Experimental Investigations and comparison of Heat Pipes

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Abstract - Heat pipes are highly efficient heat transfer devices, which use the continuous vaporation/condensation of a suitable working fluid for two-phase heat transport in a closed system. Since the latent heat of vaporization is very large, heat pipes transport heat at small temperature difference, with high rates. Heat pipes must be tuned to particular cooling conditions. The choice of pipe material, size and coolant all have an effect on the optimal temperatures at which heat pipes work. When heated above a certain temperature, all of the working fluid in the heat pipe vaporizes and the condensation process ceases; in such conditions, the heat pipe's thermal conductivity is effectively reduced to the heat conduction properties of its solid metal casing alone. In addition, below a certain temperature, the working fluid will not undergo phase change, and the thermal conductivity is reduced to that of the solid metal casing. So there is a need to know the optimum temperature and pressure conditions under which heat pipe can be operated. The project consists of experimental study of variations in thermal resistance and efficiency of different types of heat pipes with variations in heat input values at different flow rates. For this, the temperatures at condensor and Evaporator regions and Condensing water Jacket inlet and outlets are noted down at each set of heat input values and water flow rates. Then, thermal resistance and efficiencies are calculated. The experiment is conducted on three different types of heat pipes namely sintered copper, helical groove and mesh wick.The changes in efficiencies and thermal resistance withchange in water flow rate and heat input values are being recorded and analyzed in the project.

Keywords– Heat pipes, Electronics cooling, Efficiency, Thermal Resistance

I. INTRODUCTION

Heat pipes have been used extensively in spacecraft as a means for managing internal temperature conditions. The heat transport capacity of the heat pipe is controlled by the thermo-physical properties of working fluids [1].The common types of heat pipes primarily include as: Two-Phase Closed Thermosyphon (TPCT) heat pipes, Pulsating Heat Pipes (PHPs) and Oscillating Heat Pipes (OHPs) [2].
Heat pipes are used extensively in various applications, for achieving high rates of heat transfer utilizing evaporation and condensation processes. Heat pipes have been used in space crafts, computers, solar systems, heat and ventilating air conditioning systems and many other applications [3]. Heat pipes have been used in various applications, including Air-Conditioning Systems, the cooling of Electronic components, Thermal storage, and Solar Heating systems [2].

Heat pipes began to be used in computer systems in the late 1990s, when increased power requirements and subsequent increases in heat emission resulted in greater demands on cooling systems. They are now extensively used in many modern computer systems, typically to move heat away from components such as CPUs and GPUs to heat sinks where thermal energy may be dissipated into the environment.

Heat pipes are also widely used in solar thermal water heating applications in combination with evacuated tube solar collector arrays and to dissipate heat alongside parts of the Qinghai–Tibet Railway where the embankment and track absorb the sun's heat.
In heating, ventilation and air-conditioning systems, HVAC, heat pipes are positioned within the supply and exhaust air streams of an air handling system or in the exhaust gases of an industrial process, in order to recover the heat energy.
Since the early 1990s, numerous nuclear reactor power systems have been proposed using heat pipes for transporting heat between the reactor core and the power conversion system.
The extensive applications of heat pipe technology in industries with great prospects are based on the essential features of the heat pipe. These features, when combined with specific technical processes, bring [4]Research ,Development and Industrial Application of Heat Pipe Technology XZhang Hong , Zhuang J uninto full play of the superiority of the heat pipe technology and also solve the practical problems in industrial production in an efficient and economical way. This is the key for the application of heat pipe technology in industries.

The heat pipe thermal cycle includes the following state: [5] Heat Pipe Inspection System forThermalManagement in Electronic CircuitP. Nilas

1. The working fluids evaporate to vapour absorbing thermal energy.
2. The vapour migrates along cavity to lower temperature end.
3. The vapour condenses back to fluid and is absorbed by the wick releasing thermal energy.
4. The working fluid flows back to higher temperature end.

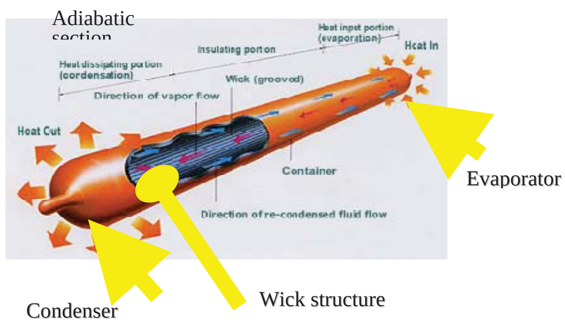


Fig.1 Working Principle of Heat Pipe

These two phase modes of heat transfer provide the heat pipe with its high effective thermal conductivity. For example, a 3mm diameter copper rod, 20cm long heated at one end, cooled at the other and insulated in between would have an end to end AT of over 300°C at IOW. A heat pipe of the same dimensions and with the same heated and cooled areas would exhibit an end to end AT under 5 'IC. This equates to a thermal conductivity for the heat pipe of 60 times that of copper.

