Experimental Investigation of Cross Flow Heat Pipe Hydraulic Oil Cooler

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Abstract - The Hydraulic oil cooler come equipped with the heat pipe cores that have a shroud with fans and other brackets and braces to secure the components into the reservoir. In application, one half of the Hydraulic oil cooler heat pipe "core" is placed in the overheating reservoir which insures that the returning oil, usually the system's hottest oil/fluid, flows over the heat pipes. The working fluid in the heat pipes respond to the application of heat by boiling, changing into a gaseous state, and transporting the heated gas to the pipe ends exposed to air. Ambient air is drawn over the exposed pipes, causing the working fluid to condense and return to the heat source (the overheating oil) to repeat the process. This is passive and efficient heat removal. As long as there is a temperature difference between the oil and the ambient air, the pipes will remove heat from the oil, thus cooling it down. It is the phase change that provides the mechanism by which heat is "removed" from one medium to another. In the case of Hydraulic oil coolers – heat is removed from oil into the ambient air

Keywords – Heat pipe, Condensation, Evaporation, Pump, Blower

I. INTRODUCTION

Due to the human need for energy, a more efficient way of using it is a major challenge in the scientific community. The thermal performance of heat pipe is one the most important part of these types of investigation in the field of heat transfer. Heat pipes are enclosed, passive two phase heat transfer devices. They make use of the highly efficient heat transport process of evaporation and condensation to maximize the thermal conductance between a heat source and a heat sink. They are often referred to as thermal superconductors because they can transfer large amounts of heat over relatively large distances with small temperature differences between the heat source and heat sink. The amount of heat that can be transported by these devices is normally several orders of magnitude greater than pure conduction through a solid metal. They are proven to be very effective, low cost and reliable heat transfer devices for applications in many thermal management and heat recovery systems. They are used in many applications including but not limited to passive ground/road anti-freezing, baking ovens, heat exchangers in waste heat recovery applications, water heaters and solar energy systems and are showing some promise in high-performance electronics thermal management for situations which are orientation specific. [1]

Thermal energy devices such as heat pipes and thermosyphon possess many advantages such as high heat recovery effectiveness, high compactness, no moving parts, and high reliability. Since the 1970s, heat pipes and thermosyphon have been extensively applied as waste heat recovery systems in many industries such as energy engineering, chemical engineering, and metallurgical engineering. The heat pipe has been, and currently is being, studied for a wide variety of applications, Covering almost the complete spectrum of temperatures encountered in heat transfer processes. The ability of the heat pipe to transport heat over appreciable distances without any need for external power to circulate the heat transfer fluid is one of its most useful properties. Elimination of the fluid pump and power supply leads to greater reliability of the heat transport system and reduced weight, in addition to the saving in power consumption (Silverstein 1992).

Heat pipes and thermosyphon have the following unique characteristics:

1. High heat transport capability due to latent heat
2. Small temperature variations
3. The ability to act as a heat flux transformer
4. Heat transfer in one direction only (thermal diodes and switches)
5. Passive heat transfer device
6. Separation of heating (heat source) and cooling (heat sink) parts
7. Heat transport capability through long distance
8. Constant temperature control (variable conductance heat pipe)
9. Heat transport with low temperature drop between heat source and sink.

Heat pipes and thermosyphon have the ability to transport very large quantities of heat with small temperature differences over relatively long distances. The applications of heat pipes and thermosyphon require heat sources for heating and heat sinks for cooling. The original development of the heat pipe and thermosyphon was directed towards space applications. The recent emphasis on energy conservation has promoted the use of the heat pipe and thermosyphon as a component in terrestrial heat recovery units and solar energy utilizations. For a thermosyphon the thermal resistance is smaller, the operating limits are 1-9 wider (as in a heat pipe the integrity of the wick material might not hold at very high temperatures), and the fabrication cost is lower than that of the capillary heat pipe, which makes a thermosyphon a better heat recovery thermal device. Primarily, the most important aspect of the thermosyphon is that it can easily be turned off when required, whereas a heat pipe cannot be turned off. This added safety feature of a thermosyphon makes licensing of the NGNP process heat transfer system comparatively easier. The results of research and development on heat pipes and thermosyphon over the past 60 years were well documented. Heat pipes are classified according to operating temperature ranges, as follows (Reay 2006):

1. Cryogenic heat pipes, T <200 K
2. Low temperature, 200<T<550 K
3. Medium temperature, 500<T<750 K
4. High temperature, 750<T<2800 K.

The physical size and configuration of heat pipes and thermosyphon can vary widely. Thermosyphon have become a unique and versatile heat transfer devices with a seemingly unlimited range of applications. Examples of these applications are presented, but technical details are not included.

II. LITERATURE REVIEW

Initially Grover was interested in the development of high temperature heat pipes, employing liquid metal working fluids, suitable for supplying heat to the emitters of thermionic electrical generators and removing heat from the collectors of these devices.

