PDHonline Course M406 (1 PDH)

Heat Pipe

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Heat Pipe

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COURSE CONTENT

To improve efficiency of plant and thereby to reduce production cost engineers are continually being asked to improve heat transfer. Increases in the rate of heat transfer will ultimately improve the processes. This course provides the information of increasing heat transfer by using heat pipes.

Introduction

A heat pipe is a device that efficiently transfers heat from its one end 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. Heat input at the evaporator vaporizes the working fluid and this vapor travels to the condenser section. Here the latent heat is rejected via condensation. The vapor of the working fluid condenses and the condensate returns to the evaporator by means of capillary action. 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 3 parts namely 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. Fins may be attached to the evaporator and the condenser portion to increase heat transfer rate depending upon the application.

Heat pipe is used for variety of applications, covering almost the entire spectrum of temperatures encountered in heat transfer processes. Heat pipes are used in a wide range of products like air-conditioners, refrigerators, heat exchangers, transistors, capacitors, space crafts, computers, etc. Heat pipes are also used in laptops to reduce the working temperature for better efficiency. Their application in the field of cryogenics is very significant, especially in the development of space technology.

Since heat pipes have no moving parts, they are extremely reliable. This is the main reason they are used extensively in space applications where maintenance is not available

Operating Principle

A heat pipe operates on a closed two phase cycle. Figure 1 shows a schematic of a typical heat pipe operation. As previously mentioned, there is liquid-vapor equilibrium inside the heat pipe. When the heat is supplied to the evaporator, this equilibrium breaks down as the working fluid evaporates.

The generated vapor is at a higher pressure than the liquid and it travels to the condenser 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 wick pumps the condensed fluid back to the evaporator section. The cycle repeats and the heat is continuously transported from evaporator to condenser in the form of latent heat of vaporization.

