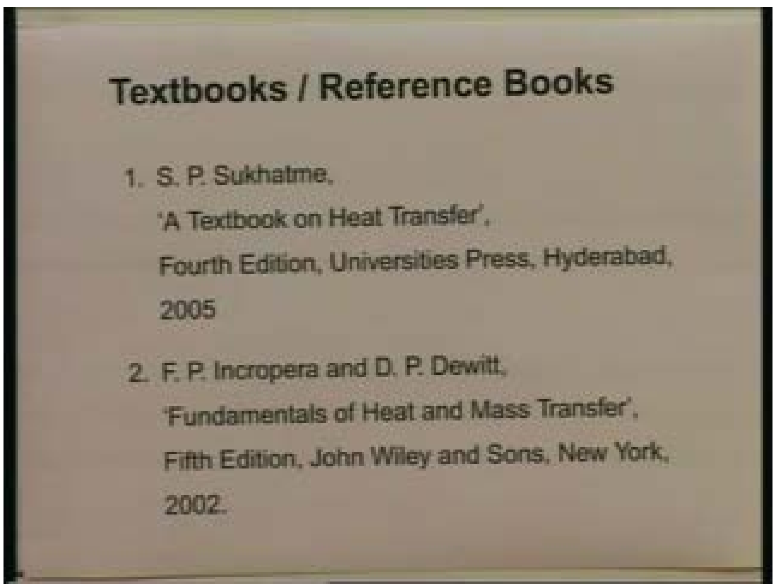

We are following my book on a textbook on heat transfer by Universities Press; we are also following Incropera and Dewitt - the fundamentals and heat and of heat and mass transfer. These are 2 books which we are closely following so if you miss some part or you are not able to take down some notes, you are not able to take down a figure generally, you will find a figure which is very similar to what we are showing in the, in one of these 2 books. Now, the first thing we ask ourselves is what are heat exchangers?

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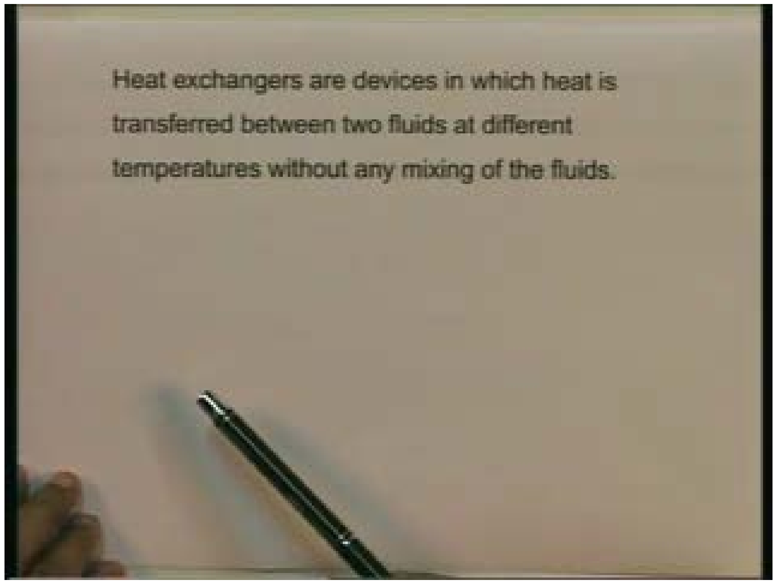

Well, heat exchangers heat exchangers are devices in which heat is transferred between 2 fluids at different temperatures without any mixing of the fluids. There are 2 fluids, one is hotter than the other, they are at different temperatures. Heat is transferred from the hot fluid to the cold fluid; a device in which this happens is called a heat exchanger. And this occurs without any mixing of the 2 fluids that is the hot fluid doesn't mix with the cold fluid; the heat transfer takes place without any mixing of the fluids with each other - that is called a heat exchanger.

Now broadly speaking there are 3 types of heat exchangers of the various, hundreds of heat exchangers which are built and hundreds of geometries, etcetera which are built. There are 3 broad classification now, 3 types of heat exchangers.

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The 3 types are: number one what is the called as the direct transfer type, number 2 what is called as the storage type and 3 what is called as the direct contact type. These are 3 broad types of heat exchangers; let us look at each of these for a moment.

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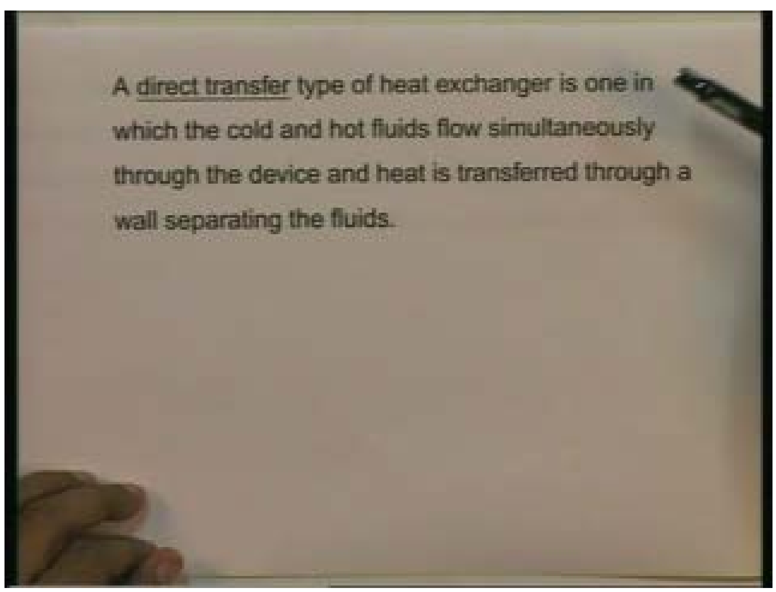

First, the direct transfer type - a direct type of heat exchanger, a direct transfer type of heat exchanger is one in which the cold and the hot fluids flow simultaneously through the device and heat is transferred through a wall separating the 2 fluids. I repeat a direct type of heat exchanger is one in which the cold and the hot fluids flow simultaneously through the device and heat is transferred through a wall separating the 2 fluids. Let us look at an example of a direct transfer type heat exchanger; the example we are going to look at is a very simple one.

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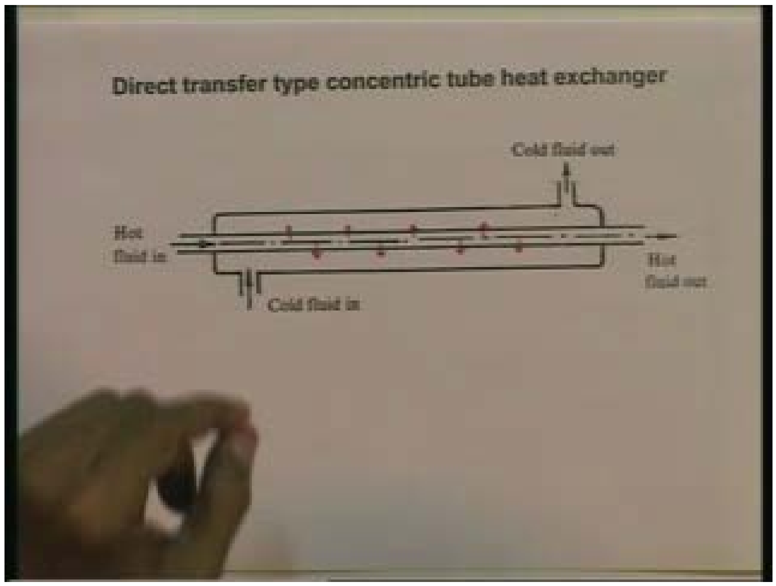

The particular one, the particular direct type of heat exchanger we are loing at is what is called as a concentric tube heat exchanger. So we say it is a direct transfer type concentric tube heat exchanger; the words 'concentric tube' describe the geometry of the heat exchanger that is there is one tube inside another tube. This is the one tube that is inside, this is the outer tube here so and they are concentric to each other; that is why it is called a concentric tube heat exchanger.

