Study of heat transfer rate of distilled water as refrigerant by using Thermosyphon Heat Pipe

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Abstract:

This article is about to find the heat transfer rate of distilled water which can be use as refrigerant in cooling systems. The process described in this article is helpful to find heat transfer rates of various refrigerants by replacing distilled water with any refrigerant whose heat transfer rate need to know.Heat pipe is a device that employs an evaporation mode of heat transfer in the evaporator section and the condensation mode in the condenser section to convey heat. The liquid flow from the condenser to the evaporator section could be produced by the gravitational force, capillary force, or other external forces that directly acting on the fluid (i.e. electrostatic force). On the other hand, the vapour flow from the evaporator to the condenser section is caused by the vapour pressure difference between these two sections

Keyword: Thermocyphone Heat Pipe, Distilled Water, Heat Transfer Rate

INTRODUCTION

Heat transfer and energy supply play a major role in various industries including transportation, air conditioning, power generation, nuclear plants, electronic devices etc. The modification of the surfaces of heat exchangers as well as use of high performance working fluids were among many techniques implemented for enhancing the overall performance of the heat exchangers.[1].Generally, the heat transfer coefficient of an air cooled system (single phase) is lower than the liquid cooled systems (single phase) due to the latter's superior thermal properties. Similarly, the heat transfer coefficient of single phase forced convective heat transfer is higher than the single phase free convection heat transfer. Hence the two phase cooling process is preferred wherever possible. However, the application of two phase cooling method is limited due to the space constraints and compatibility of the working fluids with the electronic component materials compared to those working fluids used in the immersed cooling method. In the immersed cooling method, the electronic components are directly immersed in a dielectric fluid and the boiling occurs at the surface of the electronic components.

The introduction of heat pipe was first conceived by Gaugler in 1942, of the General Motors Corporation. When he was working on refrigeration problem, he envisioned a device which would evaporate a liquid at a point above the place where condensation would occur without requiring any additional work to move the liquid to higher elevation. His device consisted of a closed tube in which the liquid would absorb heat at one location causing the liquid to evaporate.Thevapour would then travel down the length of the tube where it would recondenseand release its latent heat. It would then travel back up the tube by capillary pressure to start the process over. This concept again surfaced in 1952 in connection with the space program of NASA.

Large quantities of energy are directly discharged into environment as forms of waste heat during industrial processes without any recycle. Therefore, recovery and utilization of industrial waste heat is of substantial importance for energy saving and emission reduction.

Heat Pipe

Heat Pipe is a thermal super Conductor works under certain heat transfer conditions as they can transfer heat energy 100 times more than conventional sources like Heater, Heat exchanger, etc. because of Negligible temperature gradient exist in Heat pipe.

Heat pipe has Compactness, Light Weight, Reversible in operation and High Thermal Flux handling capability makes heat pipe to use new modern era and in many wide variety application to overcome critical heat Dissipation problem.

Heat pipe research and development activity have experienced a slow but steady progress. Heat pipes have been developed covering an enormous range of operating temperatures, from about 2 K with Helium (He) as the working fluid to about 2200 K with Aragon (Ag) as the working fluid and geometries, tubular devices about 1 mm in diameter and several millimeters long containing several milligrams of working fluid, large tubes with diameters up to 300 mm or lengths over 100 m, very complex shaped heat pipe chambers. Today, heat pipes and wickless heat pipes (two phase closed thermo syphon) are established highly efficient thermal elements, which are applied in many areas, both in space and on earth.

.Closed loop Thermosyphon heat pipe is a type of heat pipe but without wick structure. A Thermosyphon comes under the category of heat pipes but it is different from a wicked heat pipe. In a wicked heat pipe the working fluid returns to the evaporator from the condenser by capillary forces.

