Impact Factor (SJIF): 4.542

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 4, Issue 5, May-2017

"Experimental analysis of Heat Pipe"

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Abstract..Heat pipes are heat transfer devices whose conductivity is several hundred times than that of a metal rod of same dimension. It works on the principle of evaporation and condensation of a working fluid under vacuum. Heat transfer capability of a heat pipe can be further improved by changing the working fluid, modifying the wick structure and also by changing the material of pipe as well as wick. However, modifying the conventional heat pipe with working fluid as acetone was prepared. The prepared heat pipes were tested in a test rig for different inclinations and time required to reach steady state was determined. The time taken for steady state is 40-45 minute. Heat pipes were tested for different flow rate. Temperature vs Time graphs were drawn for each flow rate and all inclination. The maximum temperature difference found at flow rate of 0.007 L/sec and for 90° inclination. The experimental results were compared with the existing work of different author.

Keywords- Heat pipe, Working fluid, Acetone, Flow rate, Inclination angle

I. INTRODUCTION

The heat pipe is a device of very high thermal conductance. The idea of the heat pipe was first suggested by Gaugler in 1942. It was not, however, until its independent invention by Grover in the early 1960s that the remarkable properties of the heat pipe became appreciated and serious development work took place.The heat pipe is similar in some respects to the thermosiphon and it is helpful to describe the operation of the latter before discussing the heat pipe. The thermosiphon is shown in Fig. 1. A small quantity of water is placed in a tube from which the air is then evacuated and the tube sealed. The lower end of the tube is heated causing the liquid to vaporise and the vapour to move to the cold end of the tube where it is condensed.

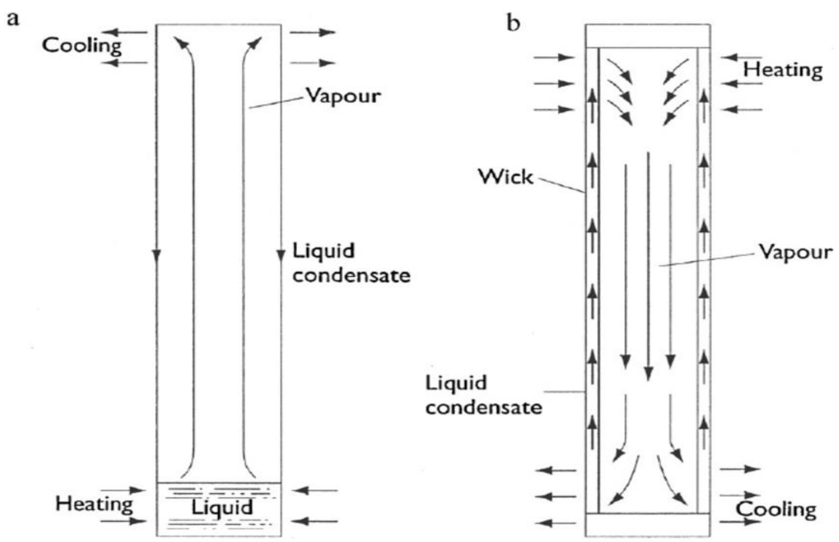


Fig.1 Thermosiphon and Heat pipe.

The condensate is returned to the hot end by gravity. Since the latent heat of evaporation is large, considerable quantities of heat can be transported with a very small temperature difference from end to end. Thus, the structure will also have a high effective thermal conductance. One limitation of the basic thermosiphon is that in order for the condensate to be returned to the evaporator region by gravitational force, the latter must be situated at the lowest point.

The basic heat pipe differs from the thermosiphon in that a wick, constructed for example from a few layers of fine gauze, is fixed to the inside surface and capillary forces return the condensate to the evaporator (Fig. 1). In the heat pipe the evaporator position is not restricted and it may be used in any orientation. The term 'heat pipe' is also used to describe high thermal conductance devices in which the condensate return is achieved by other means, for example centripetal force, osmosis or electro hydrodynamics.

The main regions of the standard heat pipe are shown in Fig.2. In the longitudinal direction (Fig. 2), the heat pipe is made up of an evaporator section and a condenser section. Should external geometrical requirements make this necessary; a further, adiabatic, section can be included to separate the evaporator and condenser.

