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HEAT PIPES

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INTRODUCTION

A heat pipe is a device that efficiently transports thermal energy from its one point to the other. It utilizes the latent heat of the vaporized working fluid instead of the sensible heat. As a result, the effective thermal conductivity may be several orders of magnitudes higher than that of the good solid conductors. A heat pipe is a heat transfer mechanism that can transport large quantities of heat with a very small difference in temperature between the hotter and colder interfaces.

Inside a heat pipe, at the hot interface a fluid turns to vapour and the gas naturally flows and condenses on the cold interface. The liquid falls or is moved by capillary action back to the hot interface to evaporate again and repeat the cycle. A Heat pipe is a self-contained passive energy recovery device. A heat pipe can transfer up to 1000 times more thermal energy, than copper, the best known conductor. One of the amazing features of the heat pipes is that they have no moving parts and hence require minimum maintenance. They are completely silent and reversible in operation and require no external energy other than the thermal energy they transfer. Heat pipes are ruggedly built and can withstand a lot of abuse.

A heat pipe is an extremely efficient thermal conductor. Typically, a heat pipe consists of a sealed container (usually aluminum or copper), a wicking structure and a small amount of working fluid under its own pressure. Applying heat anywhere along the surface of the heat pipe causes the liquid at that point to boil and enter a vapor state. When that happens, the liquid picks up the latent heat of vaporization. The gas, which then has a higher pressure, moves inside the heat pipe to the colder location where it condenses. The condensed fluid travels back along the wick and repeats the process. Noren Products Heat pipes can be built in almost any size and shape.

What is Heat Pipe?

A traditional heat pipe is a hollow pipe under vacuum filled with a vaporizable liquid. The Heat Pipe functions are as follows:

A. Latent heat of Evaporation is absorbed in the evaporating section.
B. The fluid boils to the vapor phase.
C. The vapor releases latent heat of condensation to the environment from the upper part (Condenser Section) of the pipe and condenses.
D. Condensed Liquid returns by gravity to the lower part of cylinder (evaporating section).

When heat is added to the evaporator section, the working fluid boils and converts into vapor absorbing latent heat. After reaching the condenser section, due to partial pressure build up, the vapor transforms back into liquid thus releasing latent heat. From the condenser section, heat is taken away by means of water cooling / air cooling with fins etc. The liquid condensate returns to the original position through the capillary return mechanism, completing the cycle. Due to very high latent heat of vaporization a large quantity of heat can be transferred. A heat pipe is a device that efficiently transports thermal energy from its one point to the other. It utilizes the latent heat of the vaporized working fluid instead of the sensible heat. As a result, the effective thermal conductivity may be several orders of magnitudes higher than that of the good solid conductors.

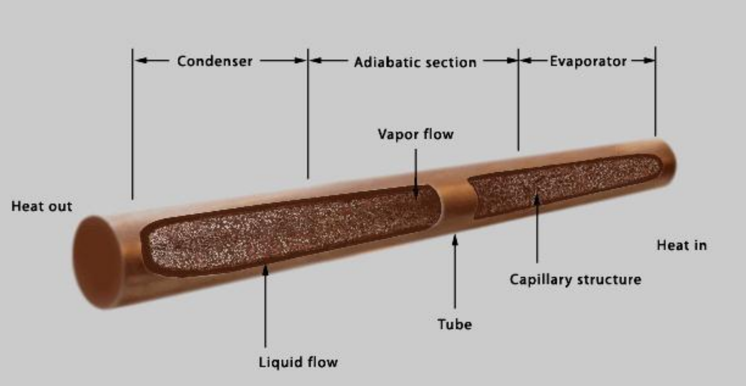

Fig.1. Heat Pipe

A heat pipe consists of a sealed container, a wick structure, a small amount of working fluid that is just sufficient to saturate the wick and it is in equilibrium with its own vapor. The operating pressure inside the heat pipe is the vapor pressure of its working fluid. The length of the heat pipe can be divided into three parts viz. evaporator section, adiabatic section and condenser section. In a standard heat pipe, the inside of the container is lined with a wicking material. Space for the vapor travel is provided inside the container.

OPERATING PRINCIPLE

Figure shows the working principle of a heat pipe. Thermal input at the evaporator region vaporizes the working fluid and this vapor travels to the condenser section through the inner core of heat pipe. At the condenser region, the vapor of the working fluid condenses and the latent heat is rejected via condensation. The condensate returns to the evaporator by means of capillary action in the wick.

