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Experimental Investigation of Heat Pipe

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Abstract: *Heat pipe is a heat transfer device that combines the principles of thermal conductivity and phase transition to efficiently manage transfer of heat between two solid interfaces. The main feature of heat pipe is that it can be designed to transport heat between the heart source and the heat sink with very small temperature difference. Based on Orientation of pipe, performance can be analysed. wick structure and the working fluid in the heat pipe play a very important role in thermal performance of heat pipe. Position of condenser and evaporator i.e. the inclination of heat pipe affects is thermal performance. Heat pipe performance with screen mesh wick structure at different angles of inclination and acetone, methanol, water as working fluid is studied.*
Keywords: *Heat pipe, Effectiveness of heat pipe, Working fluid, Inclination angle.*

I. Introduction

A Heat pipe is a heat transfer device that combines the principles of both thermal conductivity and phase transition to effectively transfer heat between two solid interfaces.

Heat pipes were developed especially for space applications during the early 60´s by the NASA. One main problem in space applications was to transport the temperature from the inside to the outside, because the heat conduction in a vacuum is very limited. Hence there was a necessity to develop a fast and effective way to transport heat, without having the effect of gravity force. The idea behind is to create a flow field which transports heat energy from one spot to another by means of convection, because convective heat transfer is much faster than heat transfer due to conduction.

Nowadays heat pipes are used in several applications, where one has limited space and the necessity of a high heat flux. Of course it is still in use in space applications, but it is also used in heat transfer systems, cooling of computers, cell phones and cooling of solar collectors. Especially for micro applications there are micro heat pipes developed as for cooling the kernel of a cell phone down .By means of a heat pipe it is possible to connect the processor cooling unit to a bigger cooling unit fixed at the outside to cart of the energy.

The basic idea of heat pipes is based on an evaporation and condensation process. At the hot side, the working fluid is evaporated and at the cool side it condensates again. A heat pipe is a heat transfer device that is capable of conveying large amounts of energy by cyclic evaporation-condensation processes. A heat pipe is comprised of a vacuumed-sealed container charged with an appropriate amount of working fluid. The inner surface of the container is covered with a wick material. When heat is applied to one end of container called the evaporator, the liquid working fluid is vaporized. The vapour then travels toward the other end of the container, called the condenser. In the condenser section of the heat pipe, the vapour condenses transferring energy to a heat sink. The resulting liquid is driven back to the evaporator by the capillary pressure provided by the wick structure. Using these mechanisms, heat pipes can exhibit heat transfer rates that are up to orders of magnitude higher than those seen in highly conductive metals. This feature makes the use of heat pipes desirable in many applications, such as thermal energy storage systems and electronic cooling.

The effective thermal conductivity of device is found to be greater than that of solid material of similar mass. The transfer of the thermal energy by conduction using solid material essentially limited by the thermal conductivity of the material structure .Because the thermal energy being transferred by evaporation condensation process rather than by a conduction, The heat pipe can transfer heat much more effectively than solid conductor of the same cross-section .Heat pipe has no moving parts, require no external energy, is reversible in operation and completely silent. When a heat pipe comes in contact with an external heat source at its evaporator, the heat is conducted into the liquid of the wicks in the evaporator. The liquid boils to vapor and moves to condenser via adiabatic region. The vapor condenses at the condenser and the condensate moves to the evaporator through the wicks under capillary pressure.