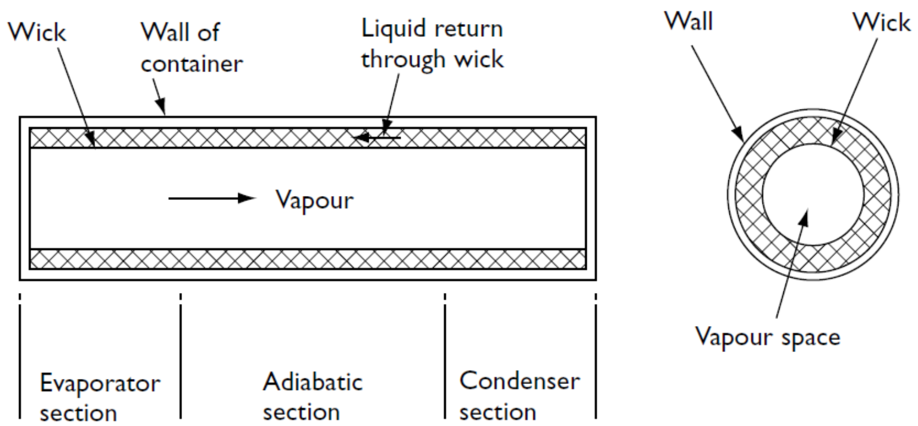


Fig.2 The main regions of Heat pipe.

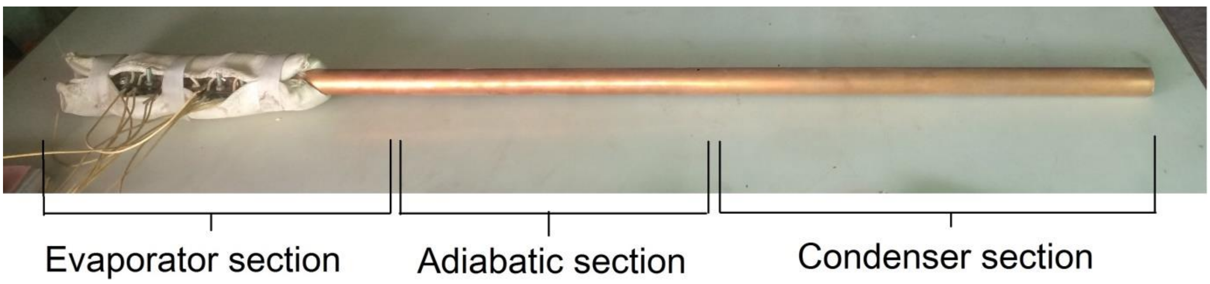


Fig.3 Copper Heat pipe

We have made a heat pipe, which have a copper envelop, use acetone as a Working fluid and typically operate in the temperature range of -40°C to 140°C. Wick structure with in heat pipe is made by copper material with 100 mesh.

II. ANALITICAL DESIGN

Characteristics of Heat pipe

A heat pipe of Copper tube with outer diameter of 25.4 mm and 100 cm of length. The heat pipe has an evaporator region with 26 cm in length and a condensation region with 30 cm in length. A characteristic of heat pipe is shown in table 1

Table 1 Analytical Design

Characteristic of Heat Pipe	Heat pipe
Heat pipe inner diameter	24 mm
Heat pipe outer diameter	25.4 mm
Evaporator length	26 cm
Adiabatic region length	44 cm
Condenser length	30 cm
Working fluid	Acetone

Heat transport limitation

1) Viscous limitation

The viscous limit occurs at low operating temperature, where the saturation vapor pressure may be of the same order of magnitude as the pressure drop required to drive the vapor flow in the heat pipe.The result in an insufficient pressure available to drive the vapor. The viscous limit is sometime called the vapor pressure limit.

2) Sonic limitation

The sonic limit is due to the fact that at low vapour densities, the corresponding mass flow rate in the heat pipe may result in very high vapour velocities, and the occurrence of choked flow in the vapour passage may be possible. The minimum axial heat flux due to the sonic limitation will occur at the minimum operating temperature, 0C, and can be calculated from below the equation.

$$q_s = \rho_v L \sqrt{\frac{\gamma R T_v}{2(\gamma+1)}}$$

gas constant for each fluid may be obtained from

$$R = \frac{Ro}{\text{Molecular weight}} = \frac{8315}{M_w} \text{ J/kgK}$$

For acetone, $\gamma = 1.4$ and its molecular weight is 58.03, q_s is given by

$$q_s = 0.26 \times 495 \sqrt{\frac{1.4 \times 8315 \times 273}{2(1.4+1)58.03}}$$

$$= 1.3 \text{ kW}/cm^2$$

3) Entrainment limitation

The entrainment limit refers to the case of high shear forces developed as the vapour passes in the counter flow direction over the liquid saturated wick, where the liquid may be entrained by the vapour and returned to the condenser. This results in insufficient liquid flow of the wick structure.

