Energy Conservation and Waste Heat Recovery
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Lecture – 38
Heat Pipe – Part II

Good morning and welcome to the next lecture of Energy Conservation and Waste Heat Recovery. So, what we are going to do is if you remember last lecture we had started with a special heat exchange device called heat pipes. We are going to continue on that today and we will we will talk about today we will start with applications if you recall last time we have started with one of the applications which is gas to gas heat recovery.

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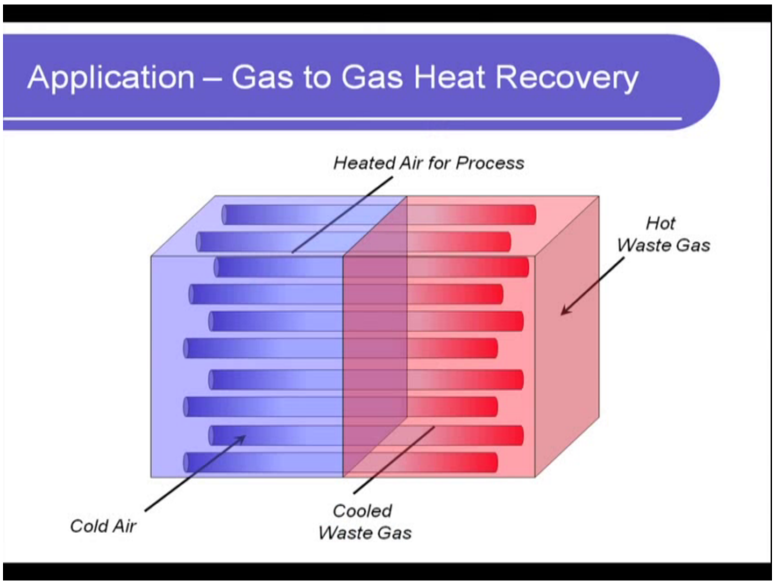

So, I will show you the slide over here once more if you recall this there were 2 chambers on one side we had hot waste gas which otherwise would have been wasted. So, that is the waste heat that we want to recover. On the other side we have a cold air it can be any other fluid also, but at this point let us say we want we have cold air supply and what we want heated air for some application or for some process.

So, what we want to do is we want to extract some of the heat from this waste gas and use that to heat up the air that we that we want to use it for the process that we that we are desiring.

So, what we you are doing is we are going to use heat pipes and connect the location of this hot waste gas to the location of this cold air stream and the heat pipes being very efficient thermal conductors is going to conduct the heat from this hot section to this cold section very efficiently all right. And this way what we are doing is we are using the thermal energy that was trapped in the waste gas and using it for an useful application in this case heating up cold air and this hot air can be used for a variety of applications as we know.

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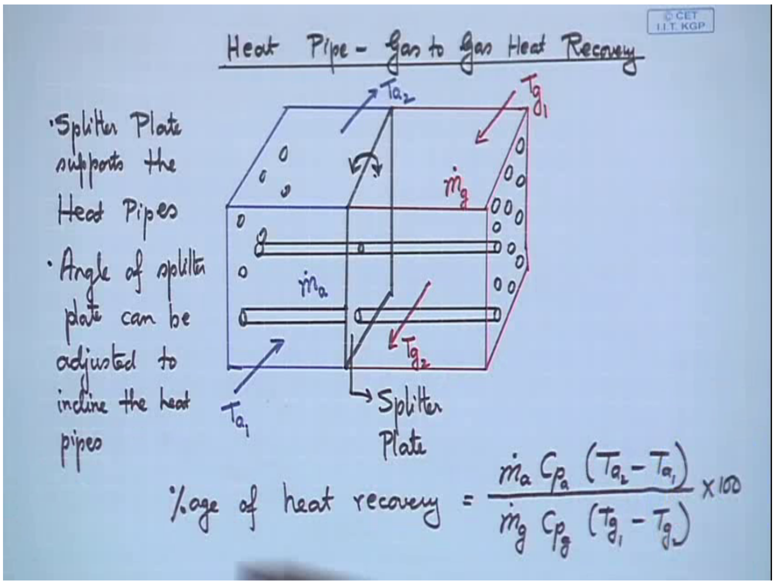

So, let us draw a schematic of this and so let us say heat pipe. So, I will use black ink Heat Pipe for Gas to Gas Heat Recovery, again keep in mind I am saying gas to gas it can be any fluid to any other fluid also . So, let us talk about these 2 chambers that we were drawing before on one side we have a hot chamber through which my hot gas is passing.

