Heat Exchangers: Fundamentals and Design Analysis
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Lecture – 43
Heat pipes and Heat pipe heat exchangers

Hello, friends. We are studying Heat Exchangers: Fundamentals and Design Analysis. From this lecture, we will switch over to a new topic that is Heat pipes and Heat pipe heat exchangers. Many of you may be familiar with the word heat pipe, some of you may know how does it work what is a heat pipe, but for the benefit of most of you let me tell you that heat pipe itself is not a heat exchanger strictly speaking.

If we take the very common perception regarding a heat exchanger that heat exchanger is a device, which facilitate heat transfer between two fluid steams from that definition point of view or from that concept point of view heat pipe is not itself is not a heat exchanger. But, heat pipe could be a part of a heat exchanger it is a very unique device. So, that is why we like to spend some time, it is a very high very highly efficient device of heat exchange of the exchange of thermal energy. That is why we like to spend some time and with the help of a single heat pipe or maybe with the help of a number of heat pipes we can have a design of heat exchanger, which is a very efficient design of heat exchanger.

So, then we have to understand how does heat pipe works and why or how it can give such a better performance to a heat exchanger.

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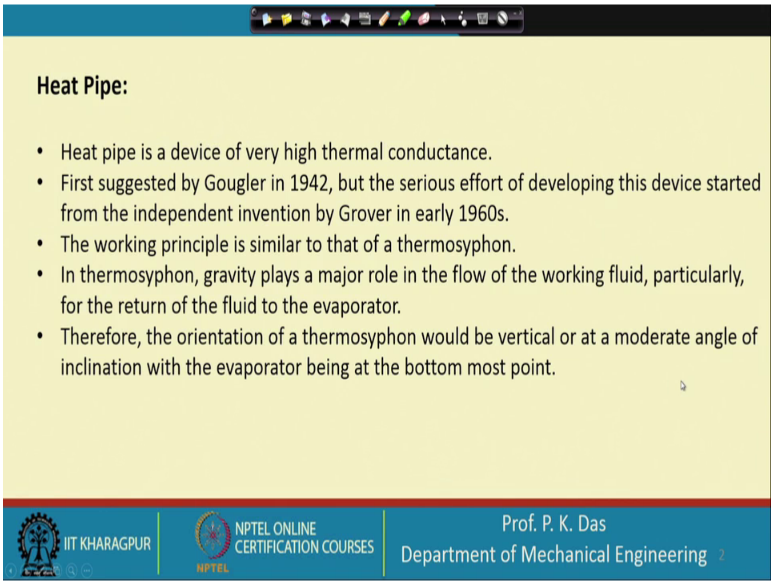

So, if we go to the next slide heat pipe. Heat pipe is a device of very high thermal conductance that is what I have told that heat pipe is a very efficient device of exchanging thermal energy. So, in general taking the heat pipe as a black box how it is doing this exchange of thermal energy that we will see later on, but if we see the heat pipe as a black box, then we can tell that heat pipe is a device of a very high thermal conductance.

Now, the heat pipe is not new for long heat pipes have been advocated or the design of heat pipe has been proposed by people. The first suggestion came from Gougler in 1942, but serious effort for developing these devices started from the independent research or independent innovation invention by Grover in early 1960s. And, from then onwards we will have different kind of heat pipe design and today heat pipe is a very established technology and it covers a very large range of temperature starting from the cryogenic range of temperature to the temperature of several thousand I mean more than 1000 degree Celsius or the liquid metal range. So, we will have heat pipes of different designs.

So, regarding the design and regarding the range wide range of heat pipe regarding it is application we will learn a bit later. But, now let us proceed with the preliminary of heat pipe how we can understand the working principle of a heat pipe. The working principle is similar to that of a thermosyphon. So, thermosyphon again it is made of two words one is thermo that is heat and another is syphon. So, syphon we know, syphon gives some sort of flow of liquid with the without the help of any pump and by the assistance of gravity.

So, in a thermosyphon there will be two things, there will be heat transfer probably the heat transfer will be responsible for part of the fluid flow and obviously, syphon; that means, the gravity that will assist the part of the fluid flow and overall there will be transfer of thermal energy. So, that is in essence is what a thermosyphon can do. And, we will see how does a thermosyphon work. In thermosyphon gravity plays a major role in the flow of the working fluid particularly for the return of the fluid to the evaporator.