The maximum heat transport due to the entrainment limit may be determined from below

$$q_s = \sqrt{\frac{2\pi\rho_v L^2 \sigma_l}{z}}$$

Which may be written

$$Q_{ent} = \pi {r_v}^2 L \sqrt{\frac{2\pi\rho_v \sigma_l}{z}}$$

Where z is the characteristic dimension of the liquid–vapour interface. The entrainment limit is evaluated at the highest operating temperature. A sample calculation for acetone is reproduced.

$$Q_{ent} = \pi\,(2.1 \times 10^{-3})^2 \times 495 \sqrt{\frac{2\pi \times 4.05 \times 0.0162}{0.036 \times 10^{-3}}}$$

= 1040W

4) Boiling limitation

The boiling limit occurs when the applied evaporator heat flux is sufficient to cause nucleate boiling in the evaporator wick. This creates vapour bubbles that partially block the 80 liquid return and can lead to evaporator wick dry out. The boiling limit is sometimes referred to as the heat flux limit.

Boiling in the wick may result in the vapour blocking the supply of liquid to all parts of the evaporator. In arterial heat pipes, bubbles in the artery itself can create even more serious problems. It is therefore desirable to have a working fluid with a high superheat ΔT to reduce the chance of nucleation. The degree of superheat to cause nucleation is given by

$$\Delta T = \frac{3.06\sigma_l T_{sat}}{\rho_v L\delta}$$

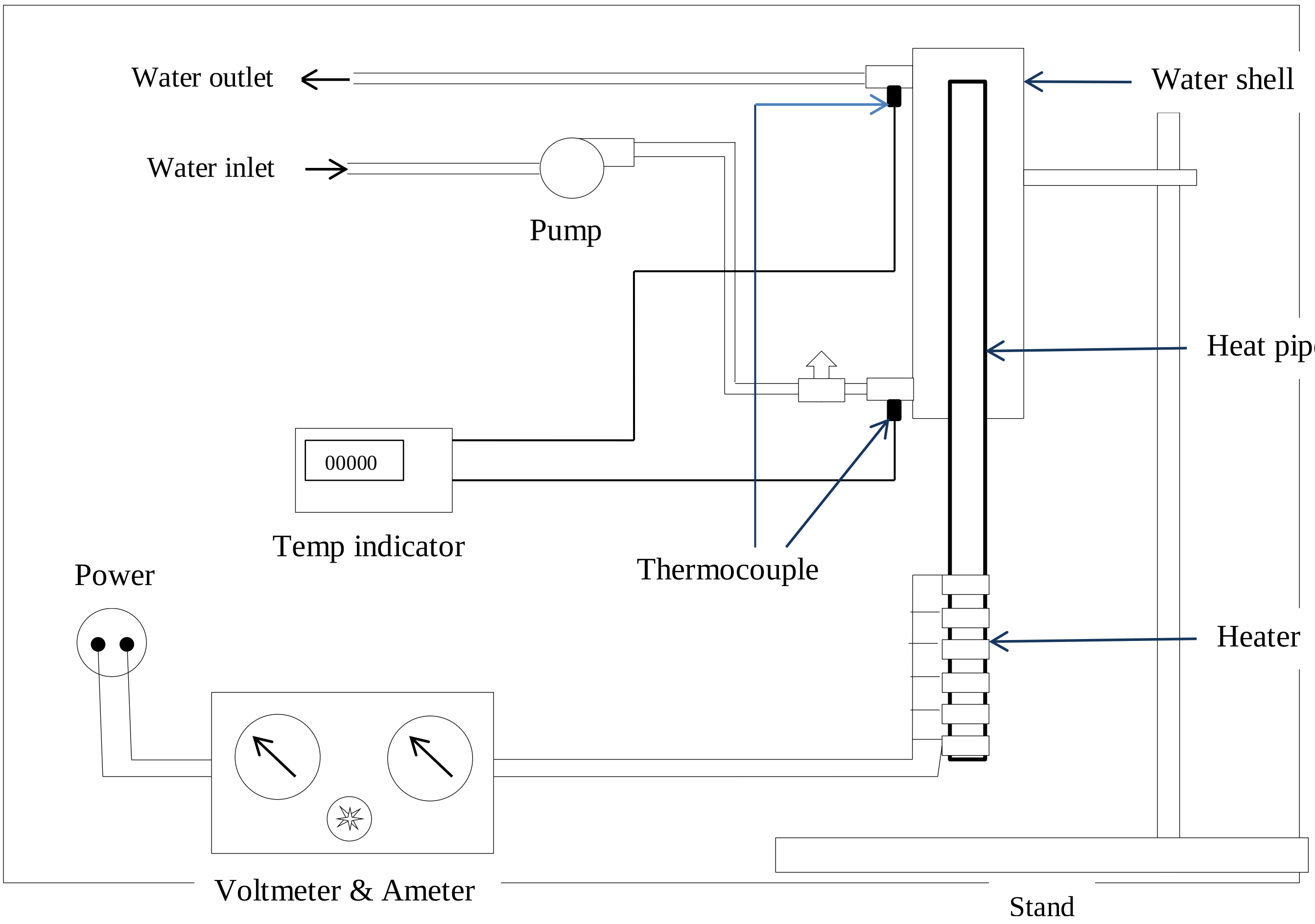
$$= \frac{3.06 \times 16.2 \times 353}{4.06 \times 495 \times 15.012}$$