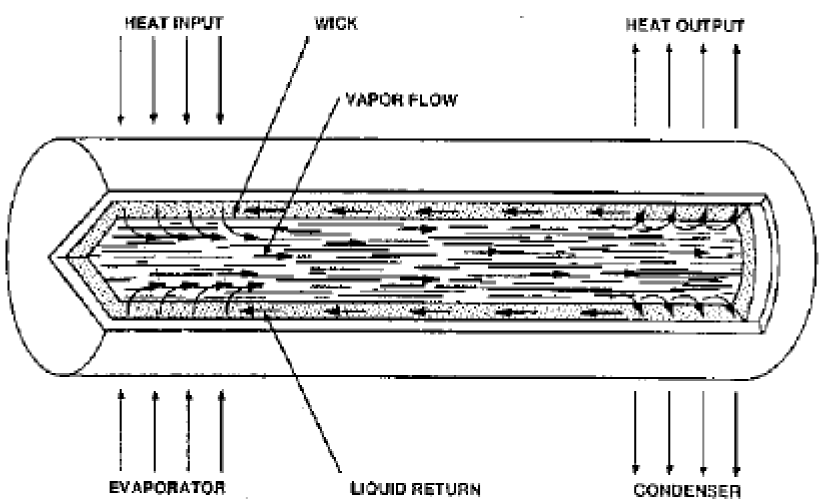

Figure 1 Operating Principle

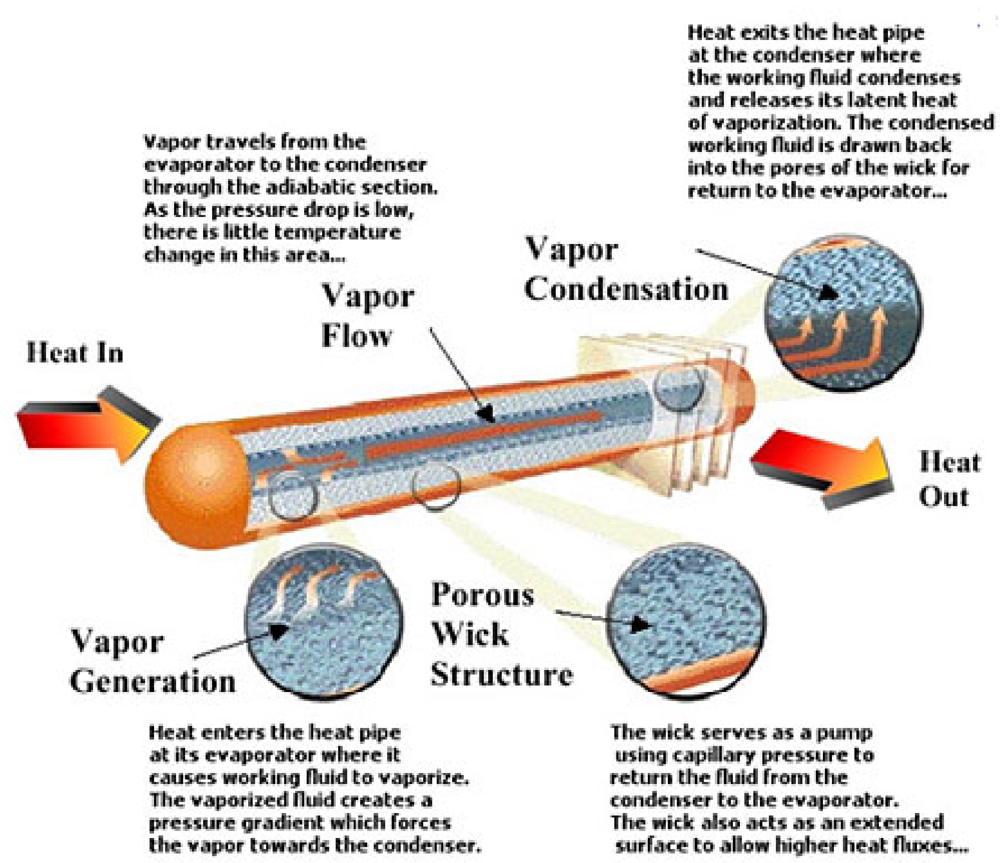

Figure 2 Operating principle

Applications

Heat pipe is used for variety of applications, covering almost the entire spectrum of temperatures (–273°C to 2300°C) encountered in heat transfer processes. Few of them are listed below:

1. Solar thermal energy application.
2. Thermal control of nuclear power plants
3. Rapid cooling in plastic die-casting and injection molding industry.
4. Road snow melting application.
5. Thermal control of electronic devices and components.
6. Cryogenics and refrigeration.
7. Thermal control of semiconductor devices in multiple chips models.
8. Dissipation of heat from leading edge of hypersonic aircraft.

9. Non surgical treatment of cancerous tissue through either hyper or hypo-thermia.
10. Heat is transferred from torso to fingertips to prevent frostbite.
11. Cooling of shafts, turbine blades, generator, motor and transformer,
12. Geothermal energy
13. Cooling of Infrared sensors

Working Fluid

Heat Pipe can work from cryogenic temperature range to liquid metal temperature range. Within the approximate temperature band, several possible working fluids may exist, and a variety of characteristics must be examined in order to determine the most acceptable of these fluids for the application considered. Based on its application internal working fluids are decided. Various working fluids are Silver, lithium, sodium, potassium, mercury, water, methanol, freon-21, ammonia, methane, oxygen, nitrogen, neon and hydrogen are normally used as working fluids. General properties required from working fluids are.

1. Thermal stability
2. Wettability of wick and wall material
3. High latent heat
4. High thermal conductivity
5. Low viscosity
6. Low freezing point
7. High value of surface tension

The selection of the working fluid is based on various thermodynamic considerations. A high value of surface tension is desirable in order to enable the heat pipe to operate against gravity and to generate a high capillary driving force. In addition to high surface tension, it is necessary for the working fluid to wet the wick and the container material i.e. contact angle should be zero or very small. The vapor pressure over the operating temperature range must be sufficiently high.

Also high latent heat of vaporization is desirable in order to transfer large amounts of heat with minimum fluid flow, and hence to maintain low pressure drops within the heat pipe. The thermal conductivity of the working fluid should preferably be high in order to minimize the radial temperature gradient and to reduce the possibility of nucleate boiling at the wick or wall surface. The resistance to fluid flow will be minimized by choosing fluids with low values of vapor and liquid viscosities. Tabulated below are a few mediums with their useful ranges of temperature.

