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A Review of Heat Pipes: its Types and Applications

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***Abstract*:- Heat pipe is also referred as superconductor of heat as it possesses excellent heat transfer and heat extraction capability. Gravitational and capillary forces play a significant role in deciding the overall performance of heat pipe because at every different tilt angle, the resultant of these two forces varies, so thus performance varies. This study also illuminates the aspect of thermosyphon, its working and effect of gravity. Moreover, different types of heat pipes are discussed such as micro heat pipe (M.H.P.), loop heat pipe (L.H.P.) and variable conductance heat pipe (V.C.H.P). With the addition of nanoparticles inside the base working fluid the thermal resistance of heat pipe decreases and thermal performance increases.**

Keywords— Heat pipe; thermosyphon; nanoparticles; thermal resistance; thermal performance.

I. INTRODUCTION

Evolution of heat, which is sometimes undesired, is common now a days. When we work on electronic equipment there is generation of heat, which needs to be dissipated. So there is need of a device which needs to loft the heat and makes the system work efficiently. So heat pipe is one of the best solution which will be used widely to solve heat dissipation problem. Heat pipe was invented in 1936 by Jacob Perkins. The first capillary driven heat pipe was patented by Richard Gaugler of General Motors in 1945 and was independently rediscovered in 1963 by George Grover at Los Alamos National Laboratory. Heat pipe are also known as superconductor of heat as they are best in heat handling abilities with minimum heat loss. Heat pipe consist of sealed container with wick lined on internal walls. Heat pipe is categorized by 3 sections that is

1) Evaporator section
2) Adiabatic section
3) Condenser section.

At heat source on evaporator section, heat pipe working fluid evaporates and it travels through sealed internal passage towards the condenser end due to pressure difference. At condenser end it releases its latent heat of condensation and then travels back to evaporator section through wick with the help of capillary action. Heat pipe is similar to thermosyphon in some aspect. The key difference is that heat pipe consists of wick which helps in returning of condensate back to evaporator section but thermosyphon does not. The container material, the working fluid and wick material are three essential components which are used in the manufacturing of heat pipe. Heat pipe are used in die casting and injection moulding, space applications which includes isothermalisation of satellites, solar water heaters, snow melting and de-icing, cooling of electronic components, internal combustion engines. Figure 1.1 shows schematic of heat pipe.

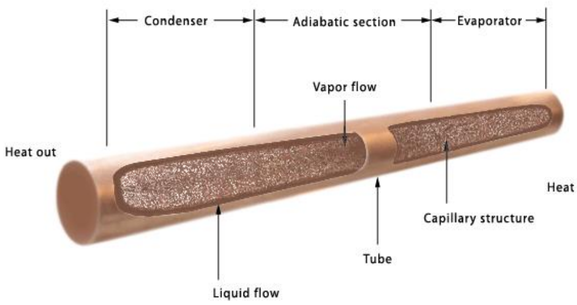

Figure 1.1 A schematic of heat pipe

II. HEAT PIPE: IT'S TYPES AND APPLICATIONS

Nuntaphan et al. [1] found that the enhancement of fin efficiency is done by replacing solid wire fin by oscillating heat pipe under forced convection. The unit was tested in a wind tunnel which acts as a duct by exchanging heat between hot water flowing inside the tube and the air stream flowing across the extended surface. Heat transfer between tube and solid wire fin was by conduction only but with oscillating heat pipe it was due to conduction and convection. Thus, heat transfer increased. Findings were that effectiveness of heat exchanger increases by 10 % and fin efficiency was higher than 5 %.

Noie et al. [2] examined the effect of inclination angle and filling ratio on thermal performance of two phase closed thermosyphon. The copper thermosyphon with distilled water working fluid of outer diameter 16 mm, inner diameter 14.5 mm and length 1000 mm was taken into consideration. Filling ratio is described as ratio of volume of working fluid to the volume of evaporator section. Filling ratio of 15 %, 22 %, 30 % was taken into consideration. They concluded that condensation heat transfer coefficient and heat transfer rate increase as filling ratio increases. The maximum condensation heat transfer coefficient for filling ratio = 22 % and filling ratio = 30 % takes place at 30° inclination and at 45° for filling ratio =15 %.

Teng et al. [3] examined the thermal efficiency of heat pipe with alumina nanofluid and considered alumina nanofluid which was produced by direct synthesis method having three different concentrations 0.5%, 1% and 3% by weight. The experiment was performed on heat pipe which was a straight copper tube with inner diameter 8 mm and length of 600 mm. At the concentration of 1 weight % the optimum value of thermal efficiency enhanced by 16.8 % when compared to base fluid.

Idrus et al. [4] reported that under his investigation, a copper water heat pipe of length 300 mm and outer diameter 10 mm was taken into consideration with K-type thermocouple attached over the surface of heat pipe. At various heat inputs and inclination angle, performance of heat pipe was investigated and analyzed. The diameter 10 mm heat pipe performs with good thermal performance at heat input of 70 W – 80 W and at inclination angle ranging between 30° to 60°.