= 0.58 K

5) Capillary limitation

Related to the fundamental phenomenon governing heat pipe operation which is development of capillary pressure differences across the liquid-vapour interfaces in the evaporator and condenser. When the driving capillary pressure is insufficient to provide adequate liquid flow from the condenser to the evaporator, dry out of the evaporator wick will occur.

III SETUP DESIGN



IV EXPERIMENTAL METHODS

The heat pipe is fabricated using a copper tube of 1000 mm length and 24 mm inner diameter and 25.4mm outer diameter. Heater having inner diameter 25.6 mm and length 25.4 mm is used. This kind of 6 heaters are attach in series to heating the evaporator section. The evaporator, adiabatic section of the heat pipe and water jacket are insulated to minimize the heat loss through them. Variac and multimeter are provided to control and measure the power input respectively. Experiments are repeat for different heat inputs with different fill ratios and various plots are draw to study the performance of heat pipe for optimize results.

1) By passing water once through the shell (At different flow rate)

For this experiment, we set this kind of arrangement in that, Water pass through the shell by pump for once. Inlet and outlet temperature will be measured with the help of thermocouple.

Time(min)	**Temp(°C)**		
	Flow rate (li/sec)		
	0.007	**0.010**	**0.016**
0	29	28	28
5	30	29	28

10	34	31	29
15	36	32	29
20	39	33	29
25	39	33	30
30	39	34	30
35	40	34	31
40	40	35	32
45	40	35	32
50	40	35	32
55	40	35	32
60	40	35	32

