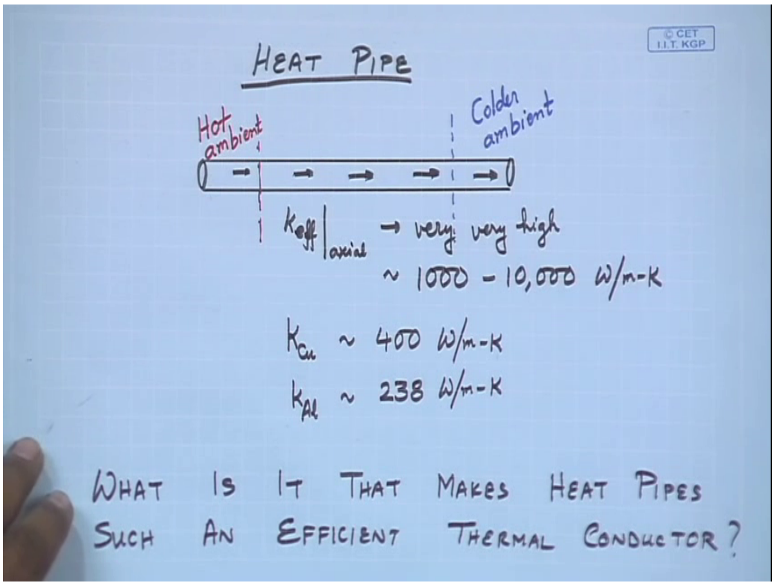
Energy Conservation and Waste Heat Recovery
Prof. Anandaroop Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 37
Heat Pipe - Part I

Good morning everyone. Welcome to the next lecture of Energy Conservation and Waste Heat Recovery. In the last few lectures you have learnt about heat exchangers, the fundamentals of heat exchangers, the different kinds of heat exchangers as well as heat exchanger networks. So, today what we are going to talk about is a special heat exchange device it is also called heat exchanger in the sense that it helps in exchanging heat from a hot stream to a cold stream or a hot surface to a cold stream, but it does. So, in a unique in a sort of unique manner the name of that special heat transfer device or heat exchange device is Heat Pipe let me write it down.

(Refer Slide Time: 01:01)



So, now, what is the Heat Pipe, if I tell you in a very crude sense a heat pipe is actually a cylindrical device or it can be a flattened cylindrical device also, a flattened circular cross section I mean which is an extremely good conductor of heat. It has a very extremely high thermal conductivity or effective thermal conductivity along it is axial directions. So, let us say if I draw something that looks like a pipe in this manner and call this a heat pipe, then the effective conductivity along the axial direction k effective let us say in the axial direction is very very high.

Now, what do I mean by very very high, it is of the order of 1000 to 10,000 watts per meter Kelvin depending on a variety of parameters which we are going to discuss later? Now is this number high let us see to compare copper which is one of the best thermal conductors that we know of the thermal conductivity of copper is around 400 watts per meter Kelvin thermal conductivity of aluminum which is also a very good conductor is around the pure aluminum is around 238 watts per meter Kelvin.

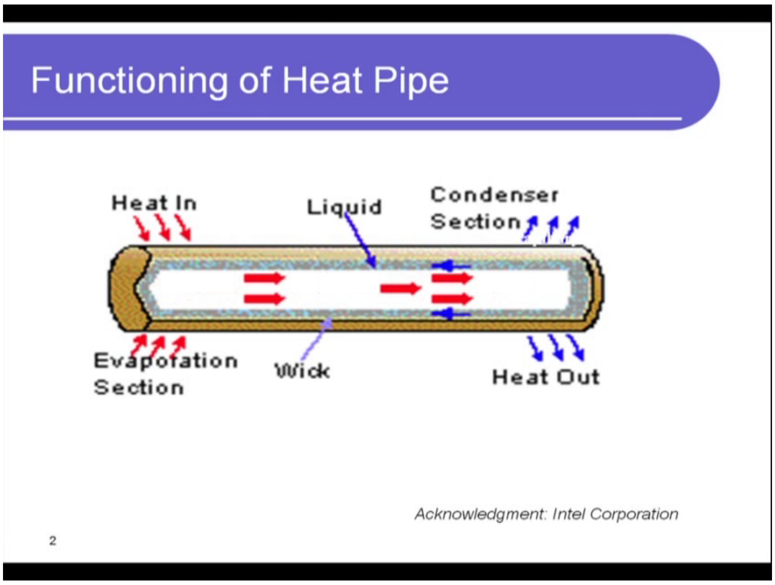
So, what does it mean what does it mean for us or how does this how can we make use of this very high thermal conductivity. So, think about it if this is my heat pipe and on one end I expose it to a heated ambient. So, I will say hot ambient on the other end I am using a blue color here and this is I would say a colder ambience a colder ambient and what I want to do is transfer some of the heat which is at this location the hot ambient as we are talking as we are calling it and we want to transfer some of the thermal energy that is present over here to the other end, where we want where it is cold and we want to heat it up or we want to utilize the thermal energy at this point.

So, effectively in from our basic knowledge of heat transfer we would say that you know we need a good conductor of heat. Now how good is good you would say we can use copper we can use aluminum, but what I am saying is let us use a heat pipe because here the thermal conductivity in this axial direction is very very high.