So, let me draw that. So, this is my source of hot gas and then on the other side I have the cold section. Again let me draw that quickly and this is where my cold air is going through and which I want to heat up and this is how I will draw it. So, what I have therefore, in this case is a bunch of heat pipes that is going from one end to the other it can be a staggered arrangement it can be an inline arrangement and so on and similarly to the other side also let me just draw a few of these. So, this is one heat pipe this is possibly, another heat pipe going to the other end and so on.

So, this plate through which the heat pipes go through is known as the Splitter Plate. So, let me say let me do something this is hot gas and let me name this temperature as T g 1 and then the cooled waste gas comes out at T g 2 and the mass flow rate let us call that as m dot g. Similarly on this section I will say that you have a cold gas or air let us say coming at a t a one leaving at an elevated temperature of T a 2 and the mass flow rate is m dot a.

So, therefore, if I have to write an expression for percentage of heat recovery, I will write it as the heat that have been able to recover which will be m dot a times the specific heat of air in this case times T a 2 minus T a 1, divided by what was available m dot g C p g times, T g 1 minus T g 2 times 100. So, this is what we normally define as percentage of heat recovery or percentage recovery all right.

So, let me write down a few points over here the splitter plate supports the heat pipes and as you can see the heat pipes are in cross flow if you remember heat exchangers that that was discussed, these are this is in the cross flow the heat exchanger or heat exchange is happening in the cross flow arrangement the other thing is Angle of splitter plate can be adjusted to incline the heat pipes.

So, which means that this splitter plate can be tilted and therefore, what happens is if this is my heat pipe if this is my heat pipe it can go tilted like this, but as we will see before normally this tilting is always done. So, that the evaporator end is at the bottom and the condenser end is at the top. I again I repeat the tilting is typically done. So, that it is condenser above evaporator why we will discuss that later when we do some mathematical analysis of heat pipes all.

So, the first application once more once again is heat pipes of heat pipes in waste heat recovery is gas to gas heat recovery next.

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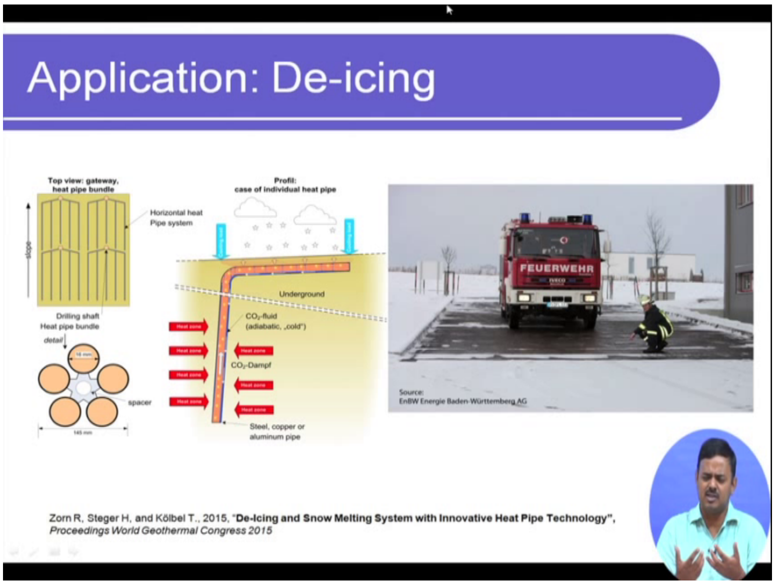

Let us look at this application on the screen over here and this is for De-icing. Now remember in very cold countries, where you have a lot of snow what happens is once this the snowfall has happened while it is falling of course, it is snow in the granular form, but later what happens is as it becomes very cold there is this thin layer of ice that forms on the surface of the road and this ice is extremely dangerous.