The 2 fluids, the one fluid in this case, the hot fluid flows through the inner tube. It is shown here, it is entering the inner tube on the left hand side, flowing along the inner tube and getting out here and the hot fluid is leaving the heat exchanger here. The cold is fluid is entering the outer tube flowing through the annulus and then exiting out here; flows around the whole length and then exiting out here. So one fluid flows inside the inner, in this case it is the hot fluid; the other fluid - the cold fluid - flows inside the annulus and that is why use the word concentric tube heat exchanger. It is also referred to sometimes as a tube in tube heat exchanger.

Now, the heat transfer in this heat exchanger takes place across the wall of the inner tube. So the hot fluid is inside the inner tube here, the cold fluid is in the annulus here, so the heat transfer is taking place like this from the hot fluid to the cold fluid across the wall of the inner tube. This is where the heat transfer is taking place and as the cold fluid flows in the annulus it is picking up heat, its temperature is rising and as the hot fluid flows along length, it is giving up heat and therefore it is dropping in temperature. So this is the heat transfer surface, this is the heat transfer surface where heat transfer is taking place - the wall of the inner tube of the heat exchanger.

So, this is a direct transfer type heat exchanger; both the fluids are flowing simultaneously through the heat exchanger and heat is flowing across the wall of the inner tube from the hot fluid to the cold fluid. There is of course no mixing of the fluids. This is one type and this is the type that we really be studying in detail. Now, we come to the second type of broad classification

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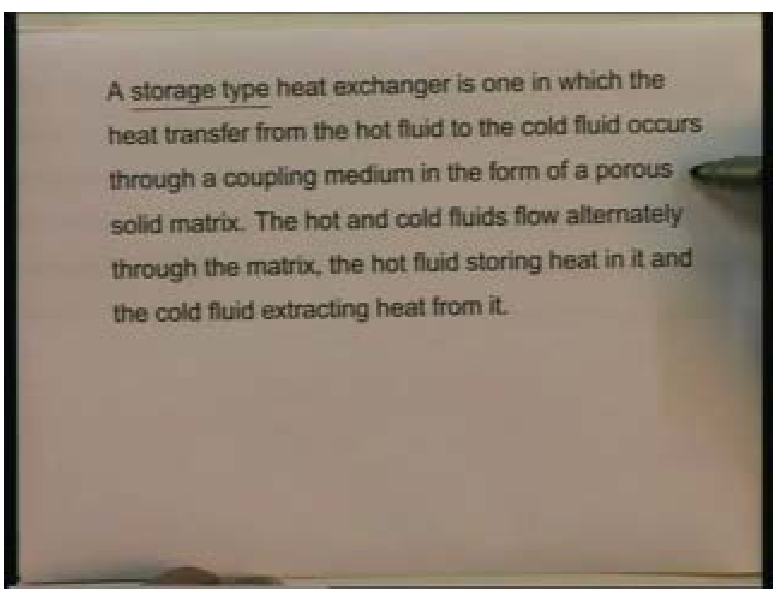

The second type of heat exchanger is what we have called a storage type heat exchanger. Now, let us look at the description of it - a storage type heat exchanger is one in which the heat transfer from the hot fluid to the cold fluid occurs through a coupling medium in the form of a porous solid matrix. I repeat a storage type heat exchanger is one in which the heat transfer from the hot fluid to the cold fluid occurs through a coupling medium in the form of a porous solid matrix. The hot and cold fluids flow alternately through the matrix, the hot fluid storing heat in it and the cold fluid extracting heat from it. The hot and cold fluids flow alternately through the matrix, the hot fluid storing heat in it and the cold fluid extracting heat from it. Not let us look at a sketch so that we describe this heat exchanger a little better.

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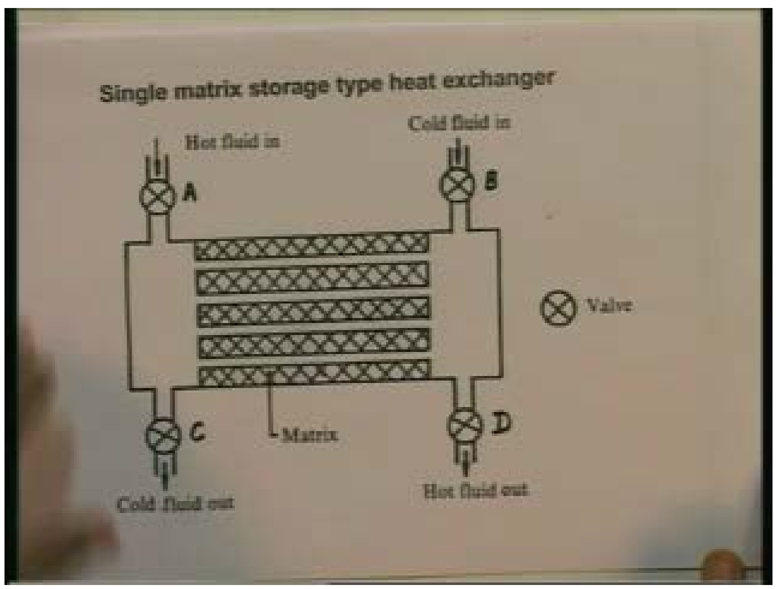

What I have shown in the sketch is a single matrix storage type heat exchanger. The cross hatching shows the porous matrix, the porous matrix for instance maybe pebbles with passages through them or it may be some brick work with holes in it - porous brick work through holes in it, could be loosely kept, some finer material loosely kept, etcetera. Basically something through which fluid can flow; a gas can flow or air can flow and something which will absorb heat or give up heat when the hot fluid or the cold fluid flows through it as maybe the case. So, this is the porous matrix and what we have here -

the circles with crosses on them - are valves which can be opened or closed. So let us just - what you call - give them a nomenclature; let us say this is valve A, this is valve B, this is valve C and this is valve D. Let us say first of all that during the operation of this heat exchanger, valves A and D are open and B and C are closed. So, obviously, the hot fluid can enter here if this valve is open, go through this porous matrix and come out through D. If it does this, it is going to give up its energy, it is hot, it is heat to the material of this porous matrix and this matrix is going to heat up; we do this for sometime, then we and during this period, of course, B and C are closed.

Now after doing this for some time, we close A and D and open B and C so that the cold fluid starts to flow through this matrix and the cold fluid picks up heat from this matrix, gets heated and then flows out. So one by one, the hot fluid flows through, stores heat in the matrix, the cold fluid flows through and picks up heat from the matrix; so that is why this is called a storage type of heat exchanger. This is, there are many versions, of course, of the storage type; this is the simplest type. We just want to show one here.

And then the third type of heat exchanger - third broad classification - is what we called as a direct contact type heat exchanger.