So, therefore, we can have very a very efficient conduction of thermal energy from the hot side to the cold side with minimal thermal resistance or in other words minimal temperature drop. So, this in essence is what a heat pipe is in Laymans term. The next question is what is it that gives this heat exchange device such a high thermal conductivity, because normally unless it is a very specialized and expensive material we do not know even if we talk about diamond and all we cannot get this kind of thermal conductivity values may be thousand with diamond is possible, but not definitely an order of magnitude higher.

So, the question therefore, is what is it that makes heat pipes such an efficient conductor such an efficient rather thermal conductor. So, that is the question that we are going to answer next.

(Refer Slide Time: 05:55)



So, what I will do now is I will quickly switch over to the slide that I have playing here it is an animation and let us using this animation let us talk about what is happening inside a heat pipe.

So, as you can see from outside the heat pipe will appear to be in this case it is showing to be a cylinder with a circular cross section as I said it does not necessarily have to be circular cross section, but whatever it is. So, on one end of the heat pipe as you can see we have this heat in. So, this is that hot ambient that I was talking about. So, essentially one end is heated the other end is exposed to a colder ambient or other end is kind of cooled.

So, what does the heat pipe contain first and foremost it is not a solid rod or a pipe rather it is a hollow tube sealed on both sides. So, it is a sealed hollow tube then what happens is in the annulus. So, around the inner diameter we have a special material which we call a wick. Typically wick can be a fibrous material it can be a sintered material it can be in the form of grooves we are going to talk about that, but they essentially this wick the function of the wick or there is a special function of the wick that we are going to see next.

Now, coming back to the construction again the third thing that is there inside a heat pipe is a few drops of liquid let us let us assume it to be water for now because that is the most the one that is most commonly used it is a few drops of water inside at a sub ambient pressure at a very low pressure. So, the whole heat pipe again to repeat it is a hollow pipe made of let us say a material like copper then inside on the inner diameter, around the annulus you have a wick material and then you have a few drops of liquid say water inside at a sub ambient pressure. So, the whole heat pipe is kind of evacuated to a low pressure and then sealed. So, that finally, what you see from outside is a sealed device with all these components inside.

Now what happens? When we heat one end the few drops of liquid that is present vaporizes remember we have evacuated it. So, it is boiling pointless thing if we consider water the boiling point of water if we is goes down if we reduce the pressure. So, for example, if we evacuate it to let us say point 3 atmospheres the boiling point will be around 70 degree centigrade and similarly for other lower pressures we can get the boiling point of the saturation temperature from steam tables we know that.

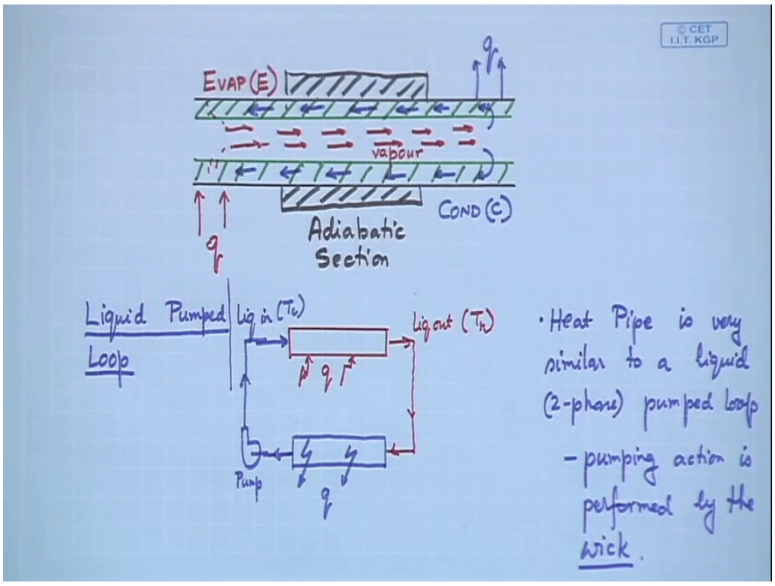
So, this few drops of water then vaporizes and as it vaporizes it starts flowing the vapor starts flowing through the core which is hollow. So, it starts to flow from one end to the other end as it reaches the other end which is cooled or subjected to a colder ambient the vaporized water or the water vapor condenses. It gives up the rejects heat and condenses again back to liquid water and the liquid water then comes back to the hot end through the wick because of capillary action.

Again I repeat on one end we are supplying heat. So, that the few drops of liquid vaporizes the vapor then flows along the hollow core to the other end where it is cooled and therefore, it condenses and converts back to liquid and the liquid is driven back again to the heated end through the wick we do 2 capillary action. Think of it when you when you light a lamp let us say during Diwali, we light a lamp and then we have this wick and we heat one end if we light the fire at the end of the wick and then what happens then the oil that is in that lamp in the dia actually goes from one end of that wick to the other end which is lighted because of the capillary reaction.

So, it is the same thing and that is why this we also call this material as the wick because it is doing the same function alright. So, a few terminologies to end this slide with the end at which we are supplying heat is known as the evaporator end or the evaporator or the evaporator section. Why evaporator section because the liquid is kind of can getting converted to wick vapor and that is why it is evaporating there fine therefore, this is the evaporator section similarly therefore, the other end where it is condensing back to liquid is known as the condenser section and the section in between where the vapor is flowing along the core and where we normally see very low temperature drop is known as adiabatic section, in many cases the adiabatic section is also insulated around. So, that we minimize heat loss from the outer walls of the heat pipe.