Wick Structure

It is a porous structure made of materials like steel, aluminum, nickel or copper in various ranges of pore sizes. They are fabricated using metal foams, and more particularly felts, the latter being more frequently used. By varying the pressure on the felt during assembly, various pore sizes can be produced. By incorporating removable metal mandrels, an arterial structure can also be molded in the felt.

Fibrous materials, like ceramics, have also been used widely. They generally have smaller pores. The main disadvantage of ceramic fibers is that, they have little stiffness and usually require continues support by a metal mesh. Thus while the fiber itself may be chemically compatible with the working fluids, the supporting materials may cause problems. Carbon fiber is also a suitable material. It can have many fine longitudinal grooves on their surface, have high capillary pressures and are chemically stable. A number of heat pipes that have been successfully constructed using carbon fiber wicks seem to show a greater heat transport capability.

The prime purpose of the wick is to generate capillary pressure to transport the working fluid from the condenser to the evaporator. It must also be able to distribute the liquid around the evaporator section to any area where heat is likely to be received by the heat pipe. Often these two functions require wicks of different forms. The selection of the wick for a heat pipe depends on many factors, several of which are closely linked to the properties of the working fluid.

The maximum capillary head generated by a wick increases with decrease in pore size. The wick permeability increases with increasing pore size. Another feature of the wick, which must be optimized, is its thickness. The heat transport capability of the heat pipe is raised by increasing the wick thickness. The overall thermal resistance at the evaporator also depends on the conductivity of the working fluid in the wick. Other necessary properties of the wick are compatibility with the working fluid and wettability.

The two most important properties of a wick are the pore radius and the permeability. The pore radius determines the pumping pressure the wick can develop. The permeability determines the frictional losses of the fluid as it flows through the wick.

There are several types of wick structures available including: grooves, screen, cables/fibers, and sintered powder metal. Figure 3 shows several heat pipe wick structures. It is important to select the proper wick structure for a particular application.

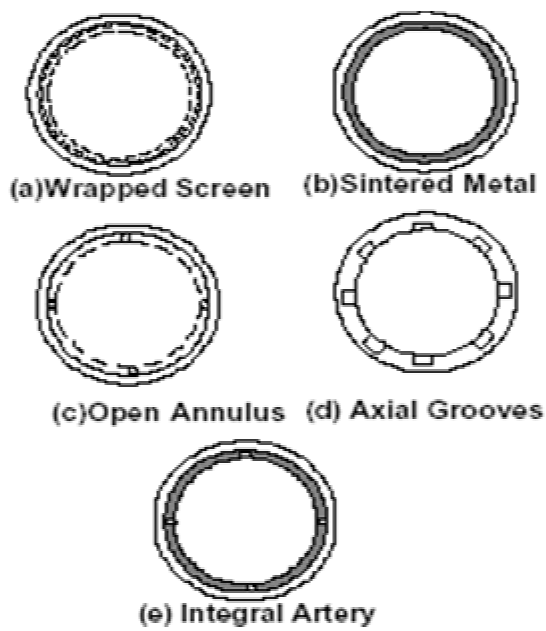

Figure 3 Wick Structures

Different types of wick structure are listed here.

1. SINTERD POWDER

2. GROOVED TUBE
3. SCREEN MESH
4. SINGLE - LAYER WICK
5. TWO- LAYER WICK
6. ARTERY WICK
7. VARIABLE THICKNESS WICK

Thermal Conductivity of Heat Pipe and its Comparison with Solid Copper Material

Heat pipes do not have a fix value of thermal conductivity like sold material. Thermal conductivity depends upon dimensions, type of working fluid, wick structure etc. Normally solid material have constant thermal conductivity for a particular temperature but it is not so in case of heat pipes. Thermal conductivity of heat pipe varies with amount of power being transferred and evaporator and condenser sizes. For a well designed heat pipe, effective thermal conductivity can range from 10 times to 10000 times that of solid copper for same dimensions. For a particular heat duty the same is explained with an example here.

Example: Compare heat transfer capacity of heat pipe and solar copper rod for temperature difference of 100 ^{o}C and a length of 8 cm.