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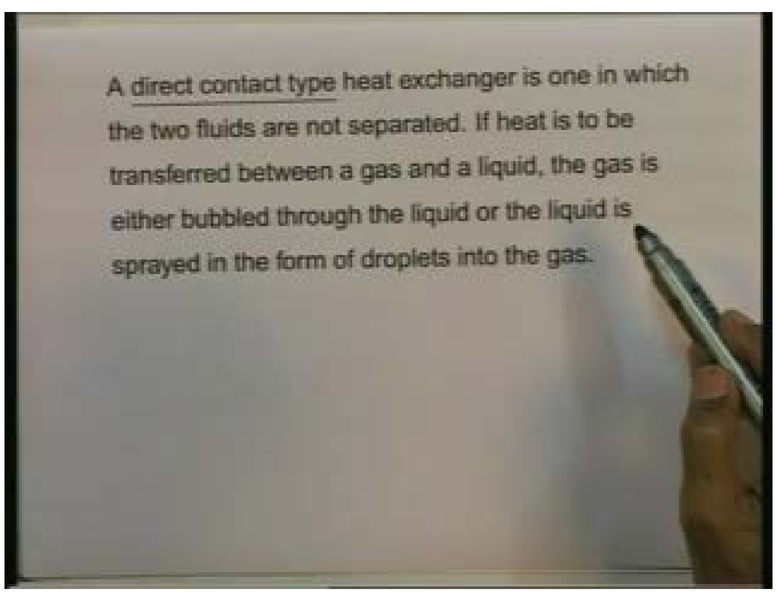

What is this? A direct contact type heat exchanger is one in which the 2 fluids are not separated. If heat is to be transferred between a gas and a liquid, the gas is bubbled through the liquid or the liquid is spread in the form of droplets into the gas and once it is spread in the form of droplets, heat gets transferred in the direction between hot fluid and the cold fluid or the gas is bubbled through the liquid in which case also heat gets transferred between the hot fluid and the cold fluid. Let us again illustrate this with a sketch to show a direct or a contact type for heat exchanger.

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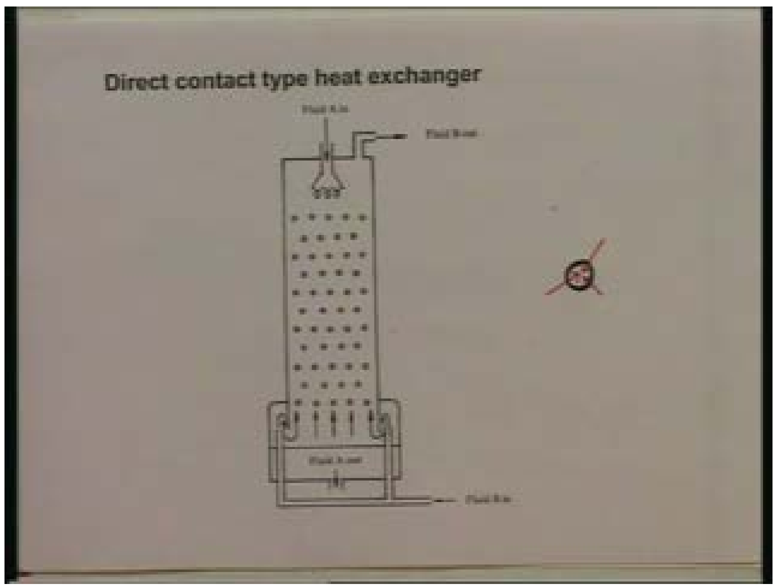

Here is a direct contact type heat exchanger now. This is a fluid A; let us say it is a liquid which is entering here so this is like a shower head, it is entering through the shower head here and bubbles, sorry, drops of this liquid come out of the shower head. These drops flow through like this and ultimately come down and collect here and go out of the heat exchanger. The other fluid - let us say it is a gas - flows in here and flows upwards through this heat exchanger so let us say it is water and air for instance. So the water is being spread in the form of drops and the air is flowing upwards through this heat exchanger.

If for instance the water is hotter than the air, obviously heat is going to flow from the water to the air or if the air is hotter than the water the reverse will happen. So this is what we call as a direct contact type heat exchanger in which one of the fluids is deformed. Deformed means put into the shape of say droplets or bubbles and then the heat transfer takes place; after heat transfer takes place, it is all collected and flows out so the droplets all get collected here and flow out. So that is why we call it a direct contact type heat exchanger because the process of heat transfer here occurs in this case at each drop.

If for instance this is a drop - one drop; then the heat transfer that is taking place assuming that there is, let us say air is hotter, the heat transfer is taking place from the air to the water like this across each drop that we are seeing here. The red arrow shows the direction of the heat transfer; if the air is hot flowing upwards and the water is cold and it is flowing downwards in the form of drops. So there is no metal wall separating the 2 as we had in a direct transfer type of heat exchanger, so we call it a direct contact type of heat exchanger. So these are 3 broad types of heat exchanger.

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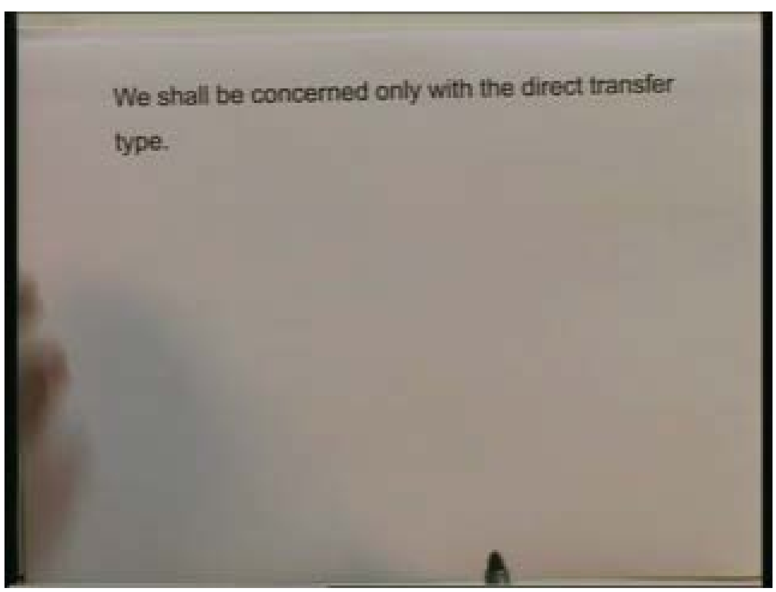

Now during these few lectures that we have, we shall be concerned, we shall be concerned only with the first type that is the direct transfer type of heat exchanger. I mean we could have looked at others but generally for an elementary undergraduate course it is adequate to look at the direct transfer type of heat exchanger. Now let us talk a little more about the direct transfer type of heat exchanger.