So, this in a sense is the construction of a heat pipe and the way it functions that is what I am trying to show through this animation and I also want to acknowledge my previous employer Intel corporation from where I have got this animation alright. So, let us come back and now that we understand how a heat pipe functions let us see therefore, look at the construction inside once more try to draw it again and this time not just as a black box or a or a you know just like a pipe from outside, but let us also draw the internals here.

(Refer Slide Time: 11:39)

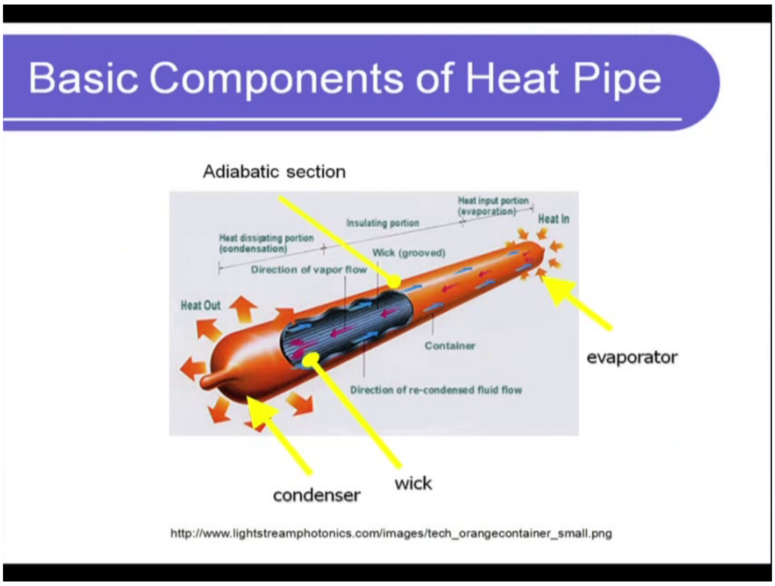


So, this is how it looks from the outside, but in us on the inner side what we have I am exaggerating it a little bit this is my wick material, which I am drawing with the green ink on one end I am supplying heat and let us normally using Norman nomenclature we will use the symbol q and on the other end I am extracting that heat out.

So, here the heat is rejected by some means because this end is kept at a lower temperature and therefore, what is happening is the water vapor or the water is converting to vapor over here and then flowing through this core and similarly from the other end also it will do the same with assuming an axis symmetric geometry here. So, this is how the vapor is traveling and then on the other end where it condenses it comes back through the wick due to capillary action.

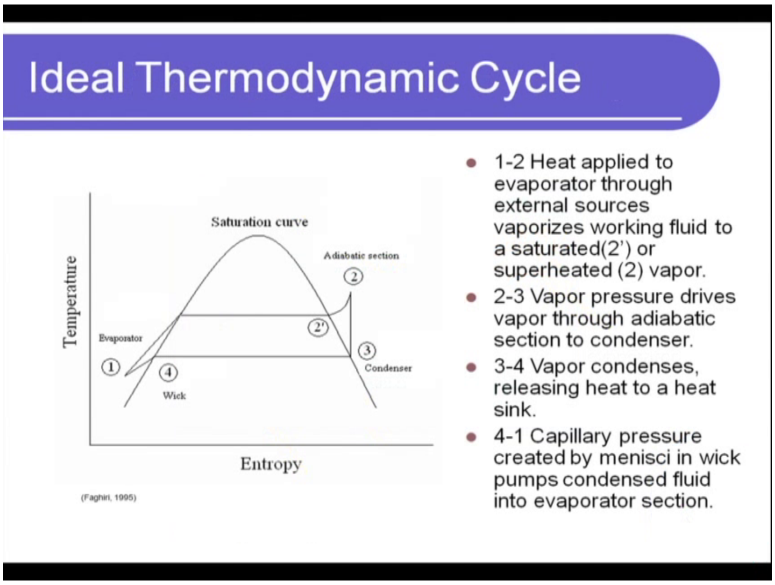
So, is it clear now? So, as we said this end we call it the evaporator section many a times we will just denote it as E and this end we will call it as a condenser section and many times we will denote it as c the middle portion over here is the adiabatic section. So, keep in mind adiabatic section it means that there is minimal heat loss it may or may not be insulated the way I have drawn is it is insulated just to show that it is an adiabatic section, but many a times even if you do not insulate it which is actually true in many applications we normally do not have too much of heat loss from one end to the other it is just because the vapor flows at a very high speed all right.

(Refer Slide Time: 14:58)



So, therefore, now let us look at a few applications or let us look at this slide again this is kind of a more detailed, rendition of what I just drew in this schematic again heat in from one end evaporate a section, heat out from the other end condenser section, and then this is the wick through which the liquid flows back this insulating portion as we called it is the adiabatic section which as I again I want to repeat may or may not be insulated in a practical application.

(Refer Slide Time: 15:26)



So, let us think about it and we will come to this slide again what exactly is happening, let us focus on the on the on the paper here see we have the would have studied through our heat transfer what is a liquid pumped loop.

Let us say I want to have liquid cooling I have a heat source over here which I need to cool and I have liquid flowing through it. So, cold liquid comes in. So, let us call it first give it a heading Liquid Pumped Loop. So, you have liquid in cold liquid that comes in and hot liquid that goes out this is T h let us say this is T c this we know, then what happens the hot liquid because this is liquid we cannot just reject it to the ambient. So, then what happens we let this one go through a loop and we bring it to another section where we have another heat exchanger where this hot liquid or fluid has to reject the heat.