A Thermosyphon is a gravity assisted wickless heat pipe charged with water for transferring the heat from source to sink by using latent heat of evaporation. Large quantity of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces. If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and loss minimized.Depending upon the type of process, waste heat can be rejected at virtually any temperature from that of chilled cooling water to high temperature waste gases from an industrial furnace or kiln. Usually higher the temperature, higher the quality and more cost effective is the heat recovery. In any study of waste heat recovery, it is absolutely necessary that there should be some use for the recovered heat. Typical examples of use would be preheating of combustion air, space heating, or pre-heating boiler feed water or process water. With high temperature heat recovery, a cascade system of waste heat recovery may be practiced to ensure that the maximum amount of heat is recovered at the highest potential. An example of this technique of waste heat recovery would be where the high temperature stage was used for air pre-heating and the low temperature stage used for process feed water heating or steam raising. In any heat recovery situation it is essential to know the amount of heat recoverable and also how it can be used.

Experimentation

An experimental setup has been built to studyperformance of heat pipe and two phase thermosyphon heat pipe charged with aluminium oxide (Al_2O_3). The fabrication procedure for heat pipes, experimental setup and testing procedures are presented in this chapter.

Selection of geometry and specification

The copper circular section geometry pipe with outer diameter (OD) 25.4 mm and inner diameter (ID) 22.4 mm was selected because in most of the applications this diameter is commonly used for present application of compact Heat Pipe Heat Exchanger (HPHE) for oil coolers of heat duty 10 kW and the selection is appropriate. The elliptical cross section geometry is achieved by pressing the circular section pipe using special dies. The elliptical section was designed for eccentricity of 0.75, because decreasing the eccentricity, the tube becomes flatter and approaches towards the flat cross section. The final dimensions of elliptical section were decided as major axis 30 mm, minor axis 19 mm and thickness of the tube 1.5 mm.

A wickless heat pipe capable of transferring heat of 850 W at a vapour temperature between 20 ^{0}C and 80 ^{0}C over a distance of 800 mm was selected for experimentation. The mass flow rates at evaporator and condenser section was considered to be constant. Therefore the length of evaporator, adiabatic and condenser section was taken as 350 mm, 100 mm and 350 mm respectively. The specifications of circular and elliptical cross section geometry are given in Table

Container Material	Copper
Cooling jacket Material	Stainless steel
Geometry	O.D.=20mm I.D.=19mm Cooling jacket Diameter= 40mm
Total length of pipe (L)	500mm
Length of evaporator section (Le)	125mm
Length of adiabatic section (La)	125mm
Length of condenser section (Lc)	250mm

Table 1. Specification of Thermosyphon heat pipeand heat pipe

A copper tube of 500 mm long and outer diameter of 20 mm is taken and both ends are sealed with end caps. One end cap carries the filling tube for charging the working fluid. One end cap carries the filling tube for charging the working fluid. This copper tube is also maintained at vacuum condition (10-4 mbar) using a vacuum pumping system (Figure 3.1) for up to 8 hours and the working fluid is injected through a capillary tube by adjusting the control valve. The heat pipe is charged with 17 ml of working fluid in order to completely saturate the wick structure. The capillary tube is then crimped and sealed. The evaporator, adiabatic and condenser sections have lengths of 125 mm, 125 mm, and 250 mm respectively. The heat leak is eliminated in the adiabatic section by glass wool insulation.

The fabrication procedure for thermosyphon is the same as that of heat pipe. However, there is no wick structure present in the thermosyphon. An copper tube with total length of 500 mm is taken and both ends are sealed with end caps. One end cap carries the filling tube for charging the working fluid. This metal tube is also maintained at vacuum condition using a vacuum pumping system (Figure 3.1) up to 8 hours and a working fluid is injected through a capillary tube by adjusting the valve. The thermosyphon is charged with 22 ml of working fluid. In this study, acetone is used as the working fluid (Reay, 2006). Then the capillary tube is crimped and sealed.

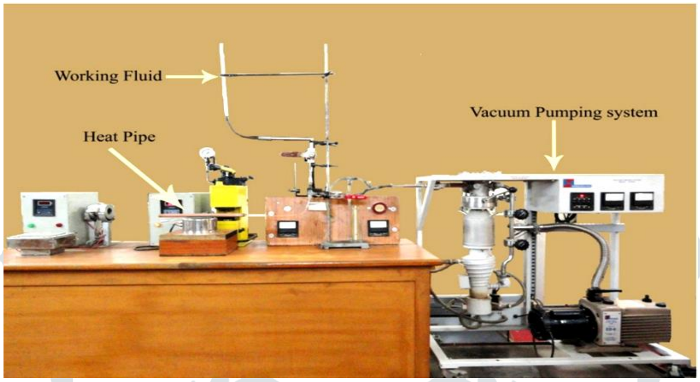

Figure 1. Vacuum pumping and charging of heat Pipe

The selection of working fluid

The prime requirements are:

