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Performance Improvement of PCM Assisted 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. Phase Change Material (PCM) storage can contribute 86.7% to the cooling application and 11.7% avoidance of heat dissipation by providing additional heat absorption [1]. PCM are substances can absorb and release heat when material changes from solid to liquid and vice versa. PCM are used in adiabatic section to improve the performance of heat pipe. Phase change material offers greater heat storage per unit volume compared with sensible heat but disadvantage is low charging and discharging rates due to low thermal conductivity. So the rate at which heat is removed from heat pipe to PCM Material is low. So to increase the heat transfer we have introduced metal rings of higher thermal conductivity which increases the surface area in contact with PCM and ultimately heat transfer rate. Results of the experimentation concluded that the performance of the heat pipe is improved by 9.38% due to the introduction of metal rings in PCM compared with without metal ring heat pipe.*

***Key Words*: Heat pipe, PCM, Heat exchanger, Heat transfer**

1. INTRODUCTION

Now a day, we use devices with higher power rating, having higher performance characteristics due to which they got heat up. The heat generated must be removed as due to prolonged use of this device will generate more and more heat which can damage its internal circuits. This problem can be solved by using the heat pipe. Heat pipe is a heat transfer device which transfers heat from hot surface to cold surface at higher rate without use of any external power source. One end of heat pipe is kept near the heat generating source and other end is kept near the heat sink where heat is to be rejected.

In 1963, George Grover invented the capillary based heat pipe. He was first to name it as Heat pipe. NASA took this invention of George Grover seriously and developed the Heat pipes which has application and reliability in space flight. In space Heat pipe has their first use in the Satellite. After this NASA tested various heat pipes [7].

2. PCM Assisted Heat pipe

PCM assisted heat pipe is same as that of normal heat pipe but it having some additional portion to increase the rate of heat transfer. By using the PCM in heat pipe performance of heat pipe is improved.

2.1 Construction

It consist of three sections condenser, evaporator and adiabatic section. Evaporator section is connected to the heat source and condenser section to heat sink. In adiabatic section PCM material is used. On the outer surface of heat pipe up to certain diameter PCM material is filled in the closed container so that PCM material is in contact with heat pipe [6].

Fig. 2.1 PCM-Assisted Heat Pipe

2.2 Working

Heat is generated in the evaporator section due to this the liquid inside the heat pipe evaporates i.e. phase change take place and flow towards the condenser section. In PCM assisted heat pipe heat rejection takes place in the two way hence the performance is improved. Heat carried by the fluid is rejected in condenser section to environment also some amount of heat is absorb by PCM due to conduction and convection and phase change of PCM take place from solid to liquid. Thus it stores energy [5]. When heat from fluid is removed it gets cool and flows towards the evaporator section. In adiabatic section there is no heat transfer to surrounding from PCM hence when source temp decreases PCM reject the heat to surrounding through condenser and again get solidified [3].

3. Problem Definition

We found that heat transfer from PCM Assisted heat pipe takes place at high rate compared to our normal heat pipe. This is due to rejection of heat takes place by two ways. First from condensation section of heat pipe and Secondly to PCM in adiabatic section. The rate of heat transfer from Heat pipe to PCM material is very low due to low thermal conductivity of PCM material [2]. So the rate at which heat is removed from heat pipe to PCM Material is low. Our project aims to increase the rate of heat transfer from heat pipe to PCM material.

4. METHODOLGY

As our aim is to increase the rate of heat transfer and heat transfer in PCM storage unit in Adiabatic Section of heat pipe takes place through conduction. The rate of heat flow in conduction depends on thermal conductivity of the material, temperature difference across the material, surface area in contact. So to increase heat transfer from Heat Pipe to Paraffin wax we can introduce another metal with high thermal conductivity than paraffin wax in contact with Heat Pipe plus by increasing the surface area in contact with PCM. To fulfil above condition we are going to introduce steel metal rings in contact with heat pipe. Introducing steel metal rings around Heat Pipe will remove heat at higher rate compared to the PCM material as thermal conductivity of Steel is very much high compared to Paraffin Wax. As thermal conductivity of paraffin wax is low and to increase heat transfer rate introducing steel rings will increase the surface area in contact with Paraffin wax which ultimately results in increase in heat transfer rate. And also steel metal rings will act as heat storage unit to increase heat storage capacity of PCM storage Unit in Adiabatic Section.