So, over here there was heat addition and over here there is heat rejection, the hot liquid again cools down and comes out as cold liquid, but then you have to pump it you have to send it back because this is a closed loop. So, therefore, what we needed was we needed a pump to pump, the cold liquid back to the heater source or the or the heat source that we want to cool or the source of heat from where we want to remove thermal energy .

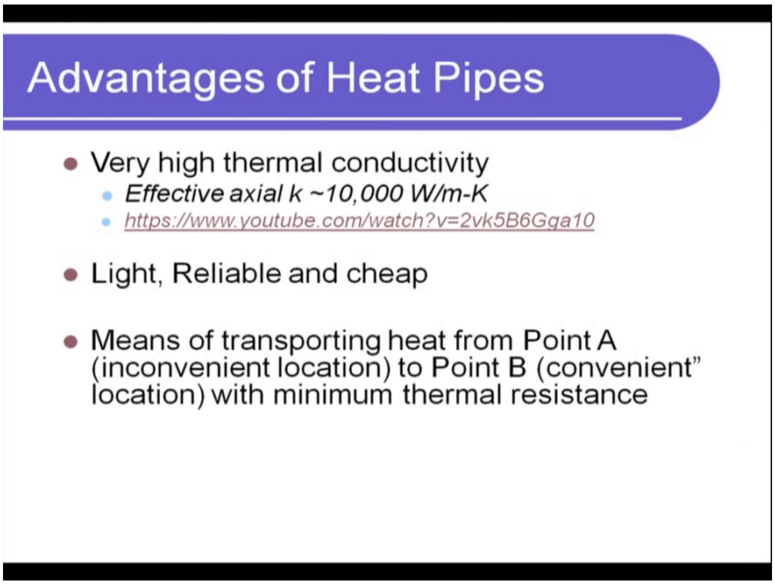
So, this is a typical liquid pump loop compare it with what is happening in a heat pipe to we have a hot section through which from where a cold liquid is removing heat yes we do which is the evaporator section to, we have another section where the hot fluid which can be single phase or 2 phase is cooled down to it is original temperature yes we do that is the condenser section do we have a pump well we do not have a pump, but the function of that pump is being done by the wick material through it is capillary reaction clear .

So, therefore, what I am trying to say is over here heat pipe is very similar to a liquid let me say 2 phase pump loop; however, the pumping action is performed by the wick clear. So, this is what I am showing here from professor Amir Faugury who is a well known authority on heat on heat pipes and this is in his book he has shown this figure trying to show the functioning of a heat pipe on a typical Ts diagram this Ts diagram like a simple Rankine cycle is very familiar to us.

So, he has modified as a Rankine cycle. So, 1 to 2 is what is happening in the evaporator section you have start with liquid and what you end up at the end of the evaporator section is actually vapor which can be saturated it can be superheated also that is what he is saying saturated or superheated. 2 to 3 is the condenser because this is where the vapor pressure drives through the adiabatic section to condenser and from 3 to 4 the vapor condenses releasing heat to the heat sink or this is where the condenser section is the vapor condenses back and finally, here the pumping action of the capillary brings it back from 4 to 1 this is slightly different from what we normally see in a pump where we typically see an isentropic line going higher up and the temperature also going up in a wick that does not happen the temperature does not go up nor is it isentropic, but this is what is happening.

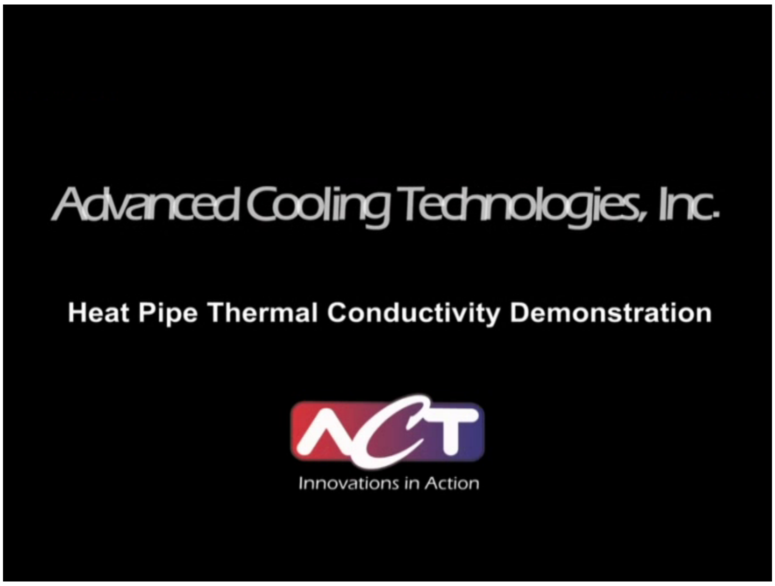
But in many in a sense this is very similar to a pumped loop or a Rankine cycle which we just discussed.