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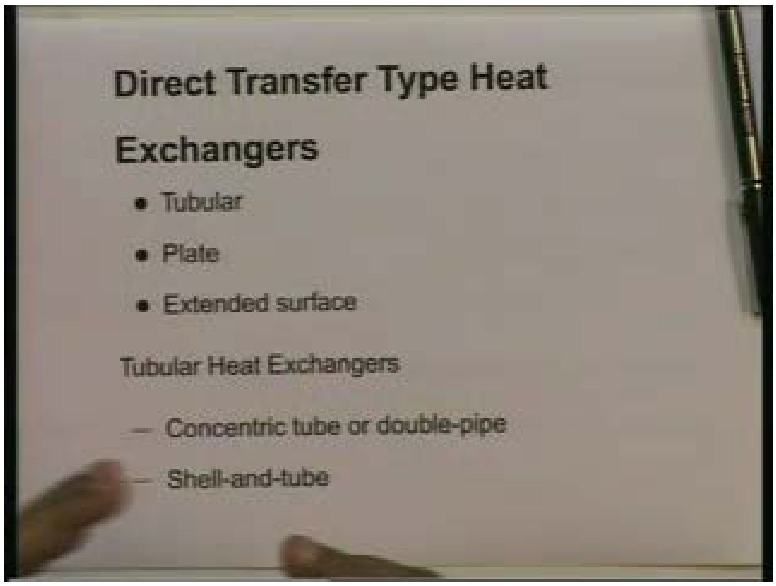

Direct transfer type heat exchangers can be broadly classified as belonging to one of 3 categories. What are these? We call them as - one category is what you call as tubular heat exchangers, second category what we call as plate heat exchangers and third as extended surface heat exchangers. Tubular heat exchangers, plate heat exchangers, extended surface heat exchangers - they are all direct transfer type heat exchangers. That means they follow the basic definition that we gave earlier: both fluids are flowing simultaneously through the device, there is some wall separating the fluids, heat transfer is taking place across the separating wall or walls; so that definition is satisfied. But depending on the shapes that we use, we give these names; we call direct transfer types as tubular heat exchangers, plate heat exchangers or extended surface heat exchangers.

Now let us look at each of these; first - tubular heat exchangers. And in fact, we have already looked at one tubular heat exchanger. What was that? That was the concentric tube or the double pipe heat exchanger. We have already looked at that - one tube inside another tube, the hot fluid, one of the fluids flowing through the inner tube, the other fluid flowing in the annulus around the inner tube. We have already seen that. Now let us look at one more tubular heat exchanger and that is called the shell and tube heat exchanger. So we are now going at another type of a tubular heat exchanger which is called as shell and tube heat exchanger. Now let me first show you a sketch of shell and tube heat exchanger and describe it.

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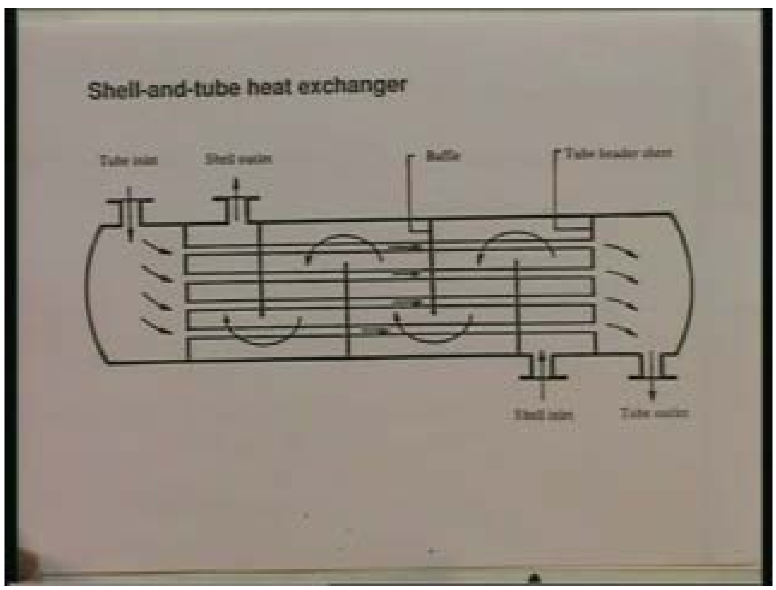

A shell and tube heat exchanger typically consists of a cylindrical shell; that is what we have here and a bundle of tubes inside the shell, I have shown here 4 tubes - 1, 2, 3 and 4. There are actually many, I will be just showing, it is a sketch so we are showing 4. It is a bundle of tubes inside a shell, the tubes, the axis of the tubes is parallel to the axis of the shell. One fluid flows inside the tubes and that is the fluid that I am showing here entering here. It is breaking the flow, flow is breaking up into 4 parts, going through each of the tubes that I am showing, flowing through the tubes, coming out here and then going out. So this is one fluid going inside, flowing inside the tubes and coming out. The other fluid flows on the shell side that is outside the tubes; it enters the shell here, flows outside the tubes in the shell space outside the tubes. And in this case, you can see it is flowing on the outside of the tubes and then it is exiting through an outlet at this point in the shell, so this is the second fluid.

Now there are some more parts inside this which I want to describe. First of all, let me again repeat. The 2 main elements of the shell and tube heat exchanger are number 1 - a cylindrical shell, number 2 - a bundle of tubes. I have shown 4 here; it will actually be a bundle whose axis is parallel to the axis of the shell so that is 2. Then the tubes are fixed in sheets at the ends here and these are usually called as tube header sheet so what we are saying here; at the ends here these are called tube header sheets in which the tubes are fixed. Then we have the front and the rear ends of the heat exchanger; this is one end of the heat exchanger, this is another cap at the end of the heat exchanger. So these are called the front and, front and rear end heads of the heat exchanger.

The fluids enter through inlets; as you can see this is the tube inlet for the tube side, this is the outlet for the tube side, this is the inlet for the shell side fluid, this is the outlet for the shell side fluid. These are typically called nozzles, these 4 are called nozzles. And finally in order that the shell side fluid should flow over all the tubes properly usually sheets are placed across the flow and which make the shell side fluid flow in the jig jag fashion as you are seeing here, which ensure a jig jag flow on the shell side and these sheets are called as baffles. So, these are the main elements of a shell and tube heat exchanger. I repeat – tube, the tubes which are enclosed, a bundle of tubes enclosed within a shell - the tube header sheets, the front, the rear end heads - the nozzles, 4 of them and baffles will ensure a good flow on the shell side of the shell side fluid.

One of the characteristics to describe a heat exchanger is the amount of heat transfer area it provides per unit volume of the heat exchanger. Typically, a shell and tube heat exchanger will provide anything from 100 to 500 meter square meters per cubic meter of volume of the heat exchanger. So keep this in mind whenever you are thinking of a shell and tube heat exchanger. Now let me again show another transparency just to repeat the same things.

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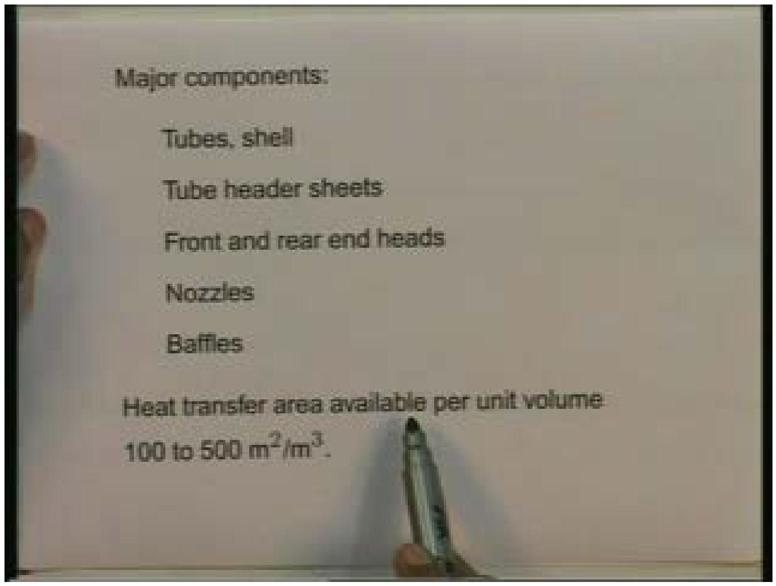

The major components of a shell and tube heat exchanger are a bundle of tubes, the shell, the tube header sheets, the front and the read end heads, nozzles and baffles. The heat transfer area available in a shell and tube heat exchanger per unit volume - it can range from 100 to 500 square meters per meter cube. Now I am going to show a typical tube bundle in a shell and tube heat exchanger; there you see it on the screen.