(i) Compatibility with wick and wall materials
(ii) Good thermal conductivity
(iii) Wettability of wick and wall materials
(iv) Vapor pressure not too high or low over the operating temperature range
(v) High latent heat
(vi) High thermal conductivity
(vii) Low liquid and vapor viscosities
(viii) High surface tension
(ix) Acceptable freezing or pour point

Property	**C(J/kg K)**	**ρ(kg/m^3)**	**λ_L(W/m K)**	**α (m^2/s)**
Water	4179	997.1	0.605	1.47
Al_2O_3	765	3970	40	1317

Table 2. Thermo physical Properties

The selection of the working fluid must be based on thermodynamic considerations which are concerned with the various limitations to heat flow occurring within the heat pipe. In heat pipe design a high value of surface tension is desirable in order to enable the heat pipe to operate against gravity and to generate high capillary driving force.

In present analysis the working temperature range was selected between 20^{0}C to 180^{0}C in which wickless heat pipe needs to operate. Therefore from the above Table 2,waterselected as working fluid in this temperature range.

Experimental Setup Equipments

Experimental set consists of some equipment the details of all equipment and instruments are given below.

Heater	Type: Band Heater Capacity: 125 Watt Quantity: 3
Motor	Capacity: 200Lph
Container	Container Capacity: 16.23 liter
Voltmeter	0-230 Volts
Ammeter	0-5 A
Temperature Sensors	Type: PT100 Digital Type

Table No3: Equipments

A. Heat pipe Evaporative section of heat exchanger will be in contact of flow of hot air and condenser section will be in contact with cold air (the air which is to be heated). Heat pipe are designed, manufactured and inserted in the existing evacuated tubes available in the collector.

B. Motor can be selected of capacity 200 Lph, Pressure of water column with electric motor 40W, 230V AC such that it can deliver the turbulent flow for given diameter of pipe.
C. Voltmeter Digital Voltmeter of Range 0-300V (AC), three and half length, Power required 230 V, AC,50 Hz
D. Ammeter Digital Ammeter of Range 0-5A (AC), Power required 230 V, AC, 50 Hz
E. Transformer Dimmerstat (variable auto transformer) 230V,2A
F. Temperature sensors and Indicators RTD's – PT - 100 Sensor (4 No.) with Digital Temperature Indicator of Range 0-400. The temperature sensors are required to measure the temperature of inlet and outlet of the air. The four RTD's (PT-100) and corresponding temperature indicator will be selected to measure the temperature up to 250 ^{0}C with indicator three and half digit for two collector.
G. Insulating material The insulating material proposed is polyurethane foam as it is having the low thermal conductivity. Name of insulating material is rockwool insulation.

The experimental setup Figure consists of three band heaters (maximum power output of 120 W), Watt meter and a varies to provide required power by the heaters. T-type thermocouples are used to measure the temperature response at different heat pipe sections.

The inlet and outlet temperatures of the cooling water are also measured using two T-type thermocouples. The thermocouple positions of heat pipe tested with distilled water and nanofluids are presented in Figure. The flow rate of the cooling water is measured when the heat pipe/Thermosyphon operates steadily. The heat pipe nanofluid are tested for the heat input varying from 100 W to 250 W. The detailed experimental chart for the heat pipe with base fluid Table 2. Similarly, the experimental schemes for the Thermosyphon heat pipe is presented in the Table 1After the insulation of heater and the adiabatic section, the power supply to the resistance heater unit is turned on. The heat input is varied using the variable transformer from 100 W to 250 W. Temperatures at different positions of the heat pipe and inlet and outlet temperatures of the cooling water are monitored by the data acquisition unit (Figure 1). The mass flow rate of cooling water at the condenser is measured when the heat pipe operates at steady state