Kang et al. [5] examined thermal performance of heat pipe with silver nanofluid of 35 nm diameter. The length of heat pipe used in this investigation is 200 mm and with outer diameter of 6 mm. Nanoparticles concentration ranges from 1 mg/l to 100 mg/l. A heat sink was connected to condenser section of heat pipe. Condenser section was cooled by water supplied. As the concentration and particle size of silver nanoparticle was increased, the thermal resistance decreases. With greater silver nano particles dispersed in working fluid, the increase in heat pipe wall temperature was smaller than that for pure water filled heat pipe under different heat loads.

Plawsky et al. [6] reported heat pipe comprises of sealed container with wick present on the inner walls. Heat pipe is made up of three sections that is evaporator section, adiabatic section and condenser section. As the heat source is applied on the evaporator section, the working fluid evaporates and travels to the condenser section where it releases its latent heat and condensate travels back with the help of capillary action through wick lined on the internal wall of container. Wicks assist in returning the condensate back to heated end. Effective wick structure is vital key to good performance of heat pipe. Among various technologies available today, heat pipes are considered to be best efficient heat transfer device. It can easily transfer heat through long distances. It is mainly used in the cooling of electronic components, since they can eliminate heat from limited volumes to environment.

Jose et al. [7] stated that Loop heat pipes are used extensively because of their high efficiency and compact size. Nanofluid have proved to be of great importance for thermal performance of heat pipe. Loop heat pipe operates on multiphase fluid flow cycle. Loop heat pipe comprises of following advantages:

1. High heat flux capability
2. Transfer of energy to long distances
3. Ability to operate over range of environments
4. Entrainment possibility is very low.

Loop heat pipes can be used in thermoelectric generators, LED street lights, for heat dissipation, solar water heaters, space application. Thermal management of electronic components, cryogenics, photovoltaic, cooling of electronic components. It was observed that thermal resistance of loop heat pipe decreases with increase in nanoparticle concentration and moreover thermal efficiency of loop heat pipe can be improved by making use of nanofluid.

Huminic et al. [8] carried out a thermosyphon heat pipe which was taken into consideration and comparison of heat transfer rate of thermosyphon was made with nanofluid and with DI-water. The iron oxide nano particle were obtained by laser pyrolysis technique having concentration of 0 %, 2 % and 5.3 %. Thermosyphon are passive heat transfer devices with high value of thermal conductivity. The thermosyphon heat pipe is divided into three sections which are evaporator (which is located near the heat source), condenser section (which is at the heat sink), adiabatic (which is between the above two). Thermosyphon is similar to heat pipe, but it is wickless heat pipe. Thermal input at the evaporator section vaporizes the working fluid and as a result of pressure difference vapors travels through sealed passage to the condenser end where it condenses and releases latent heat of condensation. In thermosyphon, evaporator is located vertically below the condenser, thus gravity will ensure the condensate return back to the evaporator. Comparing with the water thermosyphon heat pipe, there is substantial increase of heat transfer rate were observed in case of thermosyphon heat pipe filled with different concentration level of iron oxide nanoparticle. The presence of 2 % iron oxide nanoparticle increases the heat transfer rate by 19 % and 5.3 % iron oxide nanoparticles increases the heat transfer rate by 22.2 %. It was also observed that increasing nanoparticle concentration decreases the thermosyphon heat pipe thermal resistance, thus providing a better performance.

Han et al. [9] reported that pulsating heat pipes are considered to be one of the most widely used heat transfer devices due to its obvious advantages such as simple structure, low cost, excellent heat transfer capability, and high flexibility. Pulsating heat pipes (P.H.P.) are also coined as oscillating heat pipe and it was proposed by Akachi in 1990. It comprises of long capillary tube which is bent into many turns. Its manufacturing is quite easy as it comprises of no wick structure. Low cost of P.H.P. is because of its small diameter as it results in cost saving. Geometrical parameters that influence P.H.P. are inner diameter, cross section shape and channel configuration and number of turns. P.H.P. is found to have wide variety of application; may it be solar water heater. Arab et al developed a new solar water heater which was combined with two P.H.P.'s. For each P.H.P., the condenser section was put in water tank and evaporator section was placed in collector. The length of adiabatic section varied with position. It was found that the highest efficiency was reported as 53.79 %. Other applications include electronic cooling, heat recovery devices, aerospace thermal management and electron cooling.