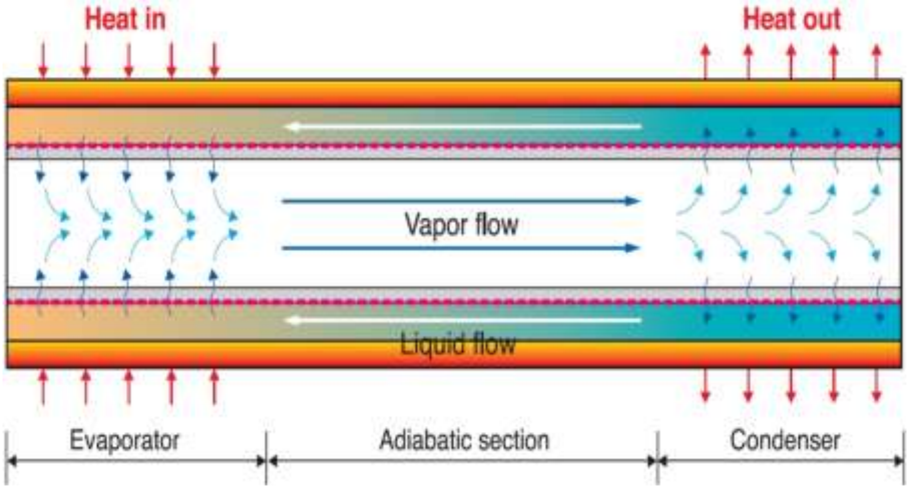


Fig.1.1 Working Of Heat Pipe

II. Literature Review

Zhisong Li [1] Axial-grooved ammonia aluminum heat pipes are the most commonly used heat pipes for spacecraft thermal management today. The axial-groove piping manufacturing requires special die manufacturing and extrusion techniques, which limits its availability to academic research and industrial applications. In this research, we propose a new heat pipe structure, replacing the conventional axial-grooved or sintered wicks with spiral coil and simple piping container. The proposed heat pipe structure is introduced thereby for its design and operational mechanism. Two test articles were fabricated. Preliminary experiments were carried out to investigate the heat transfer performance with different wire diameters and compare with a charged container without coil wick. To further verify its applicability to spacecraft engineering, an axial-grooved heat pipe of comparable cross-sectional area was also tested for comparison. The experimental data are presented and analyzed for heat pipe axial temperature profiles, transient behavior, evaporation/condensation film coefficients, and effective thermal conductivity. The study showed that the new wick structure is a viable and low-cost alternative to the current axial-grooved heat pipes for spacecraft thermal control systems.

Sumit Kumar Rai1 and K K Jain2 [2] An analytical model will be developed to evaluate the thermal performance of a Heat Pipe Heat Exchanger (HPHE) under natural convection by adopting thermal resistance approach. The model evaluates the rate of heat transport and pressure drop across evaporator system the HPHE under natural convection. The model computes various thermal resistance of the heat pipe at the external surface of evaporator and condenser as well as the internal surface of the pipe based on the correlations available in the literature. The rate of heat transport will be calculated by converting the model into a computer programme whose solution is based on an iterative procedure. The analytical model validated on a single heat pipe will extend to the HPHE by incorporating appropriate geometrical and heat transfer co-relations. Another test rig will be developed for evaluating the thermal performance of a HPHE under natural convective cooling condition as well as for validating the analytical model. The experiment will be conducted on the HPHE under natural convective condition at different tilt angles form the horizontal (150, 250, 300 and 900) and at various heating fluid temperatures (40 °C, 50 °C, 60 °C and 70 °C) at its evaporator.

Mingke Hu ,Renchun Zheng, Gang Pei , Yunyun Wang , Jing Li a, Jie Ji [3] Two different heat pipe photovoltaic/thermal (PV/T) systems, namely, wickless heat pipe PV/T system and wire-meshed heat pipe PV/T system, were proposed. In this paper, the therma performances of the two systems working on different inclination angles were experimentally investigated in an Enthalpy Difference Laboratory with a solar simulator. The thermal performance of the wire-meshed heat pipe is not as sensitive to the inclination angle as that of the wickless heat pipe. The wickless heat pipe PV/T system is recommended at latitudes higher than 20°, whereas wire-meshed heat pipe PV/T system is suggested at latitudes lower than 20°. Moreover, the thermal performances of both PV/T collectors at an inclination angle of 40° were further investigated, in which case both heat pipes worked at optimum conditions. The thermal efficiency of the wickless heat pipe PV/T system and wire-meshed heat pipe PV/T system at zero reduced temperature was 52.8% and 51.5%, respectively.