So, if we see the third bullet that is what I have the fourth bullet that is what I have read now that in thermosyphon gravity plays a very important role. So, the there will be some sort of a continuous circulation of the fluid and the fluid has to return to evaporator. It will be clear in a moment what is evaporator, why the fluid has to return to evaporator and gravity plays a very important role in that.

Therefore, as the gravity flow gravity helps in gravity helps in returning the liquid from returning the liquid from the condenser section to the evaporator section, therefore, the evaporator has to be at the bottom part of this device called thermosyphon. So, this is another important thing that the thermosyphon design is such that the evaporator will be at the bottom part of the thermosyphon. So, whatever I have told without knowing much of thermosyphon one can think that there is an evaporator in the thermosyphon and the liquid has to return.

Now, with this background let us go to the next slide and see what is a thermosyphon.

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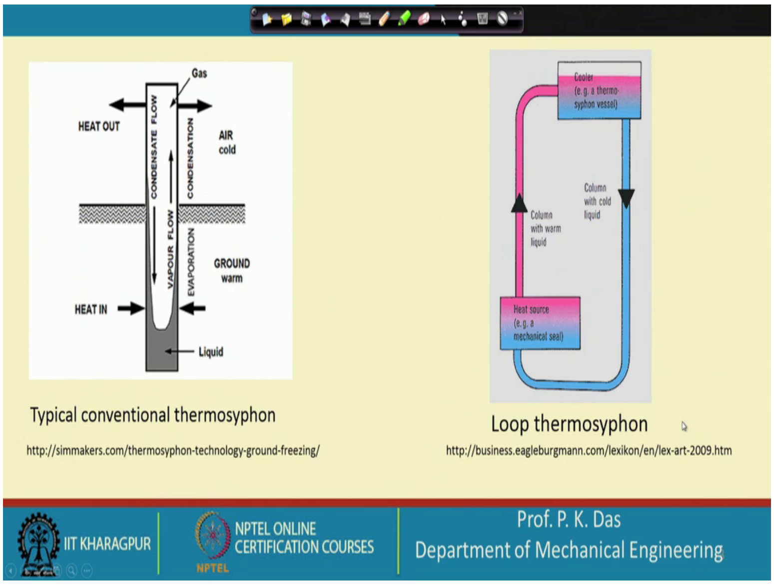

Now, if we concentrate on the diagram which is given on the left side of this slide, then there I have shown a thermosyphon. So, this is a thermosyphon and the application, this is also a very practical application. Let us say this is a cold country and at the top we have got cold air maybe in a room there is a in a space there is cold air and this cold air we want to heat how we can do it? We can do it with the help of renewable energy or non conventional energy source. We know that within the ground or below the ground level if we go little bit deep down then there will be higher temperature.

So, as there is a higher temperature below the ground and as there is a low temperature above the ground the air is cold so, one can think of transferring heat from below the ground to the air over the earth surface and heat the air. So, this could be one application and this could be one utilization of your of your renewable energy and this can be done very conveniently with the help of a heat pipe.

So, you see this heat pipe is basically it is having a tubular structure and generally it is evacuated and then there is little bit of liquid working fluid which we are calling a working fluid in this heat pipe. So, basically it is a cylindrical long cylindrical container, some partially filled with liquid then it is evacuated and again sealed and then if the liquid due to gravity it will occupy the lower part of the device, which is thermosyphon and then if we transfer heat at this point so, the liquid will try to evaporate liquid will start the evaporating.

The vapour vapour being lighter and it is becoming it is having a low density it will try to fill the space and it will go to the top portion. And, we can remember that it will it contains the vapour contents the latent heat of vaporization and then at the top as it is surrounded by the cold air so, there will be heat transfer and the vapour will condense to liquid. That liquid has to come back to the liquid reservoir at the bottom and that will take place due to the assistance of gravity.

So, then this will be a device which will run continuously without needing any kind of power from anywhere. Only thing is that there is a temperature difference and that temperature difference is creating the fluid flow and again when there is a fluid flow and phase change the way, I have told both evaporation and condensation. So, there will be a transfer of heat from the high temperature to the low temperature. So, this is what is a thermosyphon.

And, there could be loop type of thermosyphon. So, if we see right side right hand side of the slide I have given a loop type thermosyphon left hand side I have given some sort of a tubular thermosyphon, which is having some kind of a single passage which is occupied both the upward moving fluid which is vapour vapour and the downward moving fluid which is the condensate or liquid.