As previously mentioned there is liquid vapor equilibrium inside the heat pipe. When thermal energy is supplied to the evaporator, this equilibrium breaks down as the working fluid evaporates. The generated vapor is at a higher pressure than the section through the vapor space provided. Vapor condenses giving away its latent heat of vaporization to the heat sink. The capillary pressure created in the menisci of the wick, pumps the condensed fluid back to the evaporator section. The cycle repeats and the thermal energy is continuously transported from the evaporator to condenser in the form of latent heat of vaporization. When the thermal energy is applied to the evaporator, the liquid recedes into the pores of the wick and thus the menisci at the liquid-vapor interface are highly curved. This phenomenon is shown in figure.

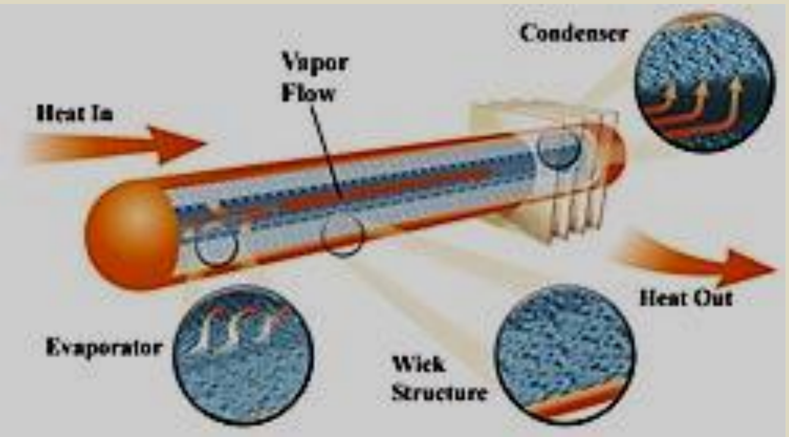

Fig.2. Operating principle of heat pipe

At the condenser end, the menisci at the liquid-vapor interface are nearly flat during the condensation due to the difference in the curvature of menisci driving force that circulates the fluid against the liquid and vapor pressure losses and body forces such as gravity.

HEAT PIPE SELECTION

Heat pipes are being used very often in particular applications when conventional cooling methods are not suitable. Once the need for heat pipe arises, the most appropriate heat pipe needs to be selected. Often this is not an easy task, and the following needs to be considered.

How to select a heat pipe?

1) Investigate and determine the following operational parameters:

   A. Heat load and geometry of the heat source.
   B. Possible heat sink location, the distance and orientation relative to the heat source.
   C. Temperature profile of heat source, heat sink and ambient
   D. Environmental condition (such as existence of corrosive gas)

2) Select the pipe material, wick structure, and working fluid. (Consult with an Enertron engineer or original heat pipe manufacturer to select the most appropriate heat pipe)

   A. Determine the working fluid appropriate for your application
   B. Select pipe material compatible to the working fluid
   C. Select wick structure for the operating orientation
   D. Decide on the protective coating.

3) Determine the length, size, and shape of the heat pipe (consult with Enertron engineer)

What materials can be used to construct a heat pipe?

A particular working fluid can only be functional at certain temperature ranges. Also, the particular working fluid needs a compatible vessel material to prevent corrosion or chemical reaction between the fluid and the vessel. Corrosion will damage the vessel and chemical reaction can produce a non-condensable gas. Refer to the following Table. For example, the liquid ammonia heat pipe has a temperature range from –70 to +60oC and is compatible with aluminum, nickel and stainless steel.

Typical Operating Characteristics of Heat Pipes

Temperature Range (ºC)	Working Fluid	Vessel Material	Measured Axial Heat Flux (kW/cm^2)	Measured Surface Heat Flux (W/cm^2)
-200 to -80	Liquid Nitrogen	Stainless Steel	0.067 @ -163ºC	101 @ -163ºC
-70 to +60	Liquid Ammonia	Nickel, Aluminum, Stainless Steel	0.295	2.95
-45 to +120	Methanol	Copper, Nickel, Stainless Steel	0.45 @ 100ºC	75.5 @ 100ºC
+5 to +230	Water	Copper, Nickel	0.67 @ 200ºC	146@170ºC
+190 to +550	Mercury +0.02%, Magnesium +0.001%	Stainless Steel	25.1 @ 360ºC	181 @ 750ºC
+400 to +800	Potassium	Nickel, Stainless Steel	5.6@ 750ºC	181 @ 750ºC
+500 to +900	Sodium	Nickel, Stainless Steel	9.3 @ 850ºC	224 @ 760ºC
+900 to +1500	Lithium	Niobium +1% Zirconium	2.0@1250ºC	270 @ 1250ºC
+1500 to +2000	Silver	Tantalum +5% Tungsten	4.1	413

The liquid ammonia heat pipe has been widely used in space and only aluminum vessels are used due to lightweight. Water heat pipes, with a temperature range from 5 to 230 oC, are most effective for electronics cooling applications and copper vessels are compatible with water.