Heat transfer in copper rod:

$$q/A = -k\left(\Delta T/\Delta x\right)$$

Substituting k as 374 W/m^{o}C, ΔT 100 ^{o}C and Δx as 8 cm

$$q/A = 0.04675\ kW/cm^2$$

While the same for the copper heat pipe is $q/A = 0.67\ kW/cm^2$

Thus heat capacity of heat pipe is 14 times higher than solid copper rod of similar diameter for similar heat duty.

Cost of Heat Pipe

Compared to less effective methods of heat transfer such as aluminum fins and casted heat sinks, heat pipes are expensive, especially in small quantities. In applications where cooling requirements can be met by simple conductive heat sinks, heat pipes are not recommended. In more demanding applications, however, the cost of heat pipes is competitive with other alternatives. The cost of heat pipes is also partially offset by the improvement in system reliability and the increased life of the system. In high quantity applications, the cost of heat pipes drops significantly and often provides the most economical solution to many cooling applications. Also when energy saving is a prime objective cost of heat pipe plays minimum role.

Selection of Heat Pipe

Selection of heat pipe depends upon more than one parameter and they are listed below:

1. Type and dimensions of heat source.
2. Distance between heat source and heat sink.
3. Type and dimensions of heat sink.
4. Temperature range of heat source, heat sink and ambient temperature.

Based on above mentioned criteria selection of a heat pipe with suitable pipe material, wick structure and working fluid is carried out.

Some images of heat pipe based applications are shown in figure 4 to 7. Thus heat pipe is very promising device to enhance heat transfer process and very useful in waste heat recovery applications.

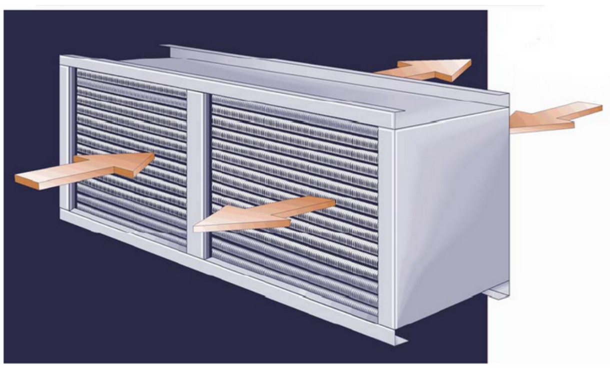

Figure 4 Heat Exchanger for waste heat recovery

Figure 5 heat pipe for electronic component

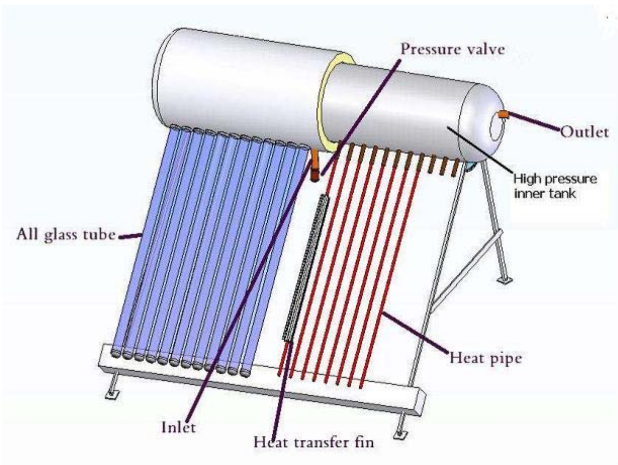

Figure 6 Heat pipe in Solar water heating

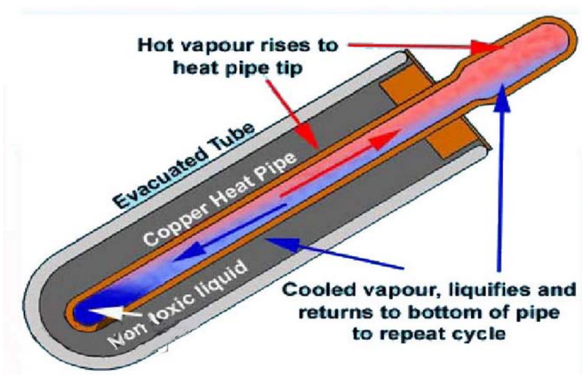

Figure 7 heat pipe for solar application