So, it is occupied by both the fluid. When we go to the loop kind of thermosyphon here one path this path is occupied by the high temperature fluid and the other path is occupied by the low temperature fluid. So, this is basically sometime some type of a circulation loop here also there is a circulation loop, but the loop is not geometrically given a loop like structure.

So, this is basically the operation of a heat pipe and this is how we can have transfer of heat from a high temperature to low temperature. The things to be noted here that as phase change is the main mechanism of transport of heat for this particular device. So, this operates at a very less temperature difference; that means that though there could be a good amount of heat transfer the temperature difference between the hot end and the cold end need not be very high.

So, this is phase change heat transfer is involved and as we know phase change heat transfer is very efficient. So, this will have a very efficient way of transporting heat requiring very small amount of delta t. That is the first feature which is a very desirable feature for any heat exchanger or to be incorporated in any heat exchanger. Second feature which we have to note carefully that the thermosyphon is oriented in such a way, so that the evaporator is at the bottom, this is the evaporator part. The evaporator is at the bottom of the thermosyphon and the condenser is at the top of the thermosyphon or the high temperature end is at the bottom of the thermosyphon and the low temperature end is at the top of the thermosyphon because we have to exploit gravity for return of the fluid from the low temperature point to the high temperature point.

So, this is one this is one limitation of operation for this thermosyphon. So, we have to understand thermosyphon and we have to understand why it is having a very high degree of rather why it is having a high performance as far as heat transfer is concerned and then we have to understand that why it is having a limitation. These three point should be clear from this slide.

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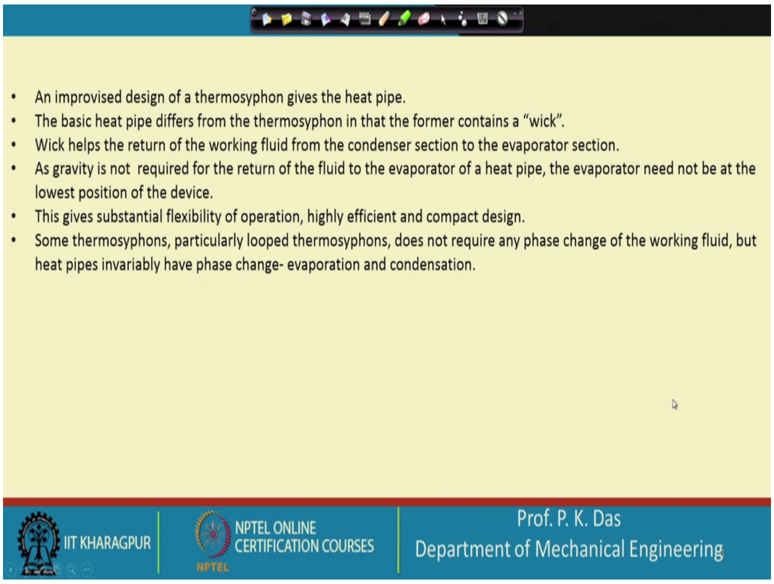

So, basically if we see the historical development of heat pipe heat pipe design came from the design of thermosyphon. So, thermosyphon is a very let us say it is highly efficient device for transport of thermal energy, but it has got a limitation that it has to be oriented in a particular fashion. The high temperature point will be below and the low temperature point will be at the top. So, that limitation is that limitation is removed in case of a heat pipe design. So, an improvised design of thermosyphon gives heat pipe.

So, that is the first point and then second point if we like to see the basic heat pipe differs from the thermosyphon in that the former contains a wick; that means, the heat pipe contains a wick.

Wick is nothing, but a capillary structure. Wick is a common reference to this capillary structure and the wick helps the return of the working fluid from the condenser section to the evaporator section. So, if wick helps return of the fluid from the condenser section to the evaporator section then we do not need the avid the assistance of gravity and then this particular orientation of thermosyphon is not essential; that means, always the hot side will be at the at the bottom and the cold side will be at the top. So, this kind of limitation of this kind of restriction will not be there in a heat pipe.

As gravity is not required to return the fluid same thing I have told that evaporated need not be at the lowest position of the device. This gives substantial flexibility of operation and it also makes the design compact and highly efficient. Some thermosyphons particularly loop thermosyphon does not require any phase change, the working fluid phase change of the working fluid, but heat pipes in variably have phase change. So, this is a small difference between these two devices.

Theoretically, we can have a thermosyphon loop type thermosyphon without any face change, but which can be used in a let us say the solar collector that with a storage device or storage tank can also work on the basis of thermosyphon, but their phase change is not essential. But, whenever we will see the design of heat pipe so, in most of the cases phase change is there. So, this is another small difference between your thermosyphon and between the thermosyphon and heat pipe. Now, let us see closely how these two things work.