Heat pipes are not functional when the temperature of the pipe is lower than the freezing point of the working fluid. Freezing and thawing is a design issue, which may destroy the sealed joint of a heat pipe when place vertically. Proper engineering and design can overcome this limitation.

What are the four heat transport limitations of a heat pipe?

The four heat transport limitations can be simplified as follows;

1) Sonic limit – the rate that vapor travels from evaporator to condenser.

2) Entrainment limit – Friction between working fluid and vapor that travel in opposite directions.

3) Capillary limit – the rate at which the working fluid travels from condenser to evaporator through the wick.

4) Boiling limit – the rate at which the working fluid vaporizes from the added c heat

HEAT TRANSFER

Heat pipes employ evaporative cooling to transfer thermal energy from one point to another by the evaporation and condensation of a working fluid or coolant. Heat pipes rely on a temperature difference between the ends of the pipe, and cannot lower temperatures at either end beyond the ambient temperature (hence they tend to equalize the temperature within the pipe). When one end of the heat pipe is heated the working fluid inside the pipe at that end evaporates and increases the vapour pressure inside the cavity of the heat pipe. The latent heat of evaporation absorbed by the vaporization of the working fluid reduces the temperature at the hot end of the pipe. The vapour pressure over the hot liquid working fluid at the hot end of the pipe is higher than the equilibrium vapour pressure over condensing working fluid at the cooler end of the pipe, and this pressure difference drives a rapid mass transfer to the condensing end where the excess vapour condenses, releases its latent heat, and warms the cool end of the pipe. Non-condensing gases (caused by contamination for instance) in the vapour impede the gas flow and reduce the effectiveness of the heat pipe, particularly at low temperatures, where vapour pressures are low. The velocity of molecules in a gas is approximately the speed of sound and in the absence of non condensing gases; this is the upper velocity with which they could travel in the heat pipe. In practice, the speed of the vapour through the heat pipe is dependent on the rate of condensation at the cold end.

The condensed working fluid then flows back to the hot end of the pipe. In the case of vertically-oriented heat pipes the fluid may be moved by the force of gravity. In the case of heat pipes containing wicks, the fluid is returned by capillary action. When making heat pipes, there is no need to create a vacuum in the pipe. One simply boils the working fluid in the heat pipe until the resulting vapour has purged the non condensing gases from the pipe and then seals the end. An interesting property of heat pipes is the temperature over which they are effective. Initially, it might be suspected that water charged heat pipe would only work when the hot end reached the boiling point (100 °C) and steam was transferred to the cold end. However, the boiling point of water is dependent on absolute pressure inside the pipe. In an evacuated pipe, water will boil just slightly above its melting point (0 °C). The heat pipe will operate, therefore, when the hot end is just slightly warmer than the melting point of the working fluid. Similarly, a heat pipe with water as a working fluid can work well above the boiling point (100 °C), if the cold end is low enough in temperature to condense the fluid.

The main reason for the effectiveness of heat pipes is the evaporation and condensation of the working fluid. The heat of vaporization greatly exceeds the sensible heat capacity. Using water as an example, the energy needed to evaporate one gram of water is equivalent to the amount of energy needed to raise the temperature of that same gram of water by 540 °C (hypothetically, if the water was under extremely high pressure so it didn't vaporize or freeze over this temperature range). Almost all of that energy is rapidly transferred to the "cold" end when the fluid condenses there, making a very effective heat transfer system with no moving parts.

APPLICATION'S

Solar Thermal

Heat pipes are also being widely used in solar thermal water heating applications in combination with evacuated tube solar collector arrays. In these applications, distilled water is commonly used as the heat transfer fluid inside a sealed length of copper tubing that is located within an evacuated glass tube and oriented towards the sun.

In solar thermal water heating applications, an evacuated tube collector can deliver up to 40% more efficiency compared to more traditional "flat plate" solar water heaters. Evacuated tube collectors eliminate the need for anti-freeze additives to be added as the vacuum helps prevent heat loss. These types of solar thermal water heaters are frost protected down to more than -3 °C and are being used in Antarctica to heat water.