1.1 Principle of Heat Pipe Cooling System

Heat pipes are sealed and evacuated vacuum tight vessels which have been partially backfilled with a fluid. This fluid serves as the heat transfer media. The internal walls of the vessel are lined with a porous media (thewick) which acts as a passive pump, via capillary action, to circulate the condensate within the heat pipe. Fig.1. is a cut away view of a heat pipe.When heat is applied, the working fluid in the heat input area (the evaporator) is vaporized. Thisgenerated vapor is slightly higher in temperature and pressure than that of thevapor in other regionsof the heat pipe. As a result of this pressure gradient, the vapor flows to the cooler regions of the heat pipe where it condenses. The condensate is then returned to the evaporator region via the wick structure. As a frame of reference, the temperature gradient associated with this.

Fig.2 Experimental Test Rig

II. EXPERIMENTAL TEST DETAILS

The experiment is conducted on three different types of heat pipes namely helical grooved, sintered copper, and mesh wick heat pipes.The setup consists of a test rig equipped with a adjustable heat input device by which we can vary the heat inputs and a condensing jacket which surrounds the condenser part of heat pipe through which cooling water is circulated to condense the vapour inside the heat pipe.

A stabilizer to take care of the fluctuation in the electric supply to the test rig. A voltmeter and an ammeter that indicate the power input given to the heat pipe. Thermocouples are used to measure the temperature of heat pipe at evaporator and condensing sections.

For obtaining the temperatures(of Condenser & Evaporator and water temperatures at Condensing water jacket inlet and outlet), thermocouples are connected to the equipment and the temperatures are read using digital temperature indicators.

Using the condenser jacket water inlet and outlet temperatures and heat input values, the efficiency is calculated for each set of reading of flow rate and heat input values. Using the evaporator and condenser temperatures and heat input values, thermal resistance is calculated for each set of readingof flow rate and heat input values.

III. EXPERIMENTAL INVESTIGATIONS

Experimental work is conducted on Sintered Copper Heat Pipe at different flow rate values of water in condensing jacket and varying heat inputs to the heater. At each heat input value, the temperature at evaporator(Te)& condenser regions(Tc) and temperatures of condensing water inlet (Twi) & outlet (Two) have been recorded.The experiment was repeated on Helical Groove & Mesh Wick type Heat Pipes. For each set of values, efficiencies of each Heat Pipe is calculated using the relation:Efficiency = (m*Cp*Δt)/Heat input in Watts,Where m is mass flow rate of water (in kg/sec) flowing in condensing,
Jacket, Cp is specific heat of water = 4.18 kJ/kgk.
ΔT is change in temperature of water in condensing jacket in °c.Similarlyfor each set of values, Thermal Resistance of each Heat Pipe is calculated using the relation:$R_{th} = (T_{evaporator} - T_{condenser})$/Heat input in Watts.The above results are analyzed theoretically and graphically.Experiment has also been conducted on these 3 types of Heat Pipes (Viz.,

Sintered Copper, Helical Groove & Mesh Wick type Heat Pipes) to observe time taken for attaining stable temperatures at evaporator & condenser regions

Fig.3 Water Jacket connected to condenser end

IV. EXPERIMENTAL RESULTS AND DISCUSSION:

From these experiments, it is observed that, in case of Sintered & Helical Grooved Heat Pipes, at lower flow rates, Thermal Resistance (TR) is decreasing with increase of Heat Input (HI), whereas, Efficiency is increasing with increase in Heat Input values. At higher flow rate value, TR is again decreasing with increase of Heat Input (HI) and Efficiency is decreasing with increase in Heat input values. At higher flow rates, TR value is slightly higher at low and at higher heat input values, TR values are comparable with that at lower flow rates. For low Flow Rates and lower heat input values Efficiency values are lower than high Flow Rate and lower heat input values. Similar observations are made with Mesh Wick type Heat Pipes except that, at higher flow rates, there is no appreciable change in efficiency with increase in heat input values.From the experiment conducted on different types of heat pipes for studying time taken to achieve stable temperature, it is seen that, the time taken in case of Sintered Coppertype Heat Pipe for Evaporator is 11.23 Sec and that for Condenser is 14.13 Sec at flow rate of 9 ml/sec and Heat Input of 150 W, The time taken are 5.39 Sec & 5.25 Sec in case of Helical Grooved type and 1.56 Sec & 2.37 Sec in case of Mesh Wick type forEvaporator & Condenser respectively.