Bahubali B. Kabnure and Rajkumar. D. Patil [4] Heat pipes are used in several applications, where one has limited space and the necessity of a high heat flux. Of course it is still in use in space applications, but it is also used in heat transfer systems, cooling of computers, cell phones and cooling of solar collectors. Especially for micro applications there is micro heat pipes developed as for cooling the kernel of a cell phone down. Due to limited space in personal computers and the growing computational power it was necessary to

find a new way to cool the processors down. By means of a heat pipe it is possible to connect the processor cooling unit to a bigger cooling unit fixed at the outside to cart of the energy.
In this paper, different tests were carried out at the different angle of inclination of heat pipe having same current and voltage. The efficiencies at each angle of inclination are calculated from the obtained data.

III. Working Principle

The heat pipe is a passive heat transfer device with an extremely high effective thermal conductivity. Its heat transfer capability ranges from one hundred to several thousand times that of an equivalent piece of copper because of its two-phase heat transfer mechanism. When constructing the heat pipe, it is evacuated and then filled with the working fluid before being sealed. Hence its internal pressure is equal to the vapour pressure of the working fluid. When heat is applied to the evaporator section of the heat pipe, the working fluid vaporizes. In thermodynamics, pressure change is directly proportional to temperature change. Hence, at a slightly higher temperature and pressure at the evaporator section, it creates a pressure gradient that forces the vapour to flow to the cooler regions of the heat pipe. As the vapour condenses on the heat pipe walls, the latent heat of vaporization is transferred to the condenser. The capillary wick then transports the condensate back to the evaporator section. This closed loop process continues as long as heat is applied. The wick structure is a concerned factor because good structure generates stable capillary pumping pressure, maintains the circulation of the fluid against the liquid and vapour flow losses, and against adverse body forces, such as gravity.

IV. Orientation

The heat pipe is tilted by changing the angle of the rotating plate of the test stand. Different thermal characteristics are observed on different orientation of heat pipe by changing the tilt angle of this plate. The different orientation angles are:

- Vertical orientation (0^0)
- 30^0 and 60^0 inclinations

Fig 3.3 show the different orientation of heat pipe and fig to shows the various components and essential apparatus to conduct of the experiment.

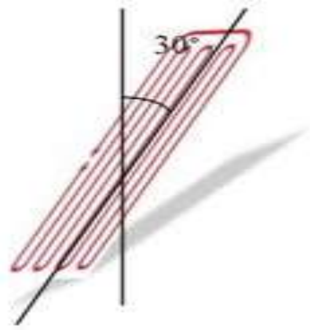


Fig 3.2: 30° Inclination

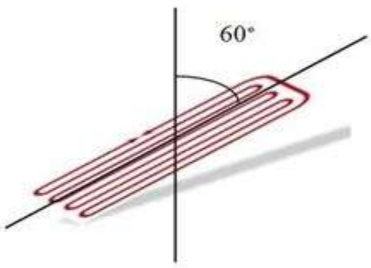


Fig 3.4: 60° Inclination

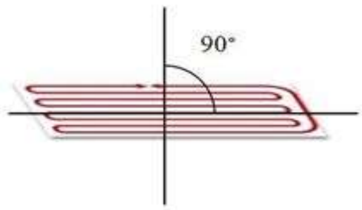


Fig 3.5: Horizontal mode (90°)