Because on this one what happens is your if you are driving your car tires will skid, it will skid and it is dangerous I mean I have I mean personally I have had this experience when I used when I was a student in us and on one of the snowy evenings, it had snowed the whole night or the whole day sorry and in the evening the snow had subsided a little bit. So, I went out to get some groceries and I was driving through the road and you know once it is ice you would not be able to make out because it is transparent.

So, I thought I was driving on the road and at 1 point what happens is the car in front of me press the brakes and it was a little unexpected. So, I also press the brake and as I press the brake my car just started skidding over the ice and mark my words it was scary because I do not have any control and then what happens I try to turn the steering and actually when you turn the steering you actually help it and the car goes the other way because you see you are not rolling you are sliding now.

So, in other words what I am trying to say is this ice formation is extremely undesirable it leads to a lot of accidents and that is why it is important that this ice is removed. So, many a times you have these snow removal trucks in cold countries which will come and remove the snow and try to prevent the ice formation as much as possible.

But this one if you look at it think about it is snowing, but what about if you go down the in the underground what happens at the depths of the; if you go deep the temperature is higher. So, therefore, what they are trying to do is they are using heat pipes over here steel copper or aluminum heat pipe and as you go underground over here the temperature is much higher compared to what is on the road.

So, it is a heat pipe with a bend. So, the evaporator section in this case in the over here is deep down the into the earth's, crust earth's crust I mean not deep down means I feel I mean a few meters and the condensed section or the cold section is right below the right below the soil or right below the road in this case.

So, what happens heat is being conducted from this hot area to this cold area and as a result what happens is the ice which is formed on this surface is going to melt and look at this picture this is done in Germany this was a pilot in Germany. So, this section is where the heat pipes are put underground and the where you have the snow covered sections or where the heat pipe is not put and you can see the difference.

So, the snow is melted right away and. So, there is no question of the snow staying over there and then getting becoming ice later on. So, De-icing a snow melting system with innovative heat pipe technology this is a paper that was presented is 2015 actually showed a practical implementation in a pilot study as is shown here. So, again a very very effective implementation or an application of heat pipes in terms of waste heat recovery.

Now, you may call it is just waste heat in the sense that this is not heat that is waste it is not industrial waste, but in the other way, but another way to look at it is this is the thermal energy source which is present to us underground and we are not utilizing it. So, in that sense it is wasted and so in this case if you are using some of the thermal energy and putting it to an useful application it is waste heat recovery all right.

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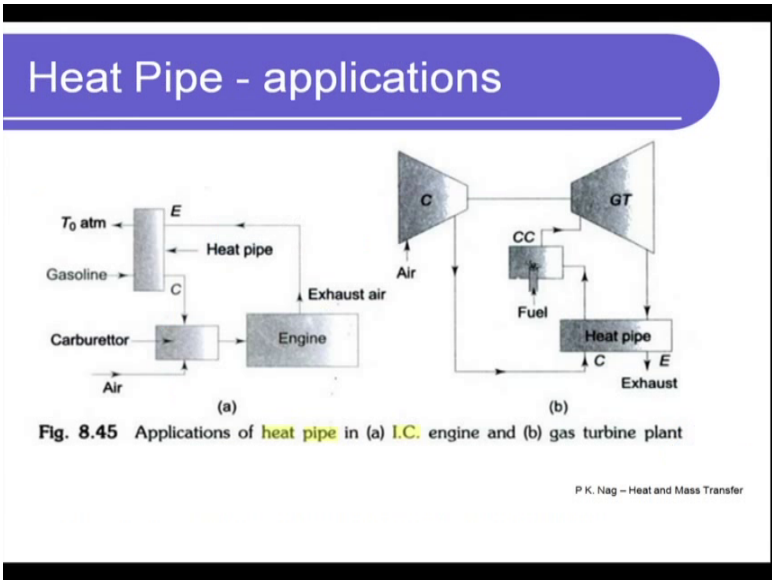

Next, so they can these are some applications not very widely used I would say, but at least potential applications that has been shown to work. The first one again I am taking this from heat and mass transfer book of professor PK Nag who was also my teacher at one point of time he is no more. So, over here what is shown in the first part is an I.C engine. So, you have the engine and the exhaust gas is coming out and which otherwise would be wasted and this exhaust gas is at an elevated temperature. So, can I use some of the trapped heat over here and put it into some useful application.