WASTE HEAT RECOVERY FROM AIR CONDITIONERS

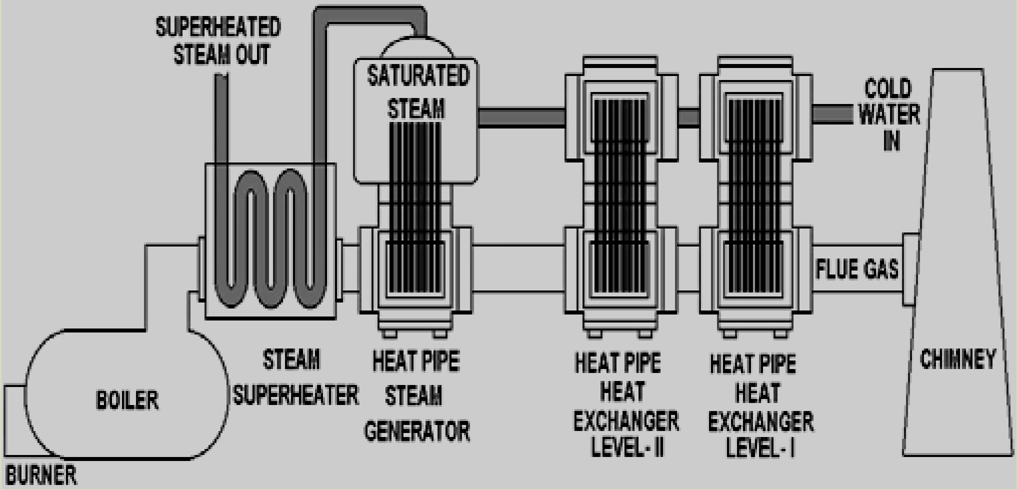

Fig.5. Waste Heat Recovery from Air Conditioners

Pipelines over permafrost

Heat pipes are used to dissipate heat on the Trans-Alaska Pipeline System. Without them residual ground heat remaining in the oil as well as that produced by friction and turbulence in the moving oil would conduct down the pipe's support legs. This would likely melt the permafrost on which the supports are anchored. This would cause the pipeline to sink and possibly sustain damage. To prevent this each vertical support member has been mounted with 4 vertical heat pipes.

SEGMENTWISE APPLICATIONS OF HEAT EXCHANGERS

- Annealing furnaces
- Humber dryer
- Bakery Oven
- Plastic laminate dryer
- Boiler
- Print dryer
- Brick Kiln
- Reverberatory furnace

LIMITATIONS

Heat pipes must be tuned to particular cooling conditions. The choice of pipe material, size & coolant all have an effect on the optimal temperatures in which heat pipes work. When heated above a certain temperature, all of the working fluid in the heat pipe will vaporize and the condensation process will cease to occur; in such conditions, the heat pipe's thermal conductivity is effectively reduced to the heat conduction properties of its solid metal casing alone. As most heat pipes are constructed of copper (a metal with high heat conductivity), an overheated heat pipe will generally continue to conduct heat at around 1/80 of the original conductivity. In addition, below a certain temperature, the working fluid will not undergo phase change, and the thermal conductivity will be reduced to that of the solid metal casing. One of the key criteria for the selection of a working fluid is the desired operational temperature range of the application. The lower temperature limit typically occurs a few degrees above the freezing point of the working fluid.

Most manufacturers cannot make a traditional heat pipe smaller than 3mm in diameter due to material limitations (though 1.6mm thin sheets can be fabricated). Experiments have been conducted with micro heat pipes, which use piping with sharp edges, such as triangular or rhombus-like tubing. In these cases, the sharp edges transfer the fluid through capillary action, and no wick is necessary.

CONCLUSION AND SCOPE FOR FUTURE WORK

Our work involves the study of variation on the temperature profile due to the varied power supply to the evaporator, variation in the coolant flow rate, variation in the working fluid, variation in the average pressure inside the heat pipe, variation due to different wick structures and finally the variation due to geometrical configuration of the heat pipe. The results of our proposed work provide an insight into the effect of parameter variation on the temperature profile of a heat pipe and experiment results will be compared with analyzed results. Thus we could suggest better ways to improve the performance of a heat pipe. Further studies on the velocity profile and pressure profile of a heat pipe can be made and it would be further used for modeling a heat pipe using any software package such as CFD.

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