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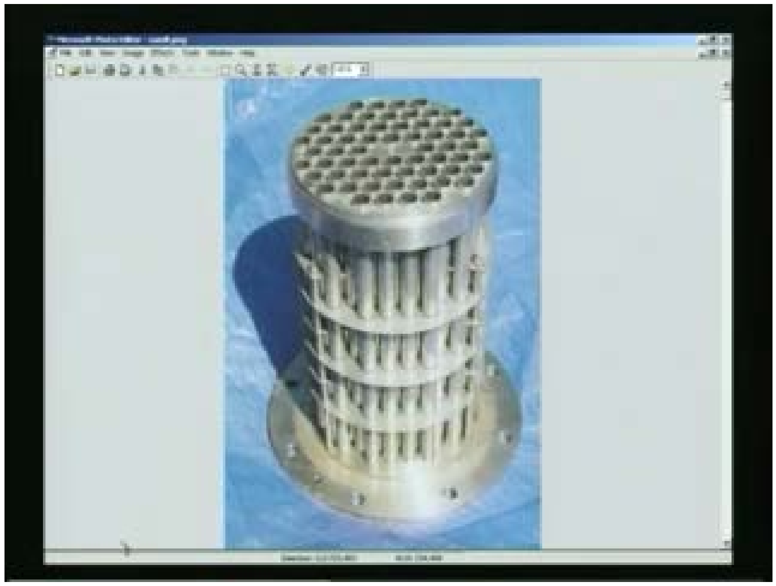

Now what you have got on the screen is a typical tube bundle; I told you there is a big bundle of tubes. In this case, as you can see you have 3369 and 16 and 24 and 731 something like 50 tubes or a little more than 50 tubes making up this heat exchanger. This plate at the end is the header sheet, the tube header sheet which I described in which the tubes are fitted. This is the other tube header sheet at the bottom and you can see it is on a flange there because it has to be fixed to the rear and the front or the front end head of the heat exchanger. And here you can see the baffle; you see this is a baffle, this is a baffle plate, this is a baffle plate to ensure that the shell side fluid flows in a jig jag fashion on the shell side and flows across all the tubes of the heat exchanger. So, I have taken out a tube bundle to show you so that you get a pictorial - a photographic view - of a typical shell and tube heat exchanger so this is a typical shell and heat exchanger.

Now let us move on; we have described the tubular heat exchanger and what did I say first? We looked of course at concentric tube heat exchanger, then at the shell and tube heat exchanger. Now. we want to look at the next one and that is a plate heat exchanger

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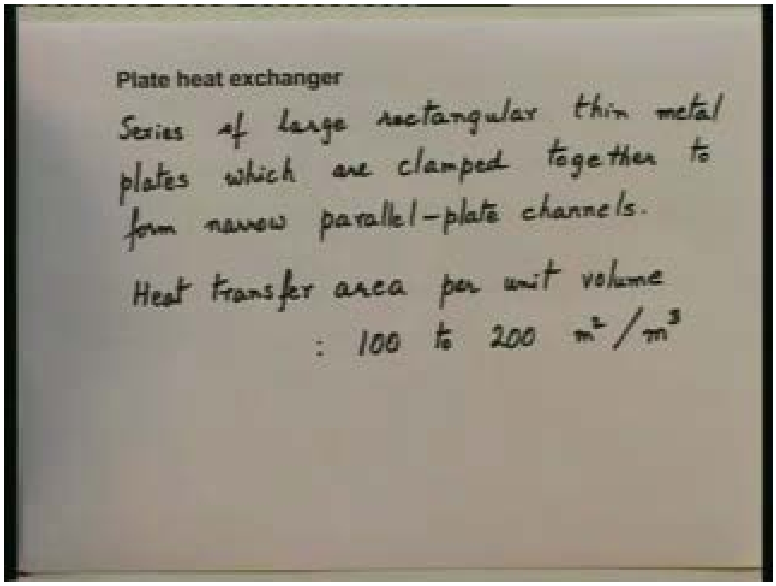

A plate heat exchanger as its very, as its name says is nothing but a series in a plate heat exchanger; we have nothing but a series of large rectangular thin metal plates which are clamped together to form. Now we look at the next type of direct transfer type of heat exchanger that is the plate heat exchanger. A plate heat exchanger in very simple terms is nothing but a large number of thin rectangular metal plates; a series of large rectangular thin metal plates which are clamped together to form narrow parallel plate channels - that is what its plate heat exchanger. And in order to illustrate this let us look at the photograph which I have here of a parallel plate heat exchanger. Here is a parallel plate heat exchanger.

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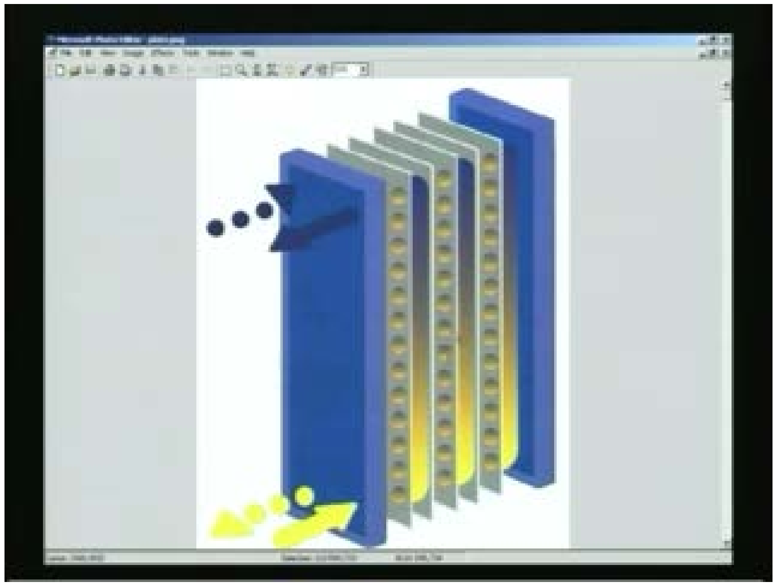

Now in the parallel plate heat exchanger these are plates which I am showing here with the cursor 1, 2, 3, 4, 5 - these are the plates. These are the end plates which are helping to clamp all those thin metal rectangular plates together. So we have a series of passages which are in the form of parallel plate channel - like this is number 1, number 2, number 3, number 4, number 5, number 6 - 6 parallel plate channels. One fluid let us say the one with dots here is entering here and flowing through these channels number 1, number 3 and number 5. It is going down through number 1, going down through number 3, going down through number 5, then it is being, there are ways in which they all join together and coming out at this point.

The other fluid you can see is entering here and there is an arrangement inside so that it automatically gets directed into passages number 2, 4 and 6; you see that there and it goes up through each of this passage. This is passage number 2, this is passage number 4, this is passage number 6 and then they again link up; the flow is all linked up together and it comes out. So basically here we have a 6 parallel plate channel heat exchanger with one fluid flowing through channels 1, 3 and 5, the other flowing through 2, 4 and 6 and heat being transferred from one fluid which is hotter to the fluid which is colder at the end. So, this is what we call as a parallel as a plate heat exchanger.

Typically for such a heat exchanger, for such a heat exchanger the heat transfer that you would get in such a heat exchanger is the heat transfer area per unit volume. For a plate, heat exchanger would typically be from about 100 to 200 square meters heat transfer area per unit volume of the heat exchanger. So this is the second type of heat exchanger - the plate heat exchanger, a series of narrow parallel plate channels. Now the third the third is what we have called as the extended surface heat exchanger.