This application is described shortly after Grover's publication; work was started on liquid metal heat pipes by Dunn at Harwell and Neu and Busse at Ispra where both establishments were developing nuclear-powered thermionic generators. Interest in the heat pipe concept developed rapidly both for space and terrestrial applications, Work was carried out on many working fluids including metals, water, ammonia, acetone, alcohol, nitrogen and helium.[1]

At the same time the theory of heat pipe become well understood. The most important contribution to this theoretical understanding was by Cotter in 1965. By following Grover's first paper in 1964 many researchers comes into picture.

The III International conference on Heat pipe, held in 1978 at Palo Alto, California, was sponsored by the American Institute of Aeronautics and astronautics. Sixty five papers included in the conference noticeably papers on 'gravity-assisted heat pipe' was becoming popular as a description of units operating with the evaporator located below the condenser, while retaining some forms of wick structure. Many Heat pipe are strictly called thermosyphon, as they do not possess capillary or other means for transporting liquid internally.[6]

The VI International Heat pipe conference was held in 1981 in London. The proceedings contain almost 70 papers, and of particular note is the contribution made to heat pipe technology , basically the dissociation were held on working fluid used in Heat pipe. [2]

VII International Heat pipe conference Held in Minsk, Byelorussia in 1990 in which 90 papers were published. The basic interest of this conference is on factors affecting performance of heat pipe.[1]

It was appropriate that the X International Heat pipe conference returned to Stuttgart in 1997, 24 years after the first conference. The XII conference, in Moscow in 2009,are indicative of the growth worldwide in research, development and application of heat pipe and some of the less conventional derivatives. By The early twenty-first century, the heat pipe is a mass-produced item necessary in 'consumers electronics' products such as computers, laptops that are made by the tens of millions per annum. [1]

III. HEAT PIPE AND THERMOSYPHON GEOMETRY AND WORKING PRINCIPLES

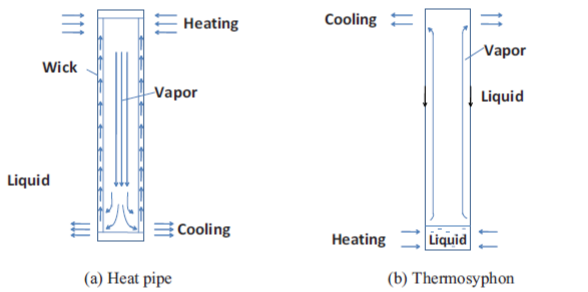

Figure 1: Two-Phase Closed Thermosyphon and Heat Pipe [9]

A cross section of a closed two-phase thermosyphon is illustrated in Fig. 1. The thermosyphon consists of an evacuated sealed tube that contains a small amount of liquid. The heat applied at the evaporator section is conducted across the pipe wall causing the liquid in the thermosyphon to boil in the liquid pool region and evaporate and/or boil in the film region. In this way the working fluid absorbs the applied heat load converting it to latent heat. The vapour in the evaporator zone is at a higher pressure than in the condenser section causing the vapour to flow upward. In the cooler condenser region the vapour condenses thus releasing the latent heat that was absorbed in the evaporator section. The heat then conducts across the thin liquid film and exits the thermosyphon through the tube wall and into the external environment. Within the tube, the flow circuit is completed by the liquid being forced by gravity back to the evaporator section in the form of a thin liquid film. As the thermosyphon relies on gravity to pump the liquid back to the evaporator section, it cannot operate at inclinations close to the horizontal position. A traditional heat pipe is a hollow pipe under vacuum filled with vaporizable liquid. The heat pipe functions are as follows

i. Latent heat of evaporation is absorbed in the evaporating section.

ii. The fluid boils to the vapour phase.

iii. The vapour release latent heat of condensation to the environment from the upper part of the pipe and condensers.

iv. Condensed liquid returns by the capillary action to the evaporator part of cylinder (evaporating section). When heat is added to the evaporator section, the working fluid boils and converts into vapour absorbing latent heat. After reaching the condenser section, due to partial pressure build up, the vapour transform back into the 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.

IV. SELECTION OF HEAT PIPE

Heat pipes are being used very often in particular applications when conventional cooling methods are not suitable. Fig 1(a) shows the basic components of heat pipe

- Container
- Working fluid
- Wick structure

1. Container

The function of container is to isolate the working fluid from the outside environment. It has to therefore leak proof, maintain the pressure differential across its wall, and enable transfer of heat to takes place from and into the working fluid. Selection of the container material depends on many factors

- compatibility with working fluid
- strength weight ratio
- thermal conductivity
- porosity
- wettability

2. Working Fluid

A first consideration in the identification of a suitable working fluid is the operating vapour temperature range. Within the approximate temperature band, several possible fluids may exist, and a verity of characteristics must be examined in order to determine the most acceptable of these fluids for application considered.

- Compatibility with wick and wall material
- thermal stability
- wettability
- vapour pressure not too high or not too low over the operating range
- high latent heat
- low liquid and vapour viscosities

3. Wick or Capillary Structure

To transport the working fluid from the condenser back to the evaporator, a wick structure is incorporated in the heat pipes top and bottom layer. As transport is based on capillary effects, the effective radius of the structure should be small. This causes a higher pressure difference across the heat pipe. However, the radius should not be too small, as this causes a low permeability of the wick due to frictional effect.