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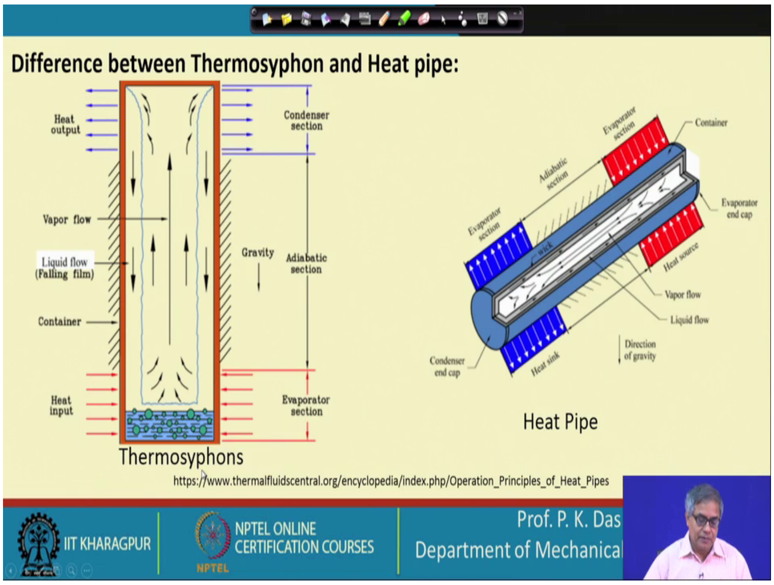

So, again on the left hand side I have shown a thermosyphon. So, thermosyphon you see that we have got a container like construction, it could be in a simplest form it could be a cylindrical tube closed at both the end. Lowest point we have got some liquid which is known as working fluid and the lowest point, there is heat input we call it evaporator section and then there will be evaporation. So, the vapour that will move with the upward direction and we have to remember that initially the pressure is inside is low because after putting the liquid we have partially evacuated it and then we have sealed it.

Then, it will go to the top most part and then at the top most part we have got the condenser so, from the condenser condensation will take place and the condensate film will come back to the evaporator. So, this will continue, as long as there is a small temperature difference between the hot end and the cold end or the top side and the sorry and the bottom side and bottom end and the top end of the of the thermosyphon.

So, we can see primarily there are three part; one is some sort of evaporator section, another is condenser section and in between there is an there is an adiabatic part or at least ideally this is an adiabatic part where no heat transfer or practically no heat transfer takes place. So, but it has to be in this kind of orientation. On the right hand side we see heat pipe. Heat pipe externally it looks just like the thermosyphon I have described, but internally if we see that there is a weak structured this grey structure that is the wick structure. And, here please note that we have put the hot section or hot part or hot end of the heat pipe at a higher elevation and the cold part of the heat pipe at a lower elevation. So, in general it should not work.

If there is no capillary structure or wick structure which I have told, but it will work because there is a wick structure and the wick structure when there will be liquid condensed at this cold end this liquid will move in the upward direction look the arrows look at the arrows so, it is going in the upward direction and again reaching the evaporator. So, this is how your heat pipe will work.

So, I will take little bit time to explain the wick action or explain the capillary reaction though it is known to many of you for the sake of completeness and for the benefit of the all the participants let us take some time to do this wick structure what is the what is the purpose of a wick structure.

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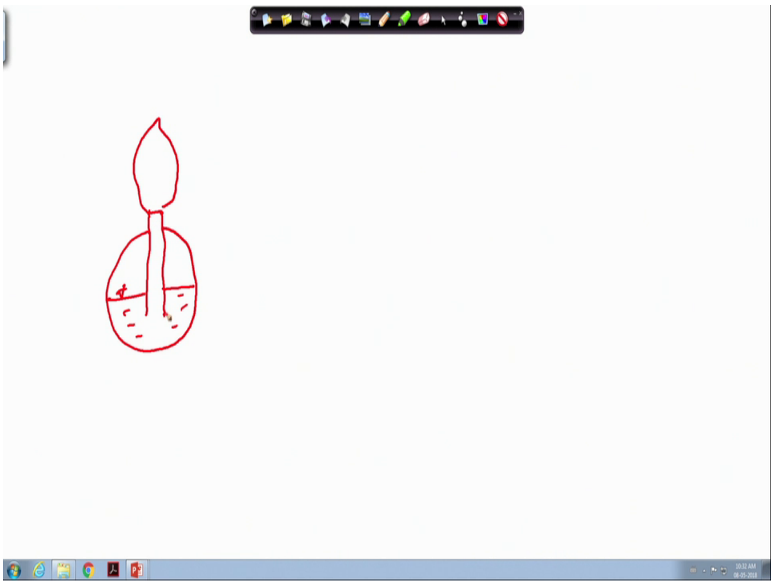