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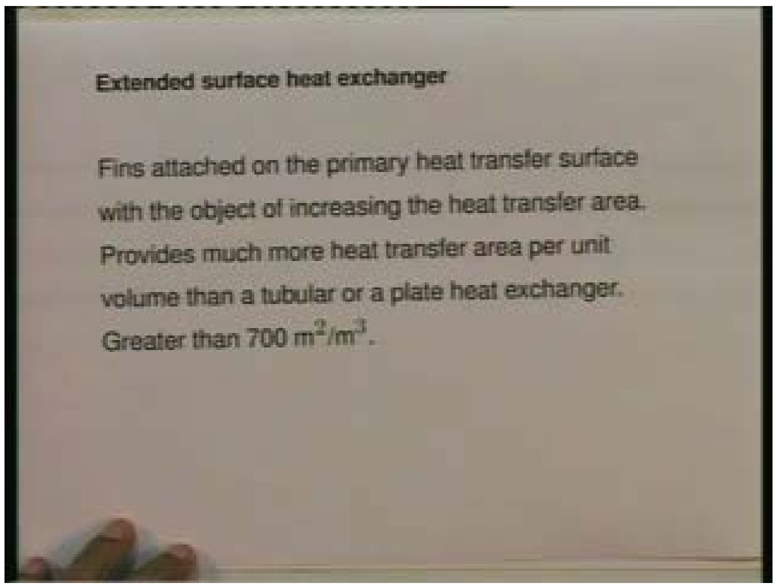

Let me first describe - its fins are attached on the primary heat transfer surface with the object of increasing the heat transfer area and as a result, because of the fins, one provides much more heat transfer area per unit volume than a tubular or plate heat exchanger. Typically in an extended surface heat exchanger because of the fins one has more than 700 square meters of heat transfer area per unit volume of the heat exchanger. Compare this with the numbers that I gave you earlier. So, you put fins on the primary heat transfer surface in order to enhance the heat transfer area per unit volume of the heat exchanger. Now again, let us look at some sketches to illustrate ideas.

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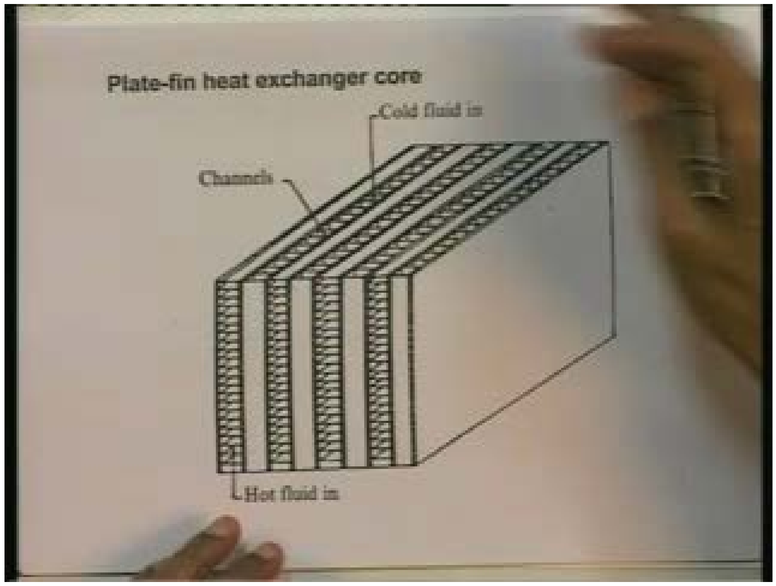

Here is what we call as the plate fin heat exchanger - so it is a plate heat exchanger but with the fins added on, it becomes really an extended surface heat exchanger. So here are the channels now; as you can see, here are the channels - this is, there are here 1, 2, 3, 4, 5, 6, 7, 8 and 9 plates. And you can see the, if I start numbering the channels from here, channels 1, 3, 5 and 7 are one set of channels and 2, 4, 6 and 8 constitute the other set of channel – 9 plates giving us 8 channels, 4 for the hot side, 4 for the cold side. And it is not just channels that we are providing but you can see that we are providing fins which are interconnecting the one side to the other. That means they are long thin strips which are inside these channels which are connecting one side to the other. I am providing this much more heat transfer area so the fluid flowing through has to flow through narrow passages, narrow in this direction, narrow in this direction as well. And the same is also true on the other side; we have got fins also on the cold side here and so there are narrow passages, narrow long rectangular passages on the cold side as well so as a result, you provide a lot more heat transfer area per unit volume.

We are showing here is only the core of the heat exchanger; in reality, there would be some manifold at the end, here a manifold at the end, here a manifold on this side. So the hot fluid enters, gets distributed into this channels, comes out at this end, gets collected and then flows out so it is not just the, it is not the whole heat exchanger. What we are showing you is just the core. Now I want you to show you a typical core of a real physical model and here we go.

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This is a core of plate for fin heat exchanger or what is broadly called as an extended surface heat exchanger and here you again see we have got in this case 1, 2, 3, 4, 5 channels here. And you can see in between the plates we have these fins which are attached; they are not all equal in size but these are the fins which have been attached in between this is one side. And then, if I go to the other side here we have the other side of the heat exchanger where you can see I have the other fluid flowing through these channels which are slightly narrower in width and again we have fins here.

So, it is an extended surface heat exchanger or to describe it in terms of its geometry, it is a plate heat exchanger with fins so we call it a plate fin heat exchanger and again this is only the core of the heat exchanger. One gas typically would flow through this side through these channels - these 4 channels - the other would flow these 5 channels. One would be hot, the other would be cold; heat would be transferred from the hot fluid to the cold fluid.

Now let us look at some more examples of extended surface heat exchangers. These are, what we showed just now was a plate heat exchanger with fins - a plate fin heat exchanger.

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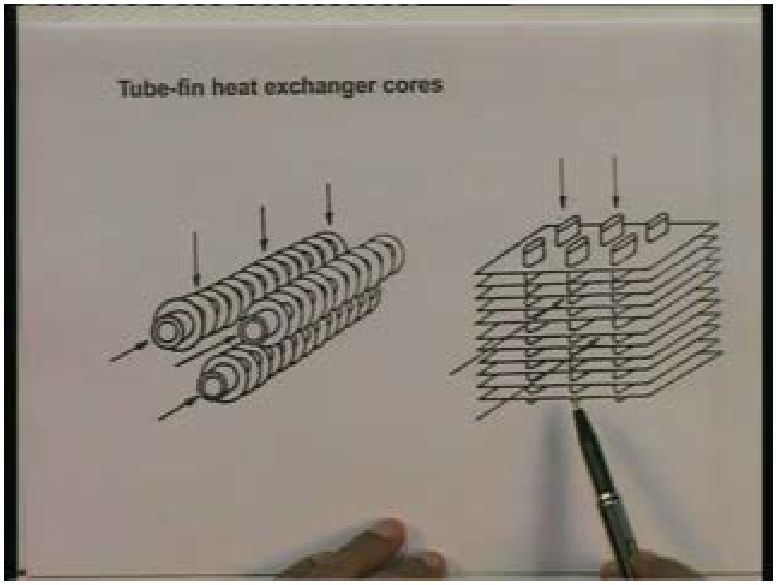

You could also put fins and tubes in which case we get what are called as tube fin heat exchanger and here we have 2 types of tube fin heat exchanger cores. Now here is a bundle of tubes; look on the left side, these are 3 tubes like this and one fluid is flowing on the outside of the tubes like this, the 3 vertical arrows, the other fluid is flowing inside the tubes. Typically, this is, this type of heat exchanger is used for exchanging heat between a gas and a liquid. So the liquid will flow inside the tube because the liquid you already have a high transfer coefficient, on the gas side you don't have a high transfer coefficient. So, in order to enhance or reduce the thermal resistance on that side, we put fins on the gas side so this is called a tube fin heat exchanger.