5. Experimental Analysis

The experiment is conducted on wire mesh wick structure PCM heat pipe without metal and with metal rings. Test setup consists of a wood table which is used to support heat pipes and incline them at desired angles to study the effect required. A control panel is used to measure heat supplied to heat pipes. It displays supply current and voltage readings through digital voltmeter and ammeter. Supply voltage and current are varied by dimmerstat. Control panel is also used to display temperature at various positions through digital thermometer and K-type thermocouple. A Thermocouple is temperature measuring device consisting of two dissimilar conductors that contact each other at one or more spots. Type K is the most general purpose thermocouple. It is inexpensive and has wide variety of probes available in its range of -200 °C to 1350 °C range. Condenser is assembled with heat pipes to absorb the heat released from condenser end. Water required for circulation is passed from one end of the condenser to the other end with help of water pump. Measuring flask of 1000 ml is used to measure the mass flow rate of circulating water. Stopwatch is used to measure the flow rate time.

5.1 Design Specifications

Experimental Setup involves heat pipes with adiabatic section filled with PCM. Length of evaporator section, condenser section, and adiabatic section is kept same for the heat pipes which is shown in Table 5.1 [4]. Dimensions of Adiabatic section and metal rings Table 5.2.

Table 5.1 Specification of Heat pipe and Cartridge Heater

Parameter	Specification
Bore	10mm
Length of Heat Pipe	300mm
Length of Evaporator Section	100mm

Length of Adiabatic Section	60mm
Length of Condenser Section	100mm
Heat Pipe Material	Copper
Working Fluid	Water
Cartridge Heater Capacity	500W
Length of Cartridge Heater	100mm
Diameter of Cartridge Heater	9.6mm

Table 5.2 Adiabatic section diameter

Parameter	Dimensions
Inner Diameter	10 mm
Outer Diameter	50 mm
Metal Ring Inner Diameter	10 mm
Metal Ring Inner Diameter	30 mm

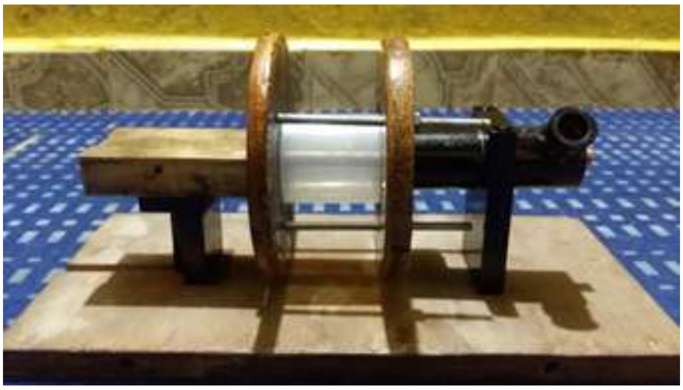


Fig 5.2 Actual Setup

5.2 Experimental Procedure

The heat pipe is placed in the position as shown in the experimental setup. The degree of inclination is then set by moving the water jacket in an inclined way. The angle is measured by using angle measuring instrument attached on wood table. The two thermocouples are fixed to the two ends of heat pipe i.e. one at evaporator section and other at condenser section with the help of locking screw. The heater is placed at the evaporator section and the heat input is given by switching on the heater. The amount of heat input can be varied through dimmer stat provided on setup. Water is being pumped continuously at condenser section through a water jacket to take away the heat from the condenser. The temperatures at evaporator and condenser sections are measured using thermocouple which is displayed on the setup. The temperatures are noted once the system reaches steady state. The mass of water flow is calculated by taking time required to fill the certain amount of 1000ml in the measuring jar. The same procedure is conducted by varying the inclination and readings are noted.

Fig 5.3 Experimental Setup

5.3. Mathematical Formulation & Observations

The amount of heat supplied at the evaporator section is absorbed by the working fluid (water) and it is released as latent heat of evaporation at condenser section.