(Refer Slide Time: 20:46)



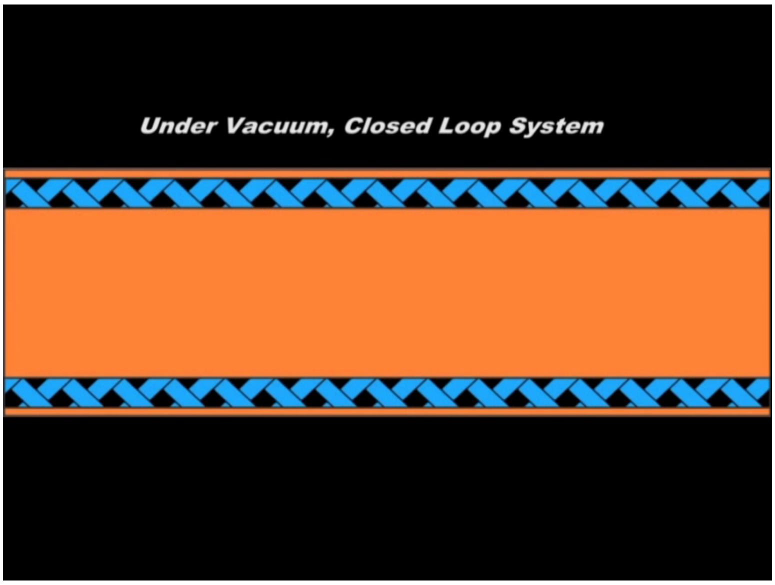
So, next what we will do is this is a very has I said this is a very high thermal conductivity extremely high effective thermal conductivity, I have a small video which is available in the you tube and you will see that you will find this link also here, I will just play it is a simple experiment to show how effective or how efficient this heat pipe is in terms of it is axial thermal conductivity.

(Refer Slide Time: 21:15)



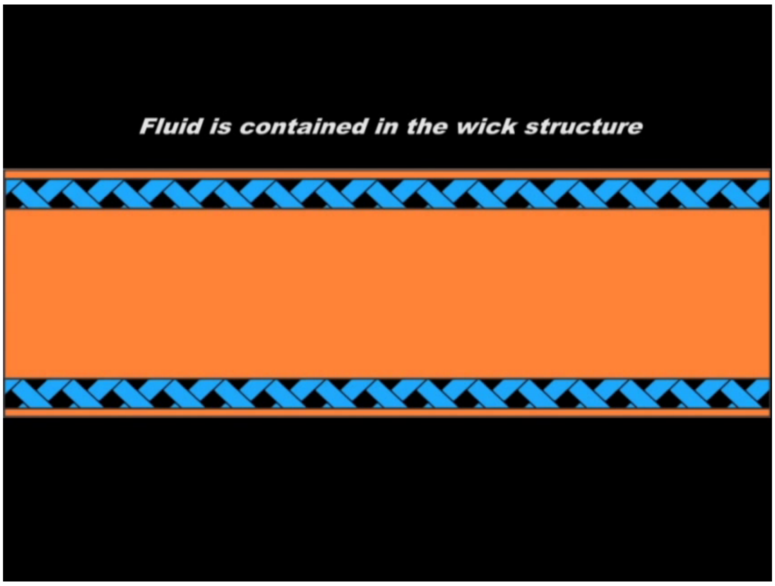
Hello and thank you for joining advanced cooling technologies for this lesson on heat pipe basics.

(Refer Slide Time: 21:22)



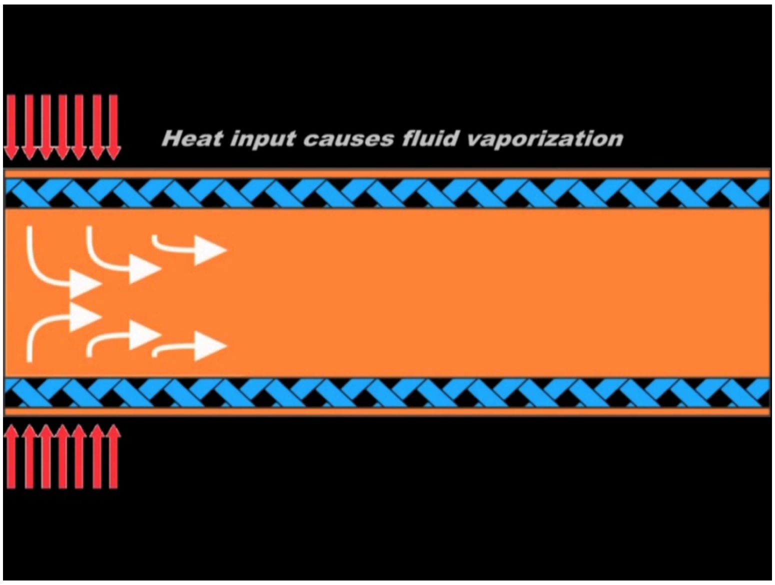
A heat pipe is sealed under vacuum with a small prescribed amount of working fluid during non operation.