Now, wick is something like this. Let us say we have got, let us say we have got this concept of wick is something like this. Let us say we have got a very traditional lamp with some sort of oil. So, here this is oil and it is in a container and at the top we have got the flame. So, now, the oil has to come to this point then only the flame will be supported. So, how it is done there is a wick. Wick is made up let us say cotton and then the continuously there will be flow of oil from the low point, I mean from a low elevation to a high elevation.

So, how that is taking place? This is taking place due to capillarity or due to a wick in action. So, this is our day to day experience common experience what we get in our day to day life. So, obviously, there will be some sort of a drive driving force which will which will help the liquid or the oil in this case to defy gravity and to come at the top and to facilitate the burning so, that we can get the flame and light.

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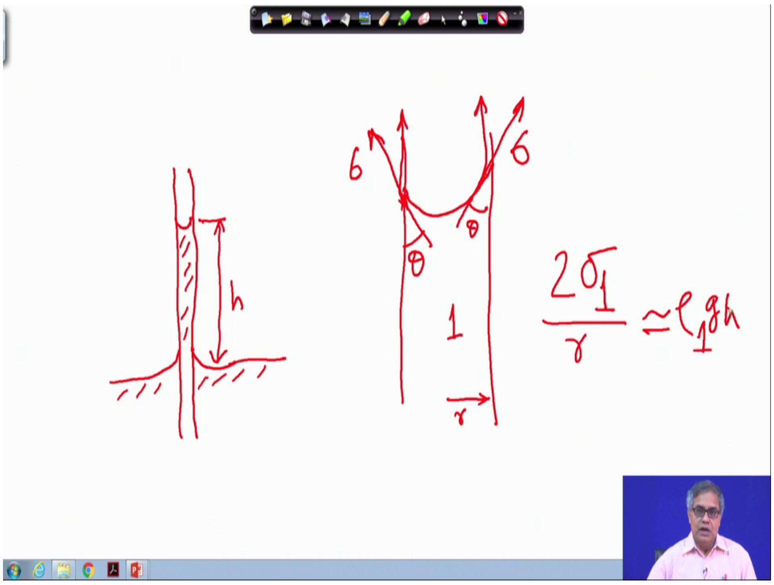

Now, actually what is happening? So, actually what is happening is like this that if we have a very narrow tube. Let us say it is a tube of solid material and then we dip. So, this tubes are called capillary tube means narrow tube. So, then if we dip in a liquid what we will find the liquid will rise up to certain level. So, this is the liquid. So, normal free surface is here, but the liquid has rise to a height h. So, here also it is defying gravity because against the force of gravity there is a rise of liquid. So, how does it take place, many of you know it from your high school physics, but if we try to explain it little bit.

So, if we draw an exaggerated diagram the meniscus of the liquid is something like this and here a force work which is your surface tension force and we denote it by sigma. So, sigma works along the periphery of the meniscus and there is a small angle. So, this angle is theta. So, you can see so, this is theta. So, you can see that the horizontal component of the surface tension that will cancel because all through the periphery there is surface tension, but the vertical component that will add up. So, this vertical component will add up. So, in the vertical direction there is a force and this force is the capillary force and it is drawing the or it is pulling the liquid in the upward direction.

So, if it is pulling the upward direction so, in general what we get is this that. This derivation you can do very easily 2 sigma and let us say this is your phase 1. So, 2 sigma 1 and 2 sigma 1 by r, where r is the radius of this tube r that is equal to or approximately equal to rho 1 into g into h. So, two things are very important that sigma surface tension that should be high to get a higher value of h and rho sorry and r, r should be small so, the as the name capillary cames that in a small tube we can see appreciable amount of liquid rise. So, that is what takes place.