Fig.:-3.5. Experimental Setup Orientation

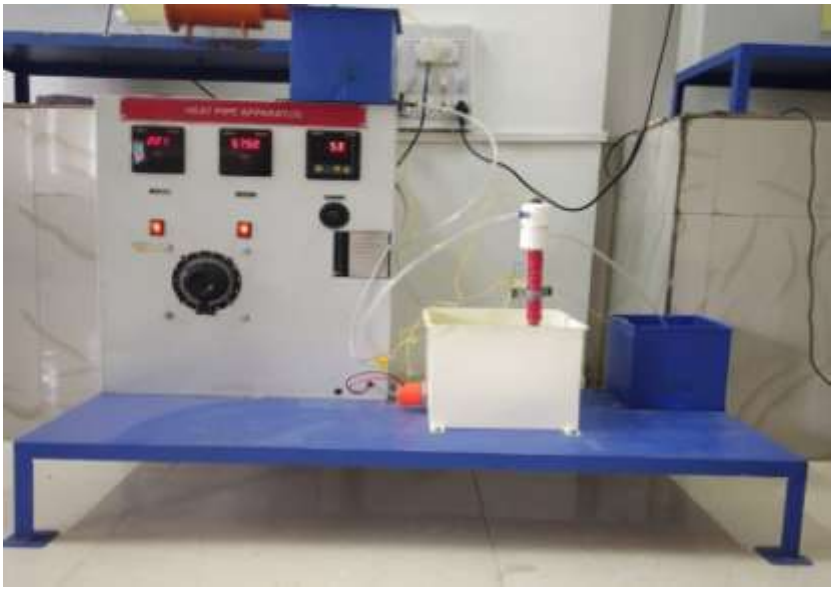


Fig.3.6. Experimental Setup

V. Stepwise Procedure:-

1. First the heat pipe is fully instrumented and set up in the instrument.
2. The evaporator section 50mm long was fitted into the heated water in the test rig. And condenser section covered by 100mm long water jacket.
3. Initially check all the electrical connections are to the mark.
4. Then supply the electrical power to the autotransformer.
5. Mass flow rate in the condenser unit is kept constant at some specific required value.
6. Adjust the current and the voltage required supplied to the heater.
7. Preferably that, input should be applied at first in steps, building up to design capability and allowing the temperature along the heat pipe to steady state.
8. Different tests were carried out at the different angle of inclination of heat pipe having same current and voltage.
9. Calculate the effectiveness at each angle of inclination from the obtained data.
10. Compare the effectiveness and discuss the results.

VI. Experimental Work

Observations

1. Internal Diameter of Heat pipe: 18mm
2. Outer Diameter of Heat Pipe: 19mm
3. Thickness of Pipe: 1mm.
4. Length of Heat pipe: 300mm
5. Volume of liquid in the cooling Jacket: 1000ml
6. Voltage: 84 Volt
7. Current: 2.216 Amp

Observation table:
Fluid Used: ACETONE (C_3H_6O)

A. For Angle 90^0

TABLE NO 4.1: OBSERVATION TABLE FOR 90^0 ANGLE

Time Interval	Qin (V*I)	T1	T2	T3	Tin	Tout	Qout	Effectiveness (Qout/Qin) %
1	189.144	37.7	35.4	33	29	30.5	104.69	55.34
2	189.144	42.5	39.3	37.6	29	30.6	111.67	59.03
3	189.144	47.3	43.9	39.2	29	30.8	125.63	66.42

Calculations for Angle 90^0

1. Mass of Liquid in Jacket (m_1) = Quantity of cooling water circulated through condenser unit.

=1000 ml. per min.

=1/60 lit/sec.

=0.0167 kg/sec (1litre=1 kg)

2. Heat Input (Q_{in}) = V*I

= 84*2.216

=189.144 Watt

Where, V= Voltage Maintained in Volts,

I= Current In ampere.

3. Heat Output (Q_{out}) = $m*Cp*(T_{out}-T_{in})$

= $0.0167*4.18*10^3 * (30.8^\circ - 29^\circ)$

= 125.63 watts.

Where,

m= mass flow rate

Cp= specific heat of water

T_{out} = outlet temperature

T_{in} = Inlet temperature

4 . Cross sectional area A =$\pi/4\ d2$

= $(3.14/4)*(0.035)^2$

= $0.94 * 10^{-3}\ m^2$.

5. Effectiveness of the Heat Pipe = Q_{out}/Q_{in}

= 125.63/189.144

= 0.6642

= 66.42%.

B. For Angle 60^0

TABLE NO 4.2: OBSERVATION TABLE FOR 60^0 ANGLE

Time Interval	Qin (V*I)	T1	T2	T3	Tin	Tout	Qout	Effectiveness (Qout/Qin) %
1	189.144	38.3	36.9	34.2	29	30	69.79	36.90
2	189.144	41	38	36	29	30.2	83.75	44.27
3	189.144	43.5	40.1	38.4	29	30.4	97.71	51.65

C. For Angle 30^0

TABLE NO 4.3: OBSE RVATION TABLE FOR 30^0 ANGLE

Time Interval	Qin	T1	T2	T3	Tin	Tout	Qout	Effectiveness (Qout/Qin) %
1	189.144	39.3	37.9	35.1	29	29.6	41.87	22.13
2	189.144	41.7	38.2	36.7	29	29.7	48.85	25.82
3	189.144	43	41.3	39.1	29	29.8	62.81	33.20