Table 1: Comparison of wicking structure [9]

Wicking Material	Conductivity	Overcome Gravity	Thermal Resistance	Stability	Conductivity Lost
Axial Groove	Good	Poor	Low	Good	Average
Screen Mesh	Average	Average	Average	Average	Average
Fine Fiber	Poor	Good	High	Poor	Average
Sintering	Average	Excellent	High	Average	High

V. PROPOSED SOLUTION: HEAT PIPE ENHANCED CROSS FLOW HYDRAULIC OIL COOLER

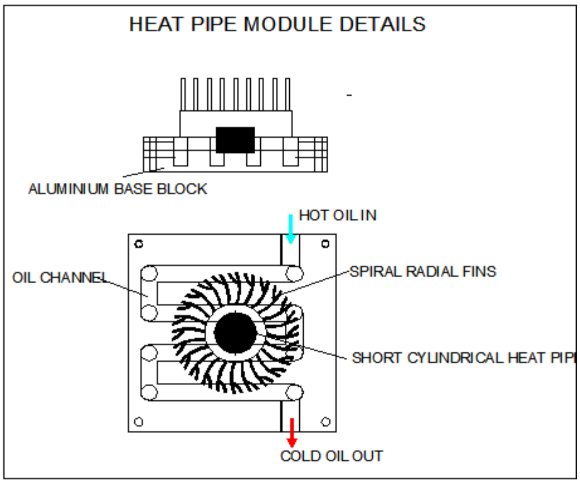

Figure 2: Experimental setup

The heat pipe module comprises of a base aluminium block with oil channels machined on the top face of the block, and then sealed by top plate. The heat pipe used to transfer the heat from the hot oil to the fins is press fitted in the cavity of the aluminium block. The heat pipe evaporator section is in direct contact with hot oil where as the condenser section of the heat pipe is fitted in the circular cavity in the spiral radial fin structure.

The heat pipe used in the module has following specifications:

a) Type: Short cylindrical heat pipe
b) Material: Copper
c) Working fluid: Water
d) Wick structure: Sintered copper

TABLE 1: GENERAL EXPERIMENTAL SETUP DESCRIPTION

Component		**Specification**
Tube Material		Copper
Diameter (mm)	Internal	26
	External	32
Dimensions (mm)	Total	12
	Evaporator	6
	Condenser	6
Working Fluid		DI Water
Heat Input (W)		for Distilled Water
Condenser Fluid flow rate (kg/s)		10
Research technique		Heat transfer enhancement Techniques

The spiral radial heat fins act as heat transfer enhancement as they offer maximum surface area in the given space. The concept of the heat pipe enhanced cross flow hydraulic cooler is oil to air cooler that uses four heat pipe modules with a radial blower system. The radial blower is 12 volt DC blower that takes cold air in the system axial and discharges it in radial direction. This cold air is then directed on to the spiral radial fins mounted on the four heat pipe modules. The oil cooler takes in hot oil with help, of hydraulic pump where as the cold oil from the oil cooler is discharged back to the oil tank. The oil cooler can be mounted externally to the oil tank system thereby ensuring contamination free operation as the oil tank is sealed. The enhanced heat pipe cross flow hydraulic oil cooler uses four individual heat pipe modules which are connected in parallel and the output oil from each module is then directed back to the oil tank after it is cooled.

VI. RESULT AND DISCUSSION

Oil coolers cooling capacity changes due to oil flow rate fig 5.1 demonstrates changing oil cooler cooling capacity with oil inlet temperature and mass flow rate of oil.

Increasing inlet temperature of fluid from 80˚C to 90˚C can enhance Nusselt number up to 4%.

Comparing experimental result with well-known empirical correlations it demonstrated that Churchill and Bernstein correlation has 12.23% average error.

Increase in mass flow rate of fluid circulating in devices temperature difference decreases slightly about 4.55%.

VII. ADVANTAGES

i) High efficiency.
ii) Simple construction.
iii) High heat recovery effectiveness.
iv) Compactness.
v) No moving parts.
vi) High reliability.
vii) No external power requirement.
viii) Economical to manufacture.

VIII. CONCLUSION

Heat pipe are effective heat transfer device which have found many application in industry. Heat pipes are passive devices that transport heat from a heat source (evaporator) to heat sink (condenser) over relatively long distance via latent heat of vaporization of working fluid.

With evaporator section, the working fluid is evaporated as it absorbs an amount of heat equivalent to the latent heat of vaporization, while in the condenser section; the working fluid vapour of condensed. Return of liquid to the evaporator from the condenser is provided by the wick structure.

Heat pipe is capable to transform more heat in comparison to simple copper rod. By the application of heat pipe way cooling of oil is more effective than conventional technique of using simple fan over pipes inside which hot oil is flowing.

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