So, the first example what I have given that we have got a cotton wick and then with the help of the cotton wick we can light an oil lamp so, there the cotton wick you can now appreciate that there are small small pores and that small pores which are there in the cotton wick that gives the capillary kind of a construction and with that we can raise the liquid. So, similarly if we can create some sort of a capillary structure so, that will drive the fluid motion and continuously at one point if the fluid is taken away which is taken away by the evaporator and continuously evaporation takes place so this flow can be maintained. In a oil lamp continuously oil is being burnt so, the flow is maintained, otherwise it will have only a static rise.

So, this is what is very important and this is how the liquid return works in case of in case of in case of heat pipe, so, we have got a capillary structure. So, with this I will again go back to the next slide we will go back and here how the capillary structure helps in return of the fluid and how does a basic heat pipe a conventional heat pipe works we can get.

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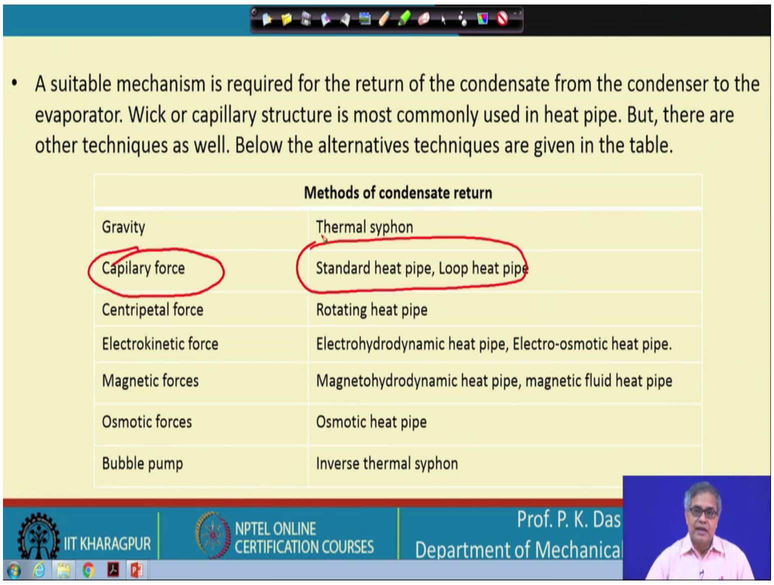

If we go to the next slide a suitable mechanism is required for the return of the condensate liquid from the condenser to the evaporator, wick or capillary structure is most commonly used in heat pipe. So, we do not want gravity to be responsible for this return of liquid from the condenser to the evaporator because then we have got a limitation regarding the orientation of the heat pipe.

So, that we do not want. So, that is why what we like to do that we want to have another mechanism. So, capillarity is one mechanism providing capillary structure is one of the mechanism by which this can be done and commonly this is done by providing a capillary structure, but there could be other methods also.

So, here some of the methods are given. Now, due to shortage of time I will not be able to show all these methods some of the method maybe we will show, but whoever is interested you can see. Gravity: first is gravity that is thermosyphon. So, basically one can say that thermosyphon is also kind of a heat pipe only restriction is that, that here we have to have a particular orientation of the thermosyphon. Then, capillary force, which is most common that is why I like to put some sort of a. So, it is good return mechanism and standard heat pipe, loop heat pipe etcetera are standard heat pipe and loop heat pipe etcetera are based on this one.

Then, we can use the centripetal force rotating heat pipe there are certain design where the heat pipe is rotated. So, there we have got centripetal force and by that also liquid can be returned or taken back to the evaporator. Then we can have electro kinetic force. So, electro hydrodynamic heat pipe, electro osmotic heat pipe, these are the heat pipe which use electromagnetic force. Then magnetic force is also possible.

So, magneto hydrodynamic heat pipe, magnetic fluid heat pipe heat pipe ferro fluid can be used for your this one as heat pipe or magnetic fluid some sort of other magnetic properties are there. So, that can also be used as your return mechanism that magnetic force. Then, osmotic force, osmotic heat pipe and bubble pumping; bubble pumping is a special device special kind of mechanism. If there are bubble trains then due to the expansion and contraction of the bubble we can pump the fluid. So, that is in inverse thermalsyphon.

So, these are some of the mechanism which I have described or which I have named. Unfortunately, all of them cannot be explained in detail only if you are interested you can see it from the net or from some suitable source. But, obviously, the capillarity is the main mechanism and we will spend some time on this capillary a device, how does it done provide the return path for the liquid and the analysis also we will try to do involving a capillary structure or wick structure.

So, that is what we are going to do in this particular course. So, more we have to know. We have to know its performance, we have to know the working principle, but today this much is for the introduction to heat pipe.

And, thank you.