4.1 Time for attaining steady state temperature values

The time taken for attaining stable temperatures for Evaporator and Condenser is highest in case of Sintered Copper heat pipe and lowest for Mesh Wick type Heat Pipe.

The following observations are made from the calculation of results.

(i) Thermal Resistance (TR) at low flow rates

TR obtained for Mesh Wick Heat Pipe at lower Heat Input values is lower than the other two types of Heat Pipes used in the study.The Thermal Resistance obtained for Helical Grooved Heat Pipe at higher Heat Input values is lower than the other two types of Heat Pipes used in the study.TR for Sintered Copper HP is decreased to one-fourth value for a Heat Input increase by five times
d) TR for Mesh Wick and Helical Grooved type pipes TR is decreased to one-tenth value (approx.) when Heat Input value increased by 5 times similar observations were made when experiment conducted at higher flow rates.

(ii) Efficiency at low flow rates

The efficiencies obtained in case of Sintered Copper and Mesh Wick Type HPs are lower (which are of order of 50%) than that in case of Helical Grooved type HP(which is of order 0f 80%) at Lower Heat Input values.At higher Heat Input values, the efficiency obtained in case of Helical Grooved type HP are lower (which is of order of 40%

) than that in case of Sintered Copper and Mesh Wick Type HPs (which are of order 0f 50% and 60% respectively).

(iii) Efficiency at higher flow rates

The efficiencies obtained in case of Sintered Copper and Mesh Wick and Helical Grooved Type HPs are comparable (which are of order of 76%) at lower Heat Input values. At higher Heat Input values, the efficiency obtained in case of Helical Grooved type HP are lower (which is of order of 45%) than that in case of Sintered Copper and Mesh Wick Type HPs (which are of order 0f 60 and 75% respectively).

Resultant Table:

Table 1:Thermal Resistance at 26 ml per5sec(i.e., 5.2ml/sec)

Q	Sintered Copper		Helical Groove		Mesh Wick	
	Δ T	R_{th}	Δ T	R_{th}	Δ T	R_{th}
15*3.3 =49.5	6	0.012	3	0.08	2	0.04
22*4.7 ~103	5	0.049	2	0.02	4	0.039
26*5.8 ~150	5	0.033	2	0.013	3	0.02
30*6.7 ~200	4	0.02	1	0.005	2	0.01
34*7.4 ~250	4	0.016	1	0.004	2	0.008

Δ T= TempDiff of Evaporator and condenser (^{0}C)
R_{th} = Thermal resistance (°c/Watt)
Q=Voltage*current (Watts)

Table 2: Thermal Resistance at 45ml per 5sec (i.e., 9 ml/sec)

Q	Sintered Copper		Helical Groove		Mesh Wick	
	Δ T	R_{th}	Δ T	R_{th}	Δ T	R_{th}
15*3.3 =49.5	4	0.081	4	0.081	3	0.06
22*4.7 ~103	2	0.019	2	0.019	3	0.03
26*5.8 ~150	2	0.013	3	0.02	3	0.02
30*6.7 ~200	4	0.02	1	0.005	3	0.015
34*7.4 ~250	4	0.016	1	0.004	1	0.004

Δ T= TempDiff of Evaporator and condenser (^{0}C)
R_{th} = Thermal resistance (°c/Watt)
Q=Voltage*current (Watts)

T_s = Stable Temp(^{0}C)
t_s = Time taken(Sec)

Table.3: Efficiency at 26 ml per 5sec (i.e., 5.2ml/sec)

Q	Sintered Copper		Helical Groove		Mesh Wick	
	Δ T	R_{th}	Δ T	R_{th}	Δ T	R_{th}
15*3.3 =49.5	1	76	1	76	1	76.0
22*4.7 ~103	2	73.04	2	73.04	2	73.04
26*5.8 ~150	2	50.16	2	50.16	3	75.24
30*6.7 ~200	3	56.43	3	56.43	5	94.05
34*7.4 ~250	4	60.19	3	45.14	5	75.24