Chan et al. [10] studied that surface tension is considered to be the important property for selection of working fluid. Higher the surface tension, higher will be the capillary effect and it must be chemically stable in the presence of wick. According to temperature ranges, heat pipes are categorized into four categories

1. >700 K working fluids such as liquid metal.
2. 550-700 K Long carbon chain organic fluids such as naphthalene and biphenyl
3. 200-550 K water, ammonia, and short carbon chain organic fluid such as methanol, ethanol and acetone.
4. 1-200 K noble gases, oxygen, nitrogen

Author also discussed various type of heat pipe

1. Variable conductance heat pipe: V.C.H.P. comprised of a reservoir of inert non-condensable gas attached to the condenser. V.C.H.P. operates in wider ranges of heat fluxes and temperature gradients.
2. Thermosyphons: They transfer heat in the same way as heat pipe, but it lacks the wick structure. As a result of the above, the condenser section is placed above the evaporator section in order to return the condensate with effect of gravity.
3. Micro heat pipe: M.H.P. uses sharp corners inherent in its non-circular design instead of wick as it provides capillary pressure for working fluid. The circulation of working fluid depends mainly on sharpness and quantity of sharp angled corners.
4. Loop heat pipe: It is also known as capillary pump loop (C.P.L.). It comprises of evaporator, a compensation chamber, a condenser and vapor and liquid transfer lines. The compensation chamber stores excess liquid and act as a precautionary measure against evaporator dry out

Hudakorn et al. [11] examined the effect of oscillating heat pipe orientation on its overall performance. The heat pipe used in the experiment was constructed with Pyrex glass tube having inner width 1mm and evaporator length 50 mm respectively. The numbers of turns in the heat pipe are 10. All the 3 sections of heat pipe are of same length. The working fluid used in the heat pipe was R123 with FR 50 %. It was derived from the results that at horizontal position of heat pipe the dry out of evaporator follows due to insufficient condensed liquid film. When the tilt angle was raised from horizontal position to vertical position, performance limit arises due to flooding of evaporator section. The author then performed another second set of experiment known as quantitative study in which oscillating heat pipes were made up of copper tubes instead of pyrex glass with inner diameters comprising of 0.66 mm, 1.06 mm and 2.03 mm respectively. The number of turns were kept same but evaporator section length was made different i.e.50 mm, 100 mm and 150 mm. It was found that for all different tilt angles, critical heat flux is inversely proportional to evaporator length and directly to internal diameter of heat pipe.

Grooten et al. [12] used large length-to-diameter ratio thermosyphons having R-134a as working fluids to conduct experiments to analyses the consequences of saturation temperature, inclination angle, filling ratio on the limiting operational heat flux. It was examined that the thermosyphon performs well under inclination angle of 83°. The heat pipe filling ratio was not critical over the values of 25 %. It was concluded that by increasing the saturation temperature and by decreasing the inclination angle, the operation limiting heat flux reduces. Inclination angles greater than 83° is not recommended for efficient working of heat pipe.

Riehl et al. [13] studied the application of water-copper nanofluid in an open loop pulsating heat pipe. An open loop pulsating heat pipe was used with water-copper nanofluid having addition of 5 % by mass of Cu nanoparticles. The author noticed improvements on the overall device operation while using the nanofluid with lower temperatures. As more bubbles were formed, so more intensive pulsations were noticed during the P.H.P. operation, which results in more presence of vapour in the channels. Thus, higher thermal conductances were noticed when compared with pulsating heat pipe operation having pure water as working fluid.

Senthilkumar et al. [14] studied the behavior of heat pipe at various orientations operated on aqueous solution of n-pentanol. A comparison test was conducted between heat pipe working with water and with n-pentanol as working fluids at different tilt angles. The result showed superior performance of heat pipe when working on n-pentanol fluid due the fact that the aqueous solution has the positive gradient of surface tension with respect to temperature. There are some disadvantages of using water as working fluid in spite of the fact that it is most widely used working fluid in order to eradicate those limitations, the working fluid water can be substituted with a dilute aqueous solution of n-pentanol. Due to high capillary limit and boiling limit of using n-pentanol which makes heat pipe suitable for large heat load applications.

Moraveji et al. [15] examined the thermal performance of heat pipe by using aluminum oxide nano particle having diameter 35nm. A heat made of cooper with varied length was taken having sintered wick structure. Tested concentrations of nano fluids were 0 %, 1 % and 3 % by weight. The result obtained with heat pipe charged with pure water were compared. The results show that with increase in heat input the wall temperature increases, the wall temperature of heat pipe with nano fluid was low as compare to the heat pipe charged with pure water, moreover wall temperature decreased higher nanoparticle concentration also with increased nanoparticle concentration, the temperature differences decreases. Results shows that the nanofluid heat pipe has lower thermal resistance then that of water heat pipe.

Ghanbarpour et al. [16] examined the outcome of increasing and then decreasing heat input on the performance of heat pipe. A copper heat pipe was taken with 6.35mm outer diameter and 200 mm length. It comprises of screen mesh wick structure and having alumina nanoparticle with different mass concentration of 5 % and 10 %. The result concluded that with 5 % concentration heat pipe performance was improved with variable heat input and when 10 % concentration was used performance of heat pipe was deteriorated.

III. CONCLUSION

From the cited literature, it has been concluded that heat pipe having very high thermal conductivity is considered as one of the best devices in solving heat dissipation problems. The thermal performance of heat pipe increases with addition of nanoparticles in base fluid. Moreover, the thermal resistance decreases as the concentration of nanoparticles varies. Due to modernization and miniaturization of equipment, heat pipe can be equipped with those spaces where there are limited volume constraints, thus making it one of the most widely used heat dissipation device.

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