So, in this case what is doing is this exhaust gas is connected or some of the exhaust gas and from where the gasoline is coming in this or the fuel is coming the 2 are connected with the heat pipe. And the heat pipe acts as a very efficient thermal conductor and conducts some of the heat that is trapped in this exhaust here and uses it to preheat the gasoline and this will help us in combustion right a preheated preheating of the fuel using done by heat pipe. So, of course, the hot end is evaporator in which is exhaust here and the cold end is the condenser end which is the fuel or gasoline here and then the preheated gasoline comes to the carburetor where it mixes with air and then it goes into the engine.

So, this is for an I.C engine automobile, if you think about gas turbine aviation what happens over here you have this combustion chamber. So, you have a compressed air and which then goes to the combustion chamber where it mixes with fuel combustion happens and the combustible gases then go to the gas turbine where it is expanded and you get work out of it and then the exhaust gas from the gas turbine is thrown out.

So, here also the exhaust gas carries a lot of thermal energy we do not want to waste it. So, can we use a heat pipe we can recover some of the waste heat from this exhaust gas, but what are we going to use it for well we can preheat the air after compression of course, the air gets heated, but; however, preheating it a little further because the more we heat up the air the higher is my combustion efficiency.

So, we use the air or we use the exhaust heat or the thermal energy trapped in the exhaust combustible gases combustion gases, to heat up the air before it enters the combustion chamber. So, this is a gas turbine application and this is an I.C engine application.

So, again what have we done when we talk about heat pipes for waste heat recovery, we have talked about gas to gas heat recovery, we have talked about De-icing and then we talked about these 2 engines I.C engine and gas turbines.

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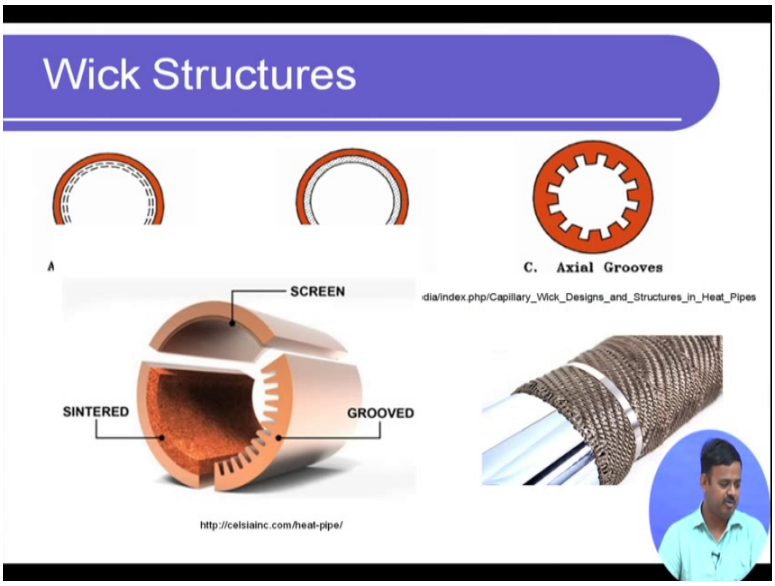

All right, so these are some of the applications of heat pipes for waste heat recovery and let us look at now on we were talking about the wick. So, what is a typical wick structure? So, the wick in the heat pipe can be of various types the 3 most important ones are shown here, the one is a wrapped screen. So, you can take a wire mesh or wire screen mesh and then take a few layers and wrap it on the inner surface of the heat pipe the inner walls of this pipe and that is how you get this wick and it is going to give you the capillary action the other one is centered metal the third one is axial grooves axial grooves with very thin gap in the in these groups. So, that it provides you the surface tension forces which is required for capillary action.

So, this is kind of a rendition this is not a picture that way this is a 3 D anima 3 D rendition of a single heat pipe which is showing the 3 types of wicks one is grooved, one is sintered metal and the other one is screened. So, this is how it actually looks if you cut open a heat pipe and then of course, magnify it this is how you will see the wick structure to be all right.