Table-2 Response of time

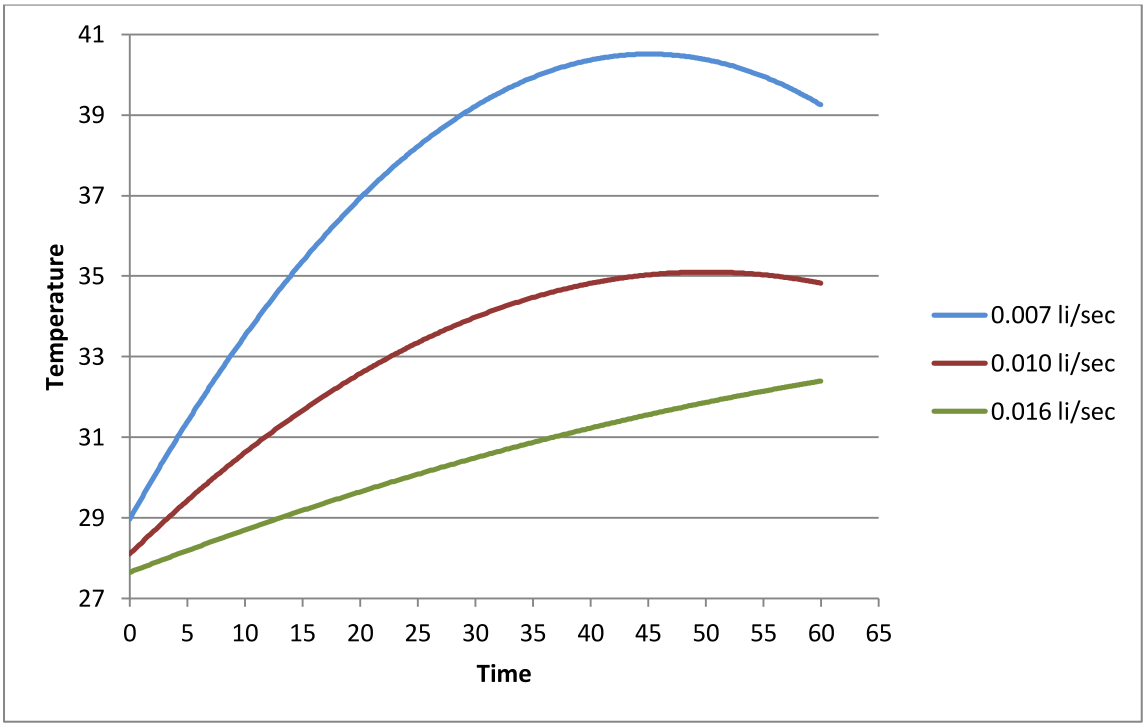


Fig.4 Time vs Temperature

Voltage = 200 V
Current = 2.1 A
Flow rate1 = 0.007 L/sec
Flow rate2 = 0.010 L/sec
Flow rate3 = 0.016 L/sec

- For flow rate =0.007 L/sec

Power $P = V \times I \times 0.8$
$= 200 \times 2.1 \times 0.8$
$P = 336$ Watt
$Q = mCp\Delta T$
$= 0.007 \times 4187 \times 11$
$= 322.39$

Efficiency $\varepsilon = \frac{Q}{P} = \frac{332.39}{336}$
$= 0.9595 \times 100\%$
$= 95.95\ \%$

- For flow rate = 0.010 L/sec
  Power P = V × I× 0.8
  = 200 × 2.1× 0.8
  P = 336 Watt

  Q = mCpΔT
  = 0.010×4187×7
  = 293.09

  Efficiency $\varepsilon = \frac{Q}{P} = \frac{293.09}{336}$
  $= 0.8722 \times 100\%$
  $= 87.22\ \%$

- For flow rate = 0.016 L/sec
  Power P = V × I× 0.8
  = 200 × 2.1× 0.8
  P = 336 Watt

  Q = mCpΔT
  = 0.016×4187×4
  = 267.96

  Efficiency $\varepsilon = \frac{Q}{P} = \frac{267.96}{336}$
  $= 0.7974 \times 100\%$
  $= 79.74\ \%$

2) Inclination Of Heat Pipe

Here the inclination of the heat pipe is analysed. Two different scenarios have been analysed the condenser positioned above the evaporator and evaporator positioned above the condenser. It is also analysed the inclination of heat pipe for the different angle and different orientation. The result is shown in table.3 and plotted graph in fig.5.2. First the condenser positioned above the evaporator. It is examine and compare with standard graph. Then evaporator positioned above the condenser and same process is applied.

Time(min)	Temp(°C)		
	Inclination		
	4.5°	45°	90°
0	28	28	29
5	29	32	32
10	31	33	33
15	32	33	34
20	33	34	35
25	33-	34	35
30	34	34	36
35	34	35	36
40	35	35	36
45	35	35	36
50	35	35	36