Now a typical, either the fins can be on individual tubes as you are seeing here, these are round fins on each tube and they will be closely stacked together or you have got a continuous fin sheet like you are seeing and the bundle of tubes is like this through which the liquid is flowing. So this is also possible in which case you have continuous fin sheets fixed on the array of tubes or here individual fins on each tube making up the tube array. This is typically what we have in an automotive car radiator; we have the tubes through which the hot water flows and these are the continuous fin sheets through which air is pulled and that helps to cool that hot water which flows back to the engine of the car. So, an automotive radiator is typical of this type; a continuous fin sheet on an array of tubes is what constitutes - what it is - a tube fin heat exchanger. And it is a compact, it is compact - the heat exchanger - in the sense it provides a lot more heat transfer area per unit volume.

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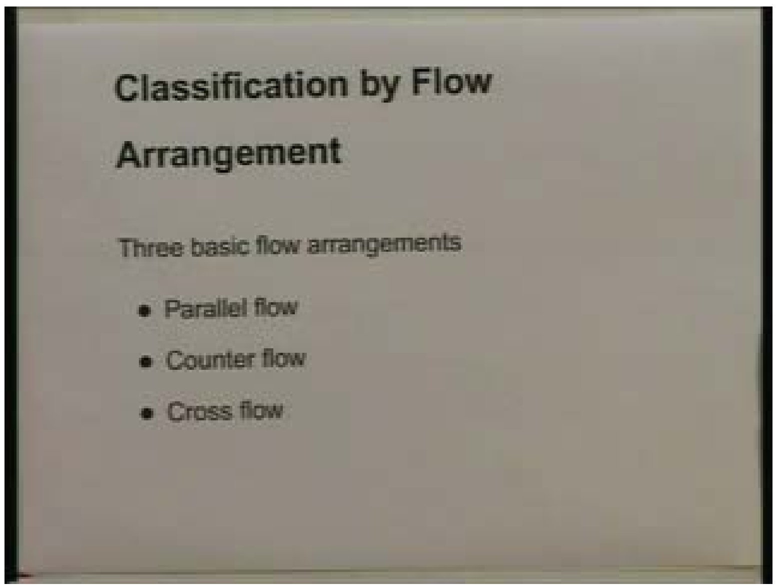

We can also classify a direct transfer type heat exchangers by the flow arrangement; we can use that also as a description of a direct transfer type heat exchanger like we have described them in terms of the geometry when we say they are tubular, say that they are plate heat exchangers or extended surface heat exchangers. Similarly, the way in which the 2 fluids flow relative to each other is another way of classifying direct transfer type heat exchangers.

So let us classify them now by their flow arrangement. There are 3 basic flow arrangements and what are these? The 3 basic flow arrangements are parallel flow, counter flow and cross flow. We want to describe each of these carefully; let us look at each of these carefully. Now first let us look at parallel flow.

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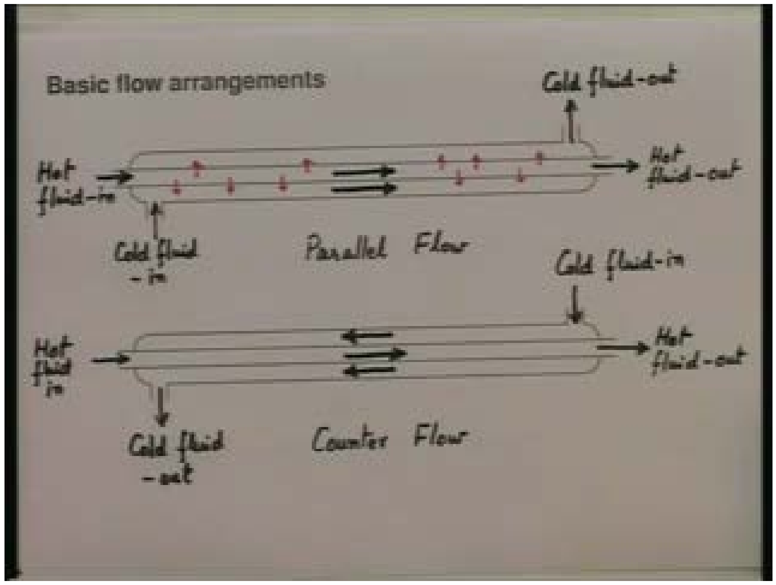

First let us look at parallel flow. I am going to describe parallel flow arrangement with respect to the concentric tube heat exchanger, concentric tube heat exchanger - this is one tube inside another tube. Now let us say this is the hot fluid flowing through the inner tube; it is flowing in at this point so we say hot fluid flowing in at this point and it is flowing out at this point so let us say this is hot fluid flowing out at this point out and in. Now the cold fluid comes in at this point; let us say this is cold fluid in and goes out at this point.

Now, notice the 2 fluids - the hot fluid and the cold fluid - are both flowing parallel to each to other in the same direction along the length of the heat exchanger. The hot fluid is flowing through the inner tube like this and the cold fluid is flowing through the annulus like this. Since they are both flowing in the same direction we call this a parallel, when they are both flowing in the same direction we call it a parallel flow arrangement. And of course as mentioned earlier, the heat transfer is taking place through the surface of the inner tube. This is the heat where the heat transfer is taking place from the hot fluid to the cold fluid across the surface of the inner tube, so this is why we call it a parallel flow arrangement.

On the other hand, if I reverse the flow of one of these fluids then it will get a counter flow arrangement. So, all I have to do now for a counter flow arrangement is to reverse the flow of one of the fluids. So let us say now, this is still the hot fluid in, we will call this still hot fluid in and going out here hot fluid out. But now, the cold fluid enters at this point so we will say this is cold fluid in and leaves at this point. So now, notice the hot fluid flowing through the inner tube is flowing axially in this direction, the cold fluid flowing through the annulus is flowing in this direction. They are flowing in opposite directions, both parallel to the axis of the heat exchanger but in opposite directions and that is what we call as a counter flow arrangement. The heat exchanger is still taking place in the same way from across the surface of the inner tube; there is no change there but the direction of the 2 fluids relative to each other is different. So this we call as a counter flow arrangement when the 2 fluids flow in opposed directions.

The third type of basic arrangement is what we call as a cross flow arrangement and let me describe that for you now next.