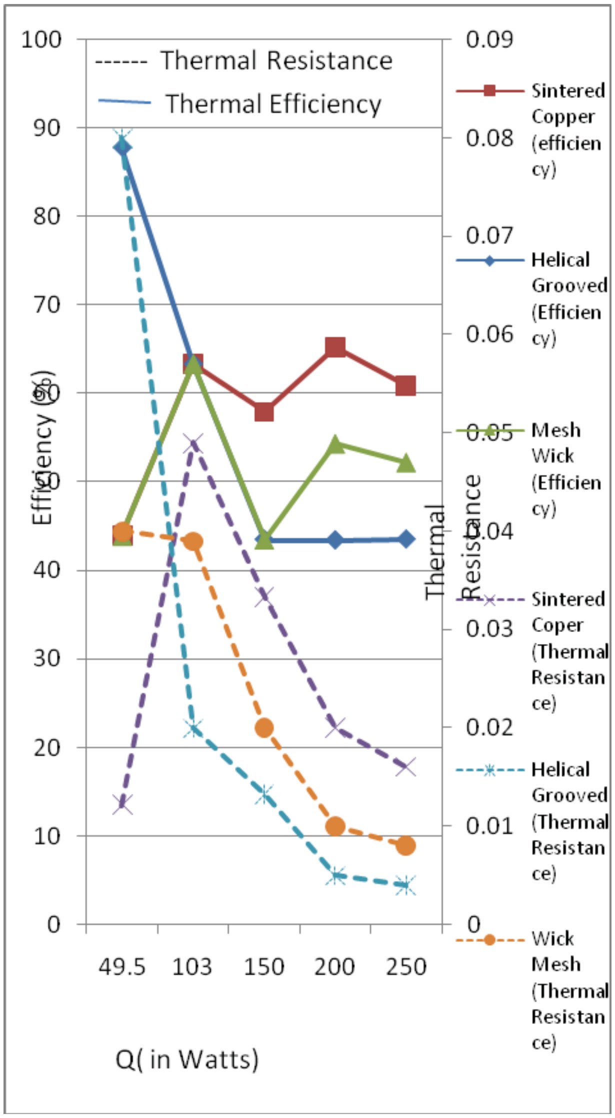
Table.4: Efficiency at 45ml per 5sec (i.e., 9 ml/sec)

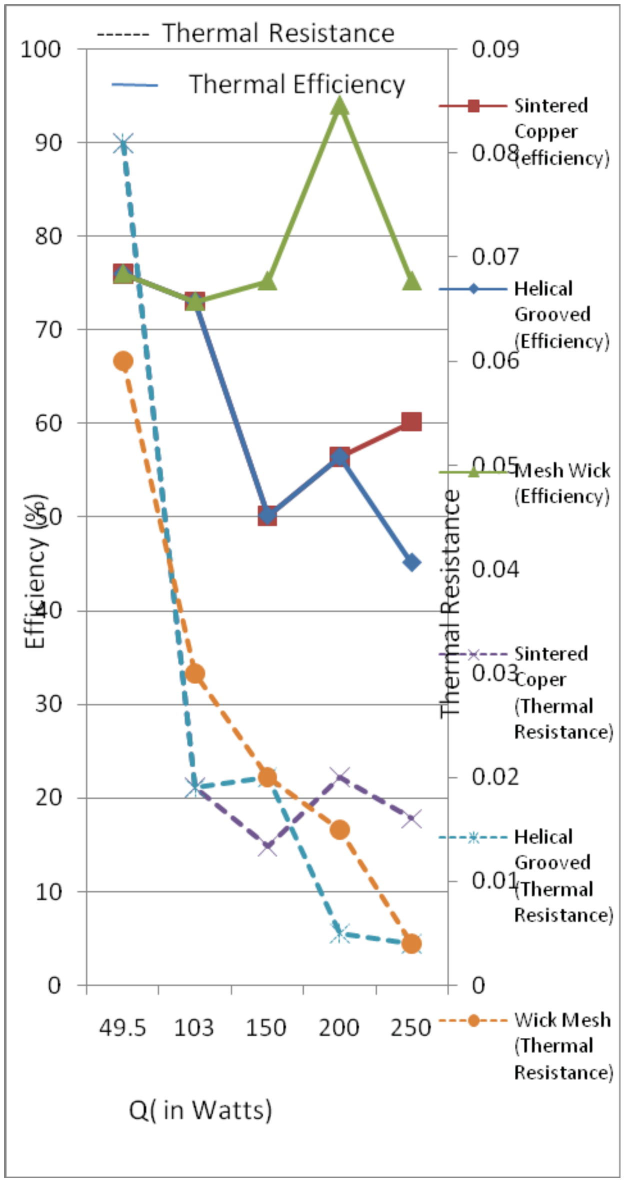
Q	Sintered Copper		Helical Groove		Mesh Wick	
	Δ T	R_{th}	Δ T	R_{th}	Δ T	R_{th}
15*3.3 =49.5	1	43.9	2	87.8	1	43.9
22*4.7 ~103	3	63.3	3	63.3	3	63.3
26*5.8 ~150	4	57.9	3	43.47	3	43.5
30*6.7 ~200	6	65.20	4	43.4	5	54.3
34*7.4 ~250	7	60.86	5	43.5	6	52.2