So, now that we I think right now we have a good understanding of what a heat pipe is what it does and how it can be used for waste heat recovery, but let us talk a little bit about history of heat pipes it is interesting to know where did it start who is the one who invented heat pipes. So, heat pipe was invented by NASA and it is first application was in space when it sent space satellites, what happened was when part of it the one side of the satellite which would face the sun would get much heated which would get heated up and the other end would be much cooler and the temperature gradient used to be very large. And there was a need to uniformalize the temperature and for that NASA came up with heat pipes which was first implemented in it is space shuttles.

So, the first heat pipe was probably about if I call it if I recall properly it was like 5 to 10 meters several meters let us say in length it was a few inches in diameter and was used to uniformalize the temperature of a large range of temperature in many cases like 50 70 degree centigrade and so on. However, today even though the focus of this course is waste heat recovery and we looked at some of the applications for waste heat recovery using heat pipes, of most common example or most common application of heat pipe is inside laptop computers; any of our laptops today have a heat pipe the thermal solution for cooling the CPU inside a laptop is heat pipes the way it is done is the reason why we need it need a heat pipe is the following.

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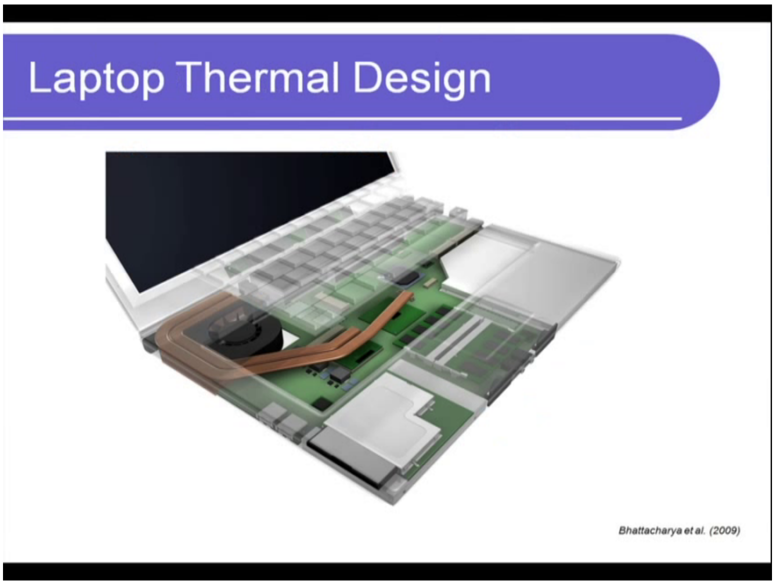

See we have the CPU which is inside on your motherboard and in order to cool that CPU and dissipate the heat that is generated we need a fan and a heat exchanger or a heat sink. However, the size of the fan and heat sink which I am trying to show over here in this schematic is much larger than what is available to me at the location of the CPU. In other words it is not possible we do not have the space to accommodate this fan and heat sink on the at the CPU location unlike for example, a desktop very our heat sink and a fan right on the CPU.

So, therefore, I can put the fan and heat sink at one corner or one location or one corner or one side of my laptop where I have a cutout in the motherboard. That is where I have a fan which blows here it comes through this finned heat sink and the exhaust air comes out in any of your laptop if you try you will see there is an exhaust vent, if you look through that from where hot air comes out and if you look through the vent you will be able to see this copper or aluminum finned heat sink and there is actually a fan just upstream of that which is blowing it.

Now, therefore, the challenge for me is to conduct the heat from this CPU location to the location where I have the heat is heat sink and the fan and the way that is done is use is by a heat pipe. So, this is how it is shown over here in this schematic and in this picture in this slide this is what I am trying to show I have a CPU which is the die and which is where I need to extract the heat and the heat has to be rejected using a heat exchanger or heat call it heat exchanger sometimes we call it heat sinks also and a fan.