Table-3 Heat pipe at angle

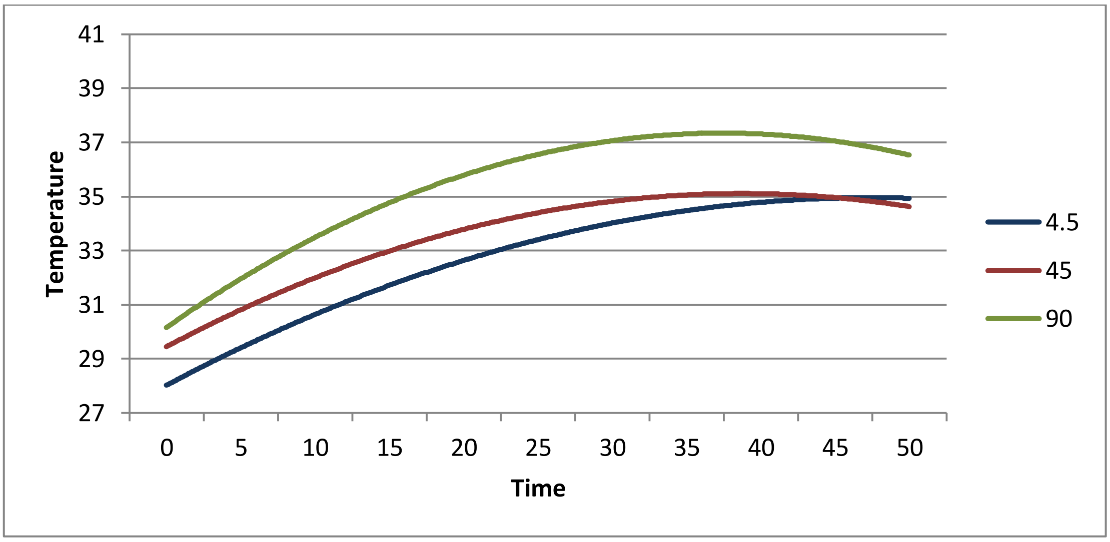


Fig.5.Time vs temperature

Voltage = 200 V

Current = 2.1 A

Flow rate = 0.010 L/sec

- For inclination at 4.5°

Power P = V × I× 0.8

= 200 × 2.1× 0.8

P = 336 Watt

Q = mCpΔT

= 0.010×4187×7

= 293.09

Efficiency $\varepsilon = \frac{Q}{P} = \frac{293.09}{336}$

= 0.8722 × 100%

= 87.22 %

- For inclination at 45°

Power P = V × I× 0.8

= 200 × 2.1× 0.8

P = 336 Watt

Q = mCpΔT

= 0.010×4187×7

$= 293.09$

Efficiency $\varepsilon = \frac{Q}{P} = \frac{293.09}{336}$

$= 0.8722 \times 100\%$

$= 87.22\ \%$

- For inclination at 90°

Power P = V × I× 0.8

$= 200 \times 2.1 \times 0.8$

P = 336 Watt

Q = mCpΔT

$= 0.010 \times 4187 \times 8$

$= 334$

Efficiency $\varepsilon = \frac{Q}{P} = \frac{334}{336}$

$= 0.9904 \times 100\%$

$= 99.04\ \%$

IIV RESULTS

1 Effect of flow rate

Experiments were carried out with different flow rate and at inclination. The results are shown below for 0.007 L/sec, 0.010 L/sec and 0.016 L/sec flow rates and 4.5°, 45°, 90° angle.Heat pipe is analysed for three flow rate. Result found as followed, for flow rate of 0.007 L/sec temperature difference between inlet and output found to be 10°C.For second flow rate of 0.010 L/sec temperature difference found to be 7°C and further increasing flow rate of 0.016 L/sec temperature difference found to be 4°C. The above data shows that slope of temperature distribution for different flow rate affect the efficiency. Efficiency of heat pipe for different flow rate is shown in table-4.

Flow rate(L/sec)	Inclination(℃)	Efficiency (%)
0.007	4.5	95.95%
0.010	4.5	87.22%
0.016	4.5	79.74%

Table-4 Results at different flow rate

2 Effect of Inclination

Heat pipe is analysed for different inclination at constant flow rate. Result found as followed, for angle 4.5° temperature difference found to be 7°C. For the 45°angle temperature difference 7°C and for the 90°angle temperature rise found to be 8°C. So, Inclination of heat pipe improves the efficiency. Efficiency of heat pipe for different inclination is shown in table-5.

Flow rate(L/sec)	Inclination(°C)	Efficiency (%)
0.010	4.5	87.22%
	45	87.22%
	90	99.04%

Table-5 Results at different angle

Conclusion

The experiment was conducted on heat pipe. Heat pipe is analysed for different flow rates, at constant power input. From the above results, we concluded that by increasing flow rate in the shell results in decrease of the temperature difference between inlet and outlet. Hence, the efficiency decreases with increases of flow rate at same power input.

Heat pipe is also analysed for different inclination at constant flow rate and constant power. From the above results, we concluded that by increasing angle of the shell and heat pipe, results in increase of the temperature difference between inlet and outlet. Hence, the efficiency increases with increases of angle at constant power input and flow rate.