(Refer Slide Time: 21:32)



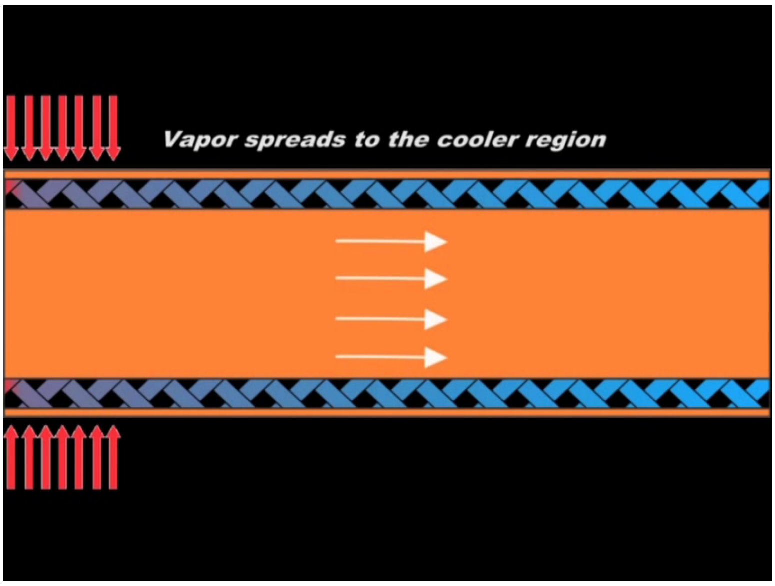
The fluid is contained inside the wick structure that lines the inner diameter of the heat pipe.

(Refer Slide Time: 21:35)



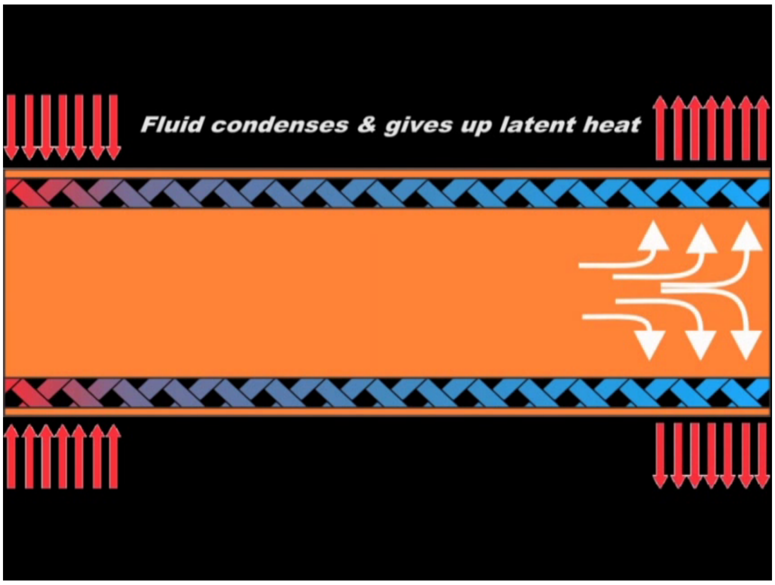
When a heat source such as an electronic component generates heat the fluid vaporizes at what is known as the evaporator section.

(Refer Slide Time: 21:42)



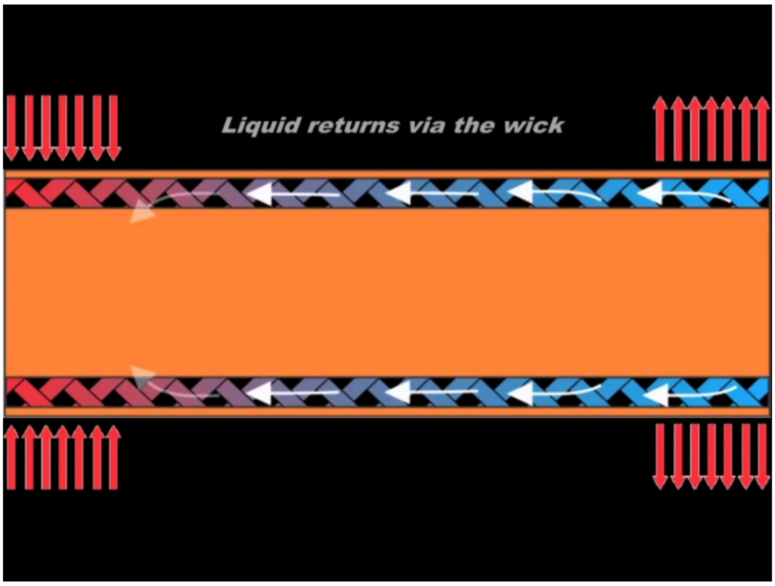
The fluid vapor quickly spreads to the other end of the heat pipe using pressure generated by the temperature difference.

(Refer Slide Time: 21:50)

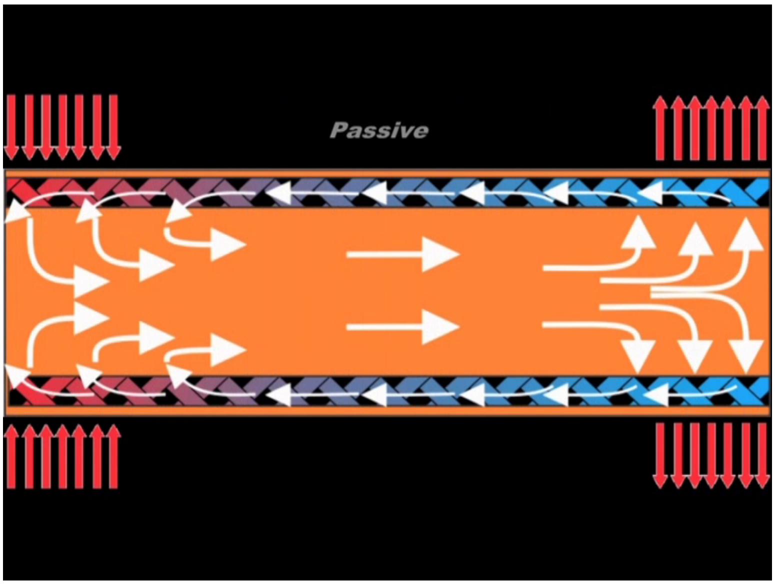


At the opposite end known as the condenser the fluid gives up it is latent heat which is rejected to an external heat sink. The fluid then returns to liquid form and the wick structure passively pumps the fluid back to the evaporator using capillary force.