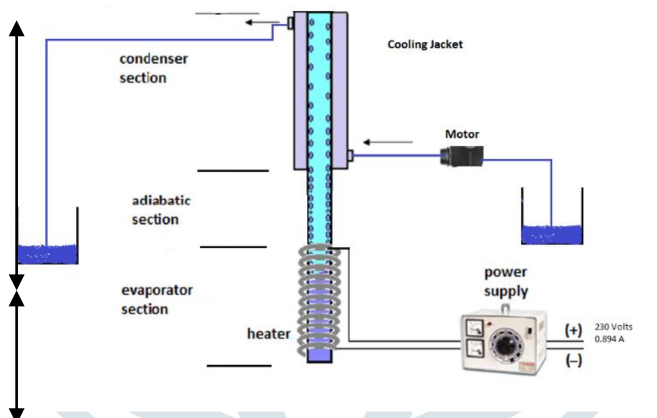

Fig 2: Experimental Setup

The temperatures of the heat pipe wall were measured by PT100 thermocouples at thelocations depicted in Figure 1. A cooling jacket was attached to the heat pipe wall in thecondenser section at the top. The flow rate, the coolant temperatures at the inlet and outlet of the cooling block were used to estimate the amount of heat actually transported through the heat pipe, where m*f* and C*p* represent mass flow rate and specific heat of coolant. A series of experiments was conducted during this study against variations in the working fluid, heat input, tilt angle, mass flow rate by using TPCT. Based on the comparison between Qin and Qrec , the heat loss of the setup was estimated to be less than 15% sometimes heat loss exceeded 20%.

The observations were taken by keeping mass flow rate at 64.5 and 116.5 lph respectively, accordingly we changed the tilt angle of heat pipe. Then for the TPCT we performed the same procedure and the performance characteristics are obtained with the help of collected data, with the help of which one can understand the difference between Heat Pipe and TPCT heat pipe and one can choose the heat pipe which is necessary provide the required work for their particular operation.




Results and Conclusion:

The two different thermosyphons are compared in which one is having Al_2O_3 filled in it and the other is having distilled water filled in it. From the performed investigation following conclusions could be drawn.

The Al_2O_3 shows better heat transfer characteristics compared to distilled water.

In condenser section, pipe wall temperatures increase towards the end where the coolant outlet pipe was located. The increase was due to the gain of heat by coolant water flowing from inlet to outlet section of condenser.

The inclination angle had a significant effect on wall temperatures along the wickless heat pipe. The wall temperature in evaporator section was observed to be lower at inclination angles 0^0 to 20^0, after that wall temperatures increases and reached maximum at 60^0 to 90^0. This trend was observed for all the pipes charged with water and Al_2O_3 as working fluid.

The maximum heat transfer rate was found to be high for Al_2O_3 compared to water.

The heat transfer coefficient was observed to be higher for tilted pipes of inclination angle 10^0-20^0 and poorest for almost horizontal wickless heat pipe.

While considering the observations related to inclination angle for both fluids the vertical thermosyphon or inclination angle of 90 º proves to be efficient.

In the consideration of varying mass flow rate, we can conclude that, higher the flow better is the heat transfer in the thermosyphon.

Future Scope:

Electronic equipment's are being used in every aspect of modern life from toys and home appliances to high power computers; from space systems to process industries. The reliability of the electronic components of a system is a major factor in the overall reliability of the system. Heat generation is an inescapable factor in all these systems. Continued miniaturization of the electronic circuits and the resulting high packing density has resulted in a dramatic increase in heat generation. A high rate of heat generation leads to corresponding high operating temperature of the electronic components which compromises its safety and reliability resulting in the higher failure rate of the systems. Hence the thermal control is an important factor in the operation of electronic equipment.

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The heat pipe is widely used because of simple structure, stable operating conditions during steady state and its wide operating temperature range. Therefore, wickless heat pipes are being used in many applications such as: heat exchangers (air preheater or systems that use economizer for waste heat recovery), solar energy systems, cooling of gas turbine rotor blades, electrical machine rotor cooling, transformer cooling, nuclear reactor cooling, electronic cooling, etc. Understanding of many problems associated with heat pipes has experienced an enormous progress, and technology progress was at least as great.

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