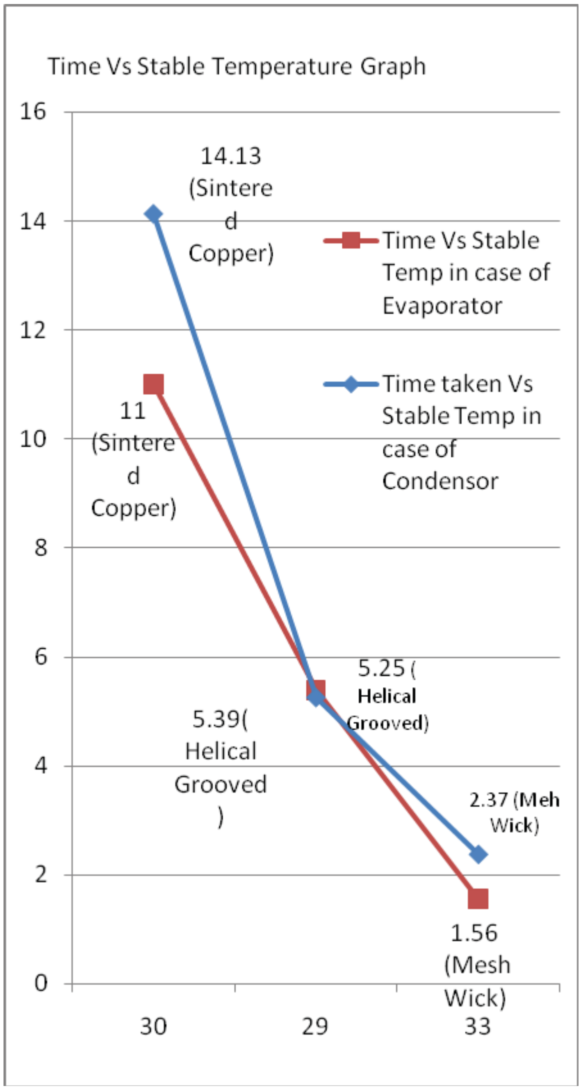
Table.5: Time taken for Stable Temperatures:

	Sintered Copper		Helical Groove		Mesh wick	
	T_s	t_s	T_s	t_s	T_s	t_s
Evaporator	32	11	30	5.39	36	1.56
condenser	30	14.13	29	5.25	33	2.37

Comparison of Heat Pipes by variations:




------ Thermal Resistance
Thermal Efficiency
Efficiency (%)
Thermal Resistance
Q(in Watts)
100
90
80
70
60
50
40
30
20
10
0
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
49.5
103
150
200
250
Sintered Copper (efficiency)
Helical Grooved (Efficiency)
Mesh Wick (Efficiency)
Sintered Coper (Thermal Resistance)
Helical Grooved (Thermal Resistance)
Wick Mesh (Thermal Resistance)



V. CONCLUSIONS

On comparison of various results discussed above, the following conclusions are drawn:

a) At any flow rate, the Thermal Resistance in case of Mesh Wick Type HP is lowest than other two types of HPs at lower Heat Input values.

b) At higher Heat Input values, Thermal Resistances of Mesh Wick and Helical groove type appears to be lowest compared to Sintered Copper type and are comparable.

c) The change in Thermal Resistance with Heat Input is more predominant in case of Mesh Wick and Helical groove types when compared to Sintered Copper type

d) At any flow rate, the efficiency obtained with Helical Grooved HP is highest compared to other two types at lower Heat Input values.

e) No appreciable change in efficiency with change in Heat Input is observed in case of Mesh wick HP.

f) For Helical Groove HP, change in efficiency is more predominant with HI values compared to other type HPs

g) The time taken to obtain stable temperatures for Evaporators and Condensers are least in case of Mesh Wick HP.

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