(Refer Slide Time: 22:01)



(Refer Slide Time: 22:08)



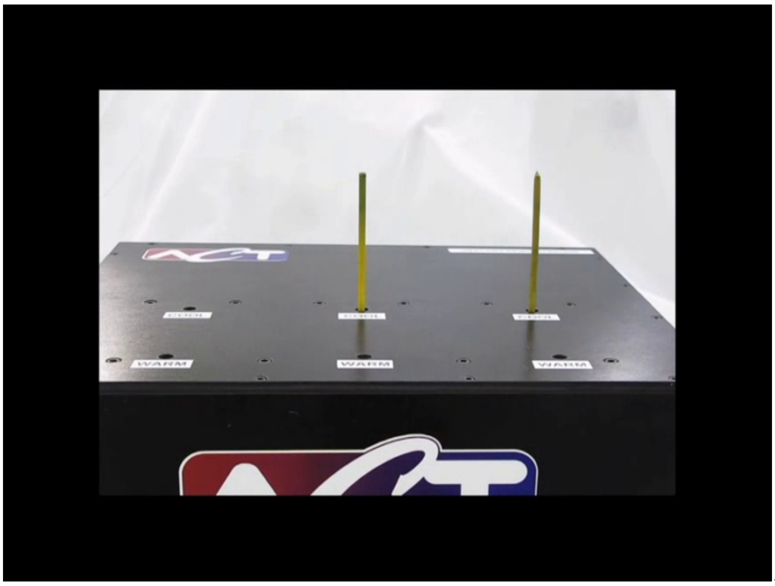
By utilizing liquid and vapor phases the heat transport is extremely efficient because it is a closed loop system heat pipes operate continuously and passively creating a very reliable component in your thermal management system.

Now, go through a quick demonstration on heat pipe thermal conductivity in this demo will examine the heat transfer capability of a copper rod versus a heat pipe.

(Refer Slide Time: 22:27)

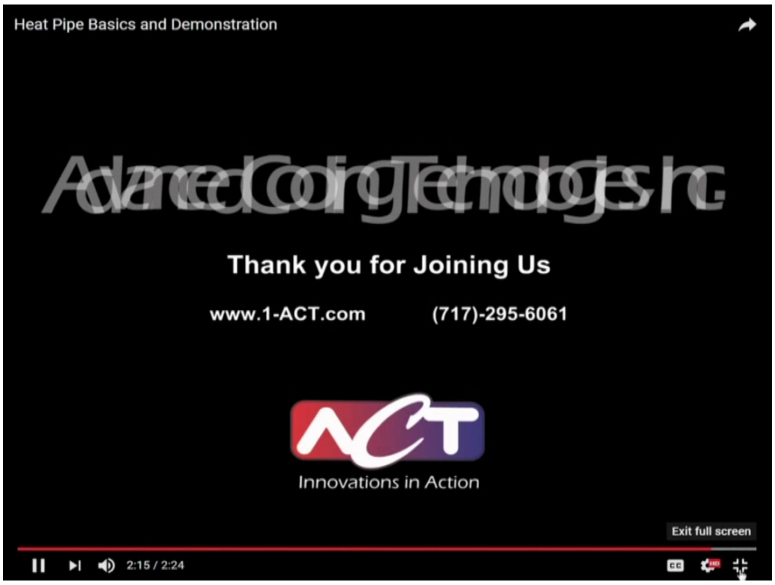
On the outside of both samples there is a paint that changes from green to yellow when the temperature exceeds 40 degrees C will. Now place the copper rod into the hot side of the unit and let it heat up the hot side is well above the 40 degree C color change temperature copper has a thermal conductivity of 400 watts per meter K which is high for most metals. You can begin to see color changing as the copper conducts heat away from the heaters below. Now first the heat pipe into the hot side most of the heat pipe reaches steady state almost instantaneously with minimum temperature gradient compared to the copper rod.

(Refer Slide Time: 23:13)



Now, will move both the copper rod and heat pipe into the cooler side the heat pipe simply changes the direction of the thermodynamic loop and reaches the lower temperature steady state in seconds while the copper rod struggles to reset steady state temperature.