Fluid Used:- METHENOL (CH3OH)

For Angle 90^0

TABLE NO 4.4: OBSERVATION TABLE FOR 90^0 ANGLE

Time Interval	Qin	T1	T2	T3	Tin	Tout	Qout	Effectiveness (Qout/Qin) %
1	189.144	38.2	35.9	33.1	29	30.2	83.75	44.27
2	189.144	42.8	39.9	36.5	29	30.4	97.71	51.65
3	189.144	46.6	44.2	42.2	29	30.6	111.67	59.03

B. For Angle 60^0

TABLE NO 4.5: OBSERVATION TABLE FOR 60^0 ANGLE

Time Interval	Qin	T1	T2	T3	Tin	Tout	Qout	Effectiveness (Qout/Qin) %
1	189.144			58	29	29.7	48.85	25.82
2	189.144			63	29	30	69.79	36.89
3	189.144			68	29	30.1	76.77	40.58

C. For Angle 30^0

TABLE NO 4.6: OBSERVATION TABLE FOR 30^0 ANGLE

Time Interval	Qin	T1	T2	T3	Tin	Tout	Qout	Effectiveness (Qout/Qin) %
1	189.144				29	29.5	34.89	18.44
2	189.144				29	29.7	48.85	25.82
3	189.144				29	29.9	62.81	33.20

Fluid Used: WATER (H20)

For Angle 90^0

TABLE NO 4.7: OBSERVATION TABLE FOR 90^0 ANGLE

Time Interval	Qin	T1	T2	T3	Tin	Tout	Qout	Effectiveness (Qout/Qin) %
1	189.144				29	30.1	76.77	40.58
2	189.144				29	30.3	90.73	47.96
3	189.144				29	30.4	97.71	51.65

B. For Angle 60^0

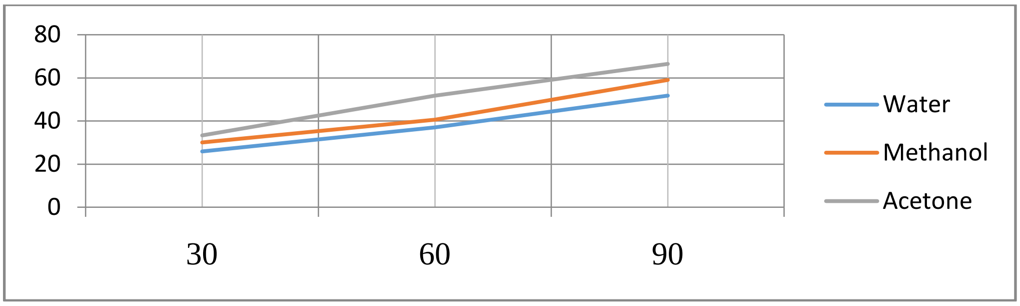
TABLE NO 4.8: OBSERVATION TABLE FOR 60^0 ANGLE

Time Interval	Qin	T1	T2	T3	Tin	Tout	Qout	Effectiveness (Qout/Qin) %
1	189.144					29.7	48.85	25.82
2	189.144					29.8	56.83	30.4
3	189.144					30	69.79	36.89

C. For Angle 30^0

TABLE NO 4.9: OBSERVATION TABLE FOR 30^0 ANGLE

Time Interval	Qin	T1	T2	T3	Tin	Tout	Qout	Effectiveness (Qout/Qin) %
1	189.144				29	29.5	34.89	18.44
2	189.144				29	29.6	41.87	22.3
3	189.144				29	29.7	48.85	25.82



Graphical representation (Effectiveness v/s Angle of inclination)

VII. Results And Discussion

From this experiment we can clearly see that the effectiveness of heat pipe is dependent on angle of inclination of heat pipe and the working fluid used in the heat pipe. The above graph shows that as the angle of heat pipe increases the effectiveness of heat pipe increases

Most effective angle of inclination = 90^o
Effective working fluid is Acetone..

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