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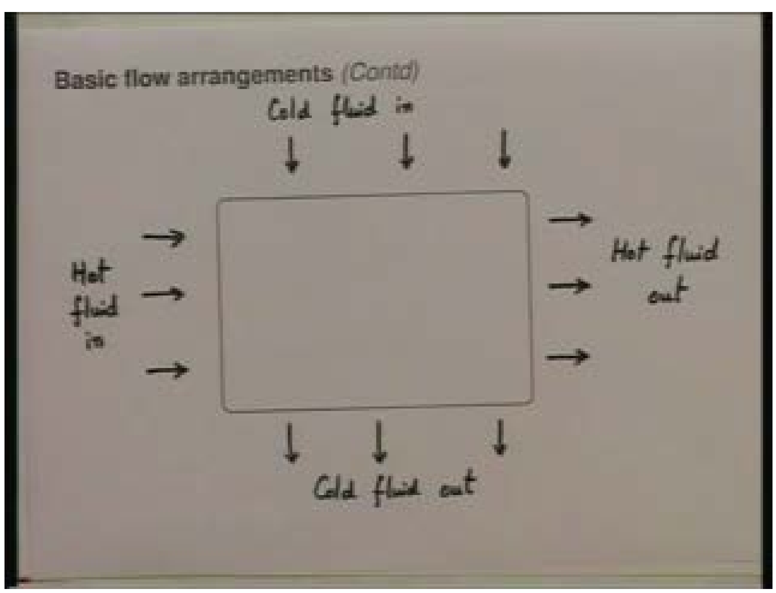

In a cross flow arrangement, the 2 fluids basically flow at right angles to each other like this. Let us say this rectangle which I am showing is part of some heat exchanger; it is a plate which is part of some heat transfer surface. And the hot fluid let us say is flowing on the backside of this plate so we will say this is hot fluid in and flowing out here; so let us say the hot fluid is flowing on the backside of the this plate and the cold fluid is flowing on the front side of this plate here like this. So we will say cold fluid in and flowing out like this, so we say this is cold fluid out.

Now this is a cross flow arrangement in which the 2 fluids are flowing at right angles to each other. One, in this case this is the heat transfer surface which is the plane of this paper, one fluid is flowing maybe in front of this paper, one fluid is flowing at the back of this paper. Now let us go back again to the plate fin heat exchanger which I showed you earlier; here is the plate fin heat exchanger which I showed you earlier and let us look at it again for a moment. Now look at it - this is one fluid which would be flowing like this and this is the other fluid which will be flowing through like this so this is a cross flow arrangement that you have got here.

Now there is something more which I want to also say - this is a cross flow arrangement but in addition what is to be noted is we have got fins here. Now when you have fins which are in this heat exchanger on both sides, both on the hot side and the cold side, a fluid particle which enters here say in this passage will go through the heat exchanger and come out at this end here. It has no choice - a fluid particle which enters here has to be come out at this point. A particle which goes in here has to come out at this point because the fins make passages right through along the length of the heat exchanger.

Now when this happens, when the fluid is, let us say this is the hot fluid enters like this with fins on it. It is forced to move in not only between these plates but also in the particular passage which is created by the fins which are right here so this flow, hot fluid, cannot move in a transverse direction inside these channels. Similarly, this is the cold fluid; once it enters here, some cold fluid enters here, it has to stay in that passage and move along the length of the heat exchanger. It cannot move crosswise in a transverse direction inside this parallel plate channel. So the presence of the fins in the parallel plate channels prevents any transverse motion of the fluids - either the hot fluid in its own channel or the cold fluid in its channel. Now when this happens we say this is cross flow, both fluids unmixed; unmixed means not mixed with each other but cannot mix in a transverse direction, no fluid in a direction transfer type, the cold fluid doesn't mix with the hot fluid. So, when we say unmixed, we mean mixed with each other; it cannot, it cannot mix with each other. So both fluids unmixed is the situation that you will get when you have fins on both sides like this.

Now suppose I don't have fins both the sides but I just have parallel plates, then in that case a hot fluid entering in this channel can - while flowing through - can also move in this direction and mix with itself. In which case we will say this is case of single pass cross flow, both fluids mixed because there are fins on either side, the fluid can mix with itself. And if I have fins on one side and no fins on the other side, then it will be a case of single pass cross flow mixing on one side, no mixing on the other side.

So in single pass cross flow, it is possible to have flow arrangements in which the fluids can either mix with each other or not mix with themselves. Now, therefore, we say there are 3 possibilities in single pass cross flow and 3 possibilities are cross flow unmixed on both sides, cross flow mixed on one side unmixed on the other side, cross flow mixed on both sides. When there are fins it is unmixed on both sides, when there are no fins it is mixed on both sides; keep that in mind. So, in cross flow also there are 3 categorizations possible.

Now there are 3, I mean one point which is worth noting is that generally if we calculate the heat transfer area for these 3 arrangements - that is parallel flow, counter flow and cross flow - if we calculate the heat transfer area, typically we will find that the heat for a given situation and we want to transfer a certain amount of heat. Typically, we will find that in parallel flow you need the maximum area - heat transfer area, in counter flow you require the minimum area. And cross flow whether it is unmixed on both sides or mixed on both sides or mixed on one side, unmixed on the other, will require an area in between these 2 extremes. So keep that in mind as something which is a rough idea of what will be the sizing that we get of heat exchangers in a given situation.

Now let us talk a little about the overall heat transfer coefficient and fouling factor.

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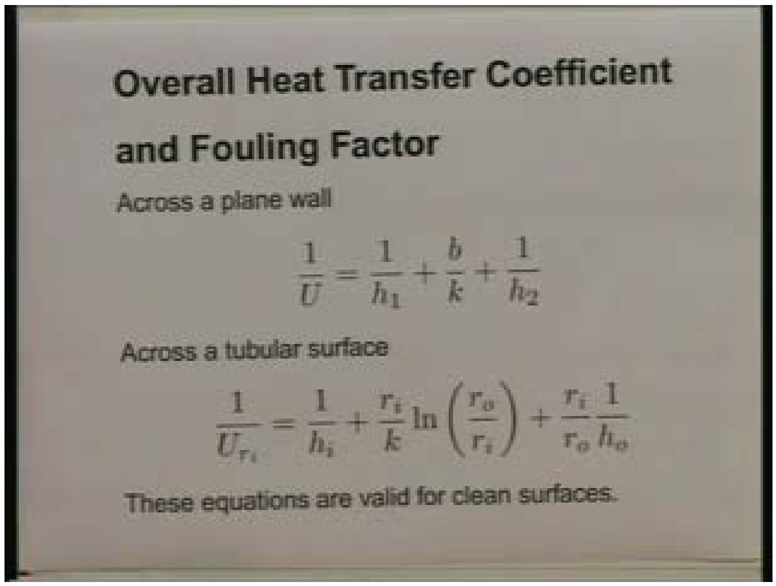

In a heat exchanger, in a direct transfer type heat exchanger suppose there is a plane wall. From your study of conduction, you know that in a plane wall there are heat transfer coefficients on the two sides - h_1 and h_2 - and if b is the thickness of the wall and k is the thermal conductivity of the wall, then the overall heat transfer coefficient is given by 1 upon U is equal to 1 upon h_1 plus b by k_1 plus upon h_2 and if it is a tube like in a shell and tube heat exchanger or a concentric tube heat exchanger, the overall heat transfer coefficient 1 upon U_{ri} will be given by1 upon h_i plus r_i by k log to the base e r_o by r_i plus r_i by r_o 1 upon h_o.

Now these equations for calculating the overall heat transfer coefficient where h_1 and h_2 will come from our knowledge of convection or h_i and h_o will come from our knowledge of convection. These equations for calculating U are valid for clean surfaces. In practice, with the passage of time, solid deposit is usually tend to accumulate in the form of thin layers on the surfaces on the heat transfer surface and these deposits present an additional thermal resistance to the flow of heat.

Now next time, we will talk about how to take account of this additional thermal resistance that comes in when because of the thin layers which form on the heat transfer surface. This formation of thin layers is called fouling and we account for it by what is known as introducing fouling factors in our expression for the heat transfer coefficient; next time, we will look at that aspect.