(Refer Slide Time: 23:27)

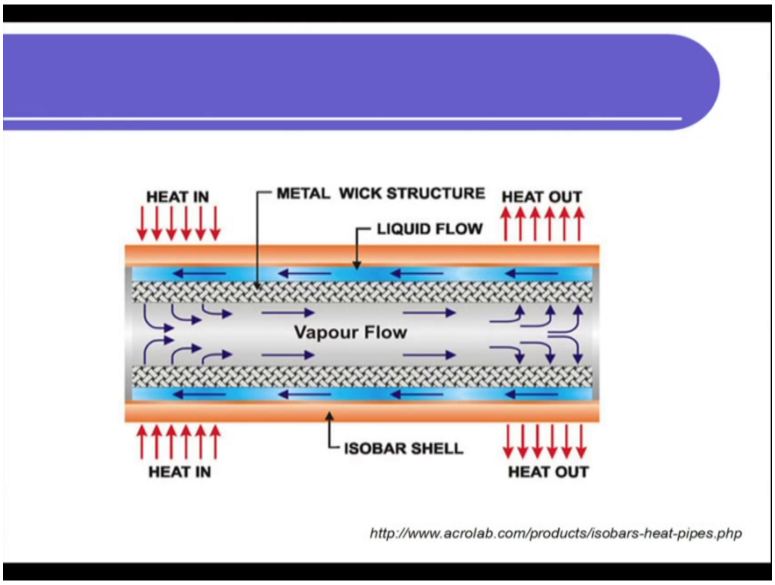


A CT would like to thank you for joining us hopefully everyone learned a little bit about the advantages of heat pipes for further.

So I think in that video what we saw was there was a copper pipe there was a heat pipe and there was some temperature sensitive dye on the surface and you could see that when event was when both the rods or both the pipes solid copper and heat pipe was dipped in the warm section the heat pipe heated up much faster compared to copper and similarly when they were again put back in the cold section the heat pipe again cooled down much faster. And this goes on to show that it is effective conductivity is much higher compared to that of copper. The other advantages of heat pipe as you can see as it is light is reliable it is cheap and more importantly it is passive. We are talking about we were comparing it with a pump loop and as you can see here we do not have a pump the wick transfer performs that function. So, there are no mechanical moving parts. So, it is very reliable once it is made and it is sealed it performs and it performs very reliably and goes on functioning for many years.

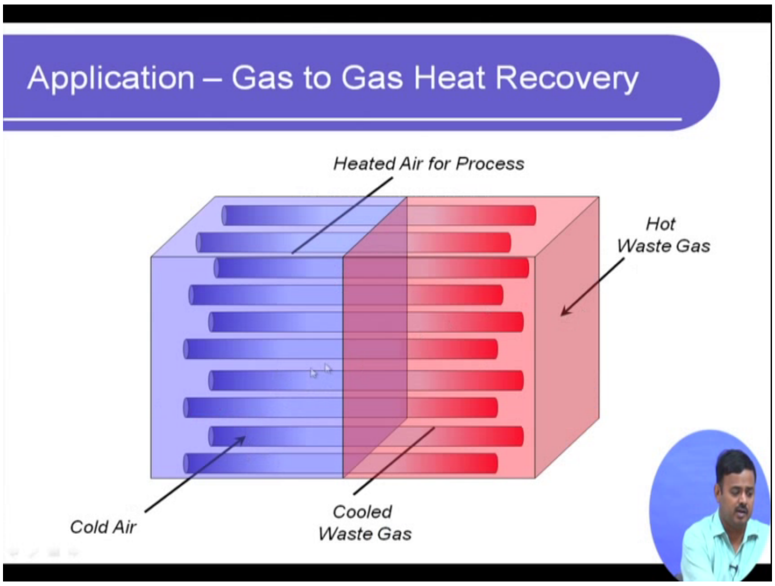
But again keep in mind this is not a heat removal device it is a means of transporting device it is a heat exchange device right it is not a thermal solution, it is a means of transporting heat from point a to A point B with minimum thermal resistance which is what we are trying to do in kinds of waste heat recovery if we think about it, we have what do what do we have we have thermal energy, due to some source which otherwise would have been wasted and we want to extract whatever is possible or whatever is possible from that source of thermal energy and utilize it is somewhere else where it can be put to benefit to be to benefit to our benefit and. So, heat pipe will enable us to do that very effectively

(Refer Slide Time: 25:18)



So, let me just this is what we saw.

(Refer Slide Time: 25:20)



Let us look at one of these applications which is called gas to gas heat recovery and this is where the schematic is shown let us think about it as 2 chambers on one hand you have hot waste gas which is coming and on the other section of this which may or may not be directly connected it can be a remote it can be remotely located also you have cool air and which we want to heat up and that heated air can be used either for room heating or for any other process and again to be to be Jen to make it more generalized it does not have to be air it can be any other fluid as also.

So, we have hot waste gas coming in over here and cold air which we want to cool which we want to heat up sorry. So, the way it is done is you have an array of heat pipes like this all these circular pipes that you see inside these are heat pipes very high effective thermal conductivity in the axial direction.

So, on one end if you just connect the 2 sections by a by an array of heat pipes like this what happens is the thermal energy or heat will be conducted very effectively with minimal temperature drop from the hot waste gas or other hot gas which would otherwise have been wasted to the fluid which we want in this case air which we are trying to heat up.

So, this is very very this is one of the very common and well established applications of heat pipes in terms for heat recovery or waste heat recovery, it is used just to let you know the plate this that is there that is separating the 2 sections is many a times called the splitter plate and the splitter plate as we will see later the splitter plate is also used the orientation of the splitter plate can be changed it can be kept perfectly worry vertical.

So, that the heat pipes are horizontal or it can be inclined to give a some inclination to the heat pipes and as we will see that the performance of a heat pipe is a strong function of it is inclination as well as other geometric parameters. So, this is what we will start within the next lecture as well as we are going to talk about a few other applications of heat pipes in terms of waste heat recovery. So, again thank you very much and we will continue on this topic in the next lecture.