Cpw be the specific heat of water = 4187 J/kg.K
Cpm be the specific heat of metal = 466 J/kg.K
Cpwax be the specific heat of wax = 4187 J/kg.K
Heat of fusion of PCM (Wax) = 210000 J/Kg

Density of Wax = 900 Kg/m^3
Mass of Wax = 0.400 Kg
Mass of Metal Ring = 0.080 Kg

Melting temperature of Wax = 37^o

Tout be temperature of outlet circulating water in °C
Tin be temperature of inlet circulating water in °C
T_E be evaporator temperature in°C
T_{Fin} be metal ring temperature in°C
Q_{IN} be amount of heat supplied at evaporator =V×I in watts
Q_{OUT} be amount of heat gained by circulating water
= m × Cpw × (Tout - Tin)

5.4 Observations

Heat input
V = 77.8 volts
I = 1.286 amp

1. Without Metal Rings

Table 5.3 Behavior of heat pipe without metal rings at saturation

Qin (W)	Te (°C)	Thp (°C)	Tin (°C)	Tout (°C)	Qout (W)
100	81.75	56.3	22.5	23.1	71.59

Time required to reach stable condition = 7200 sec

Table 5.4 Behavior of heat pipe without metal rings with time

Time	Thp (°C)	Tcover (°C)
0	25.7	25.6
5	31.8	26.7
10	41.0	27.1
15	43.0	27.9
20	44.6	28
25	49.6	28.1
30	52.7	28.5
35	53.0	29.1
40	53.7	29.8
45	53.9	30.6
50	54.2	32.5
55	54.9	33.7
60	55.1	34.2
65	55.3	35.7
70	55.5	36.8
75	55.8	36.9
80	55.9	37
85	56.0	37
90	56.1	37
95	56.1	37.2
100	56.2	37.2
105	56.2	37.3
110	56.2	37.3
115	56.3	37.2
120	56.3	37.3

2. With Metal Rings

Table 5.5 Behavior of heat pipe with metal rings at saturation

Qin (W)	Te (°C)	Thp (°C)	TFin (°C)	Tin (°C)	Tout (°C)	Qout (W)
100	82.05	56.3	34.7	22.4	23	71.59

Time required to reach stable condition = 4500 sec

Table 5.6 Behavior of heat pipe with metal rings with time

Time	Thp (°C)	Tcover (°C)
0	25.6	25.6
5	31.9	39.7
10	41.2	30.1
15	44.6	30.9
20	49.9	31.3
25	52.7	32.6
30	54.4	33.5
35	55.6	34.2
40	55.6	35.1
45	55.9	35.7
50	56.0	36.4
55	56.3	36.4
60	56.2	36.7
65	56.3	36.9
70	56.3	37.3
75	56.3	37.3
80	56.2	37.3
85	56.3	37.3
90	56.3	37.4

5.5 Mathematical Formulation & Observations

Heat Input = V × I = 77.8 × 1.286 = 100.0 W

Mass flow rate = 0.0285 kg/sec (Mass flow rate is constant for both times),
$Q_{out} = m \times C_p \times (T_{out}-T_{in}) = 0.0285 \times 4187 \times (22.4 - 23)$
$= 71.59$ W

Latent Heat Stored in Wax due to Phase Change
$Q_{hf} = m_{wax} \times h_f = 0.4 \times 210000 = 84000$ J

Heat absorbed by Wax due to change in temperature
$Q_{sf} = m_{wax} \times C_{pwax} \times \Delta T = 0.4 \times 2300 \times (37-25.6) = 10488$ J

Heat absorbed by metal ring due to change in temperature
$Q_{mf} = m_{mr} \times C_{pm} \times \Delta T = 0.4 \times 2300 \times (34.7-25.6) = 339.25$ J

1. Without Metal Rings

Heat stored in adiabatic section per sec

$Qas = (Q_{hf} + Q_{sf}) / 7200 = (84000 + 10488) / 7200 = 13.12$ J

Total Heat rejected
Q1 = Qas + Qout = 71.59 + 13.12 = 84.71 W

2. Without Metal Rings

Heat stored in adiabatic section per sec

$Qas = (Q_{hf} + Q_{sf} + Q_{mf}) / 4500$
$= (84000 + 10488 + 339.25) / 7200 = 21.07$ J