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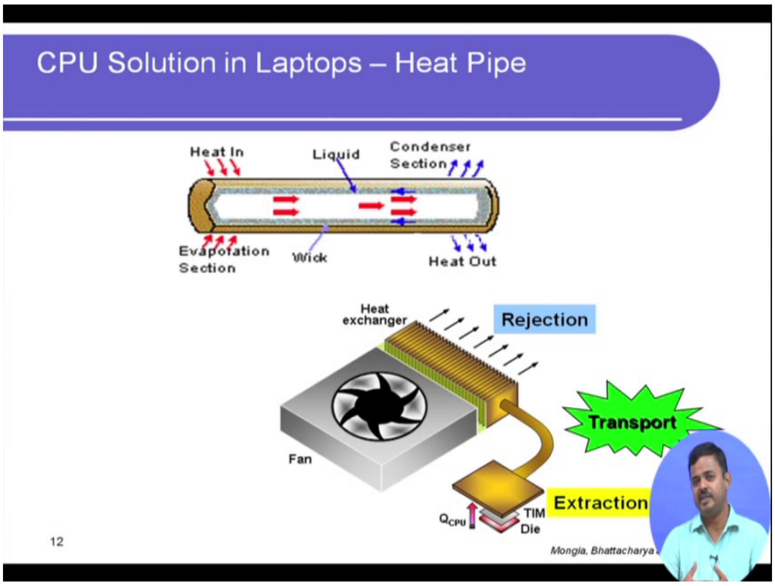

But; however, I cannot put the fan and heat exchanger right at the CPU location why because I do not have the space. So, therefore, I have extraction at one place rejection at another place I need to connect them with minimal temperature drop and the way to do that is using a heat pipe and the way I heat pipe works you have already seen that through that. So, through that animation all right.

So, this today is one of the most common applications of heat pipes and these heat pipes typically trust me are of the diameter of one millimeter or less compare that to the first one that was used in NASA which was several inches in diameter. So, the heat pipe technology over the last 50 60 years especially I would say over the last 20 years have matured tremendously and today we have really very thin heat pipes which performs extremely reliably I have worked with these I used to work for Intel for many years and I have worked with I mean I was I was a thermal designer for laptop computers.

So, I worked with this for many years for almost 4 5 years and in my 5 years of experience I never saw a heat pipe that failed, there were other reasons for which the laptop field, but not heat pipes the fan would fail there may be dust accumulation at the heat sink or the between the fence etcetera, but heat pipes never it is. So, reliable and today is extremely cheap also a typical laptop heat pipe comes for less than a dollar. In fact, like 30 cents or so.

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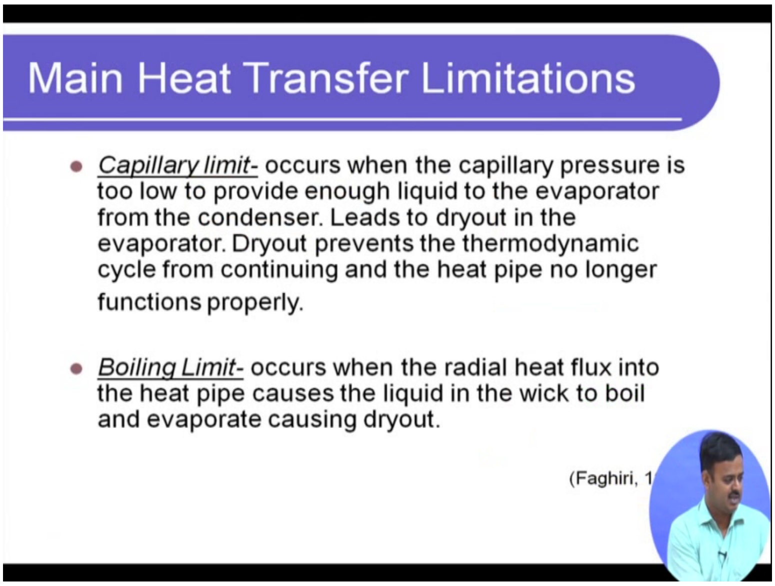

So, that kinds of tells us what is what is as a separate a different application of heat pipe which is not related to waste heat recovery, but nevertheless I believe when we are studying heat pipe we should know about this all right . So, with this discussion about applications of heat pipes let us move on to some analysis all right

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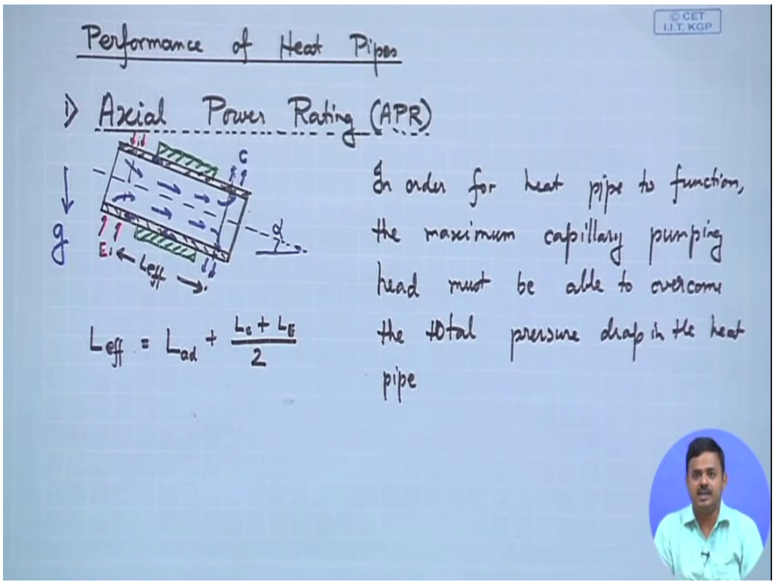

So, let us talk about performance of heat pipes and how do we when we say a good heat pipe versus bad heat pipe or when we try to quantify performance of heat pipes what is it that we are going to try and quantify. So, what we are going to talk about here is called Axial Power Rating or APR. So, let us call it axial power rating or we will many a times refer to as a pr what is an APR.

So, axial power rating if we want to look at and try to quantify what is the amount of maximum power; maximum amount of heat is there a limit to the maximum heat that the heat pipe can conduct from it is evaporator end to the condenser end if we have to quantify that what all do we have to do. So, in order to do that let us try and draw a heat pipe first and look at it is various just try to draw it over here let us call this is the axis of the heat pipe and we will draw it in this form let us call this as a heat pipe this is a little exaggerated in the sense that I made it very short and fat short and stout, but this is just a schematic and we are going to use it for our Applica for our analysis.

So, again on the annulus we have the wick then we will quickly insulate the aerobatic section though as I said it is not required in every application, but we will denote the adiabatic section through this insulation and try to see what is happening over here. So, intentionally what I have done is I have given the heat pipe an inclination with the horizontal and let us call that inclination as alpha; my gravity is in the downward direction these are going to be important as we will see later.

So, I am going to call this as a condenser section. So, because this is where the heat is getting rejected the heat is getting rejected over here and so we are going to denote it as c or condenser and the heat is getting absorbed over here and we are going to call it as evaporator all right.

Let us also define one more parameter which is called the effective length of the heat pipe, the L effective length very commonly is often taken as, the L adiabatic plus L condenser plus L evaporator divided by 2. This is a common way of or whatever this an acceptable definition of an effective length of heat pipe, but it is not necessary that you strictly follow this all right.

And now what we are going to do next is we are going to look at let us study the flow path of the fluid. So, from here if we just take the fluid path, as we saw before the fluid is flowing through the core and then coming back through the wick right.

So, if you look at it what is happening is there is a flow of the liquid through the wick there is flow of Vapour through the core. So, what is it that we are going to do and then we have to do a force balance because as it flows through these different paths there is a pressure drop and the capillary force through the wick should be able to overcome the total pressure drop in the heat pipe?

So, let us look at this let me just end this by saying that in order for heat pipe to function the maximum capillary force or capillary head capillary pumping head must be able to overcome, the total pressure drop in the heat pipe or total pressure drop of the fluid in the heat pipe. And so what is it that that constitutes a total pressure drop in the heat pipe that is what we are going to see in the next lecture.

So, we are going to end today over here with this brief definition and the brief nomenclature of the axial power rating mathematical deduction that we are going to do and we are going to do a momentum balance in the next class and try to come up with an expression for what is the maximum amount of heat that can be removed or pumped from one end to the other so.

Thank you very much and we are going to continue from here in the next lecture.