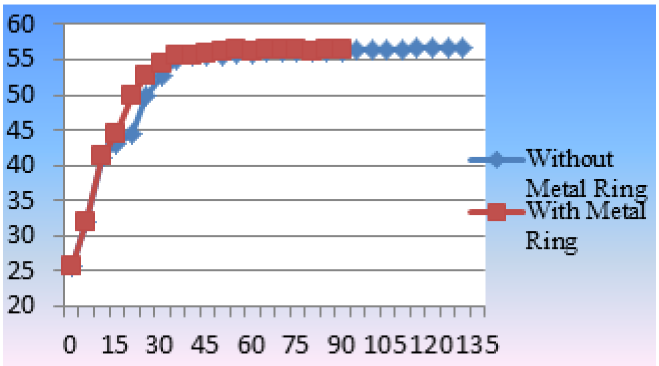
Total Heat rejected
$Q1 = Qas + Qout = 71.59 + 21.07 = 92.66$ W

% improvement in performance
$= (92.66 – 84.71) / 84.71 = 9.38\%$.

6. Result

In order to study the effect of rise in temperature of heat pipe, PCM with respect to time for heat pipe without and with metal rings and to draw conclusion from it, we shall plot the graph of temperature vs time.
In order to observe two graphs are plotted

1. Heat input conditions same, Heat pipe temperature vs Time.
2. Heat input conditions same, PCM temperature vs Time
3. Heat input conditions same, Heat input vs Heat output

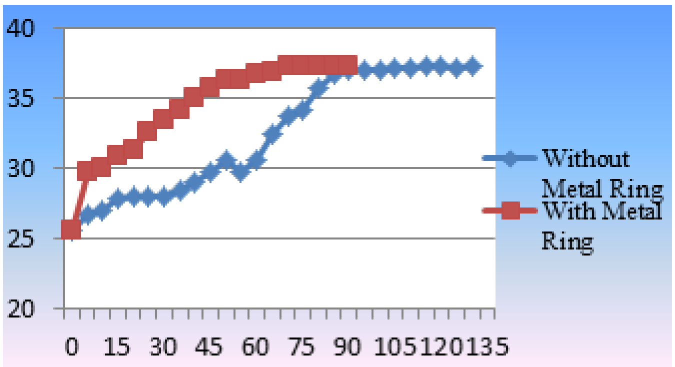


Temperature (°C)

Time **(sec)**

Fig 6.1 Heat pipe temperature vs Time

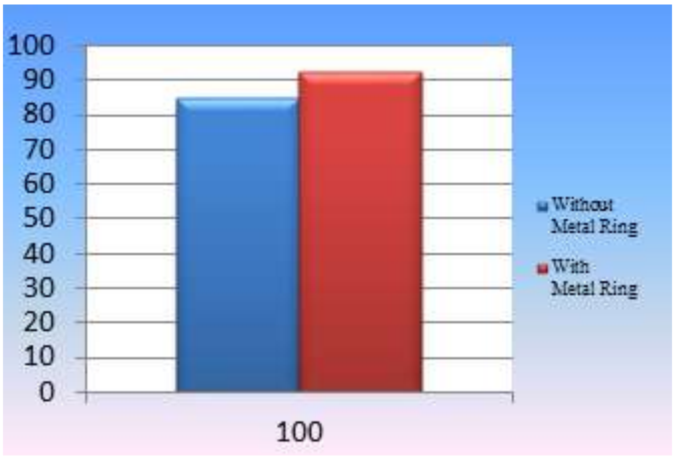
Qout (W)



Temperature (°C)

Time **(sec)**

Fig 6.2 PCM temperature vs Time



Qin (W)

Fig 6.3 Heat input vs Heat output

7. Conclusion

A Study on performance of PCM assisted heat pipe without metal rings and with metal ring was performed at 100 W. From this experiment we conclude the performance of PCM assisted heat Pipe is improved by around 9.38% with the introduction of metal rings in the adiabatic section around the heat pipe.

8. Scope for the Future

This work can be modified in the future:-

- Study and experimental analysis of diameter of metal ring in adiabatic section. In this, the optimum diameter for adiabatic section can be determined so that maximum heat transfer can be achieved.
- Experimentation on heat pipe by using middle section as evaporator and both ends of heat pipe acting as condenser

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