Proceedings of the
International Conference on Mechanical Engineering 2003
(ICME2003) 26- 28 December 2003, Dhaka, Bangladesh

ICME2003-TH-20

PERFORMANCE OF A GRAVITY ASSISTED HEAT PIPE

MD Anwarul Hasan[1], Chowdhury MD Feroz[2] and A.K.M. Sadrul Islam[2]

[1]Division of Mechanical Engineering, Kongju National University, South Korea
[2]Department of Mechanical Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh

ABSTRACT

This paper elaborately discusses the performance of a gravity assisted heat pipe of diameter 12.5 mm and length 0.50 m using water as working fluid. Experiment has been performed to investigate the performance of the heat pipe at various inclination angles and different heat flux input at the evaporator section. The study covers the range of inclination angle from 0 to 60^o, heat input from 25 to 40 W and a fill charge ratio of 0.20. The best performance of heat pipe is achieved at its vertical position where gravity serves to assist return of condensate from condenser to evaporator. The thermal resistance increases with the increase of inclination angle. Overall heat transfer coefficient is found to be proportional to the heat flux at the evaporator and inversely proportional to the inclination angle.

Keywords: Heat Pipe, thermal resistance, Overall heat transfer coefficient

1. INTRODUCTION

Heat pipe is a special type of cooling device which utilizes the exchange of latent heat of evaporation and condensation of a medium contained in a sealed pipe for cooling of a space.[1]

Heat pipe is one of the most efficient device and latest invention of thermal science in heat transfer field. Although the concept of heat pipe was generated in the 1940's it was only the mid 60's when heat pipe was developed beyond its patent stage and the early 70's when it became available in the market for commercial sales[2].

The continuous increase of the power densities and reduction in size in electronic equipment and packages has recently farther increased the interest in heat pipe. In fact heat pipe has emerged as the most appropriate technology and cost effective thermal design solution due to its excellent heat transfer capability, high efficiency and its structural simplicity. The ability to transport very large quantity of heat with small temperature differences is the main feature characterizing the heat pipe. The device has other desirable features as well. When heat is concentrated at one location, it can be removed through a heat pipe and distributed over a large region. This feature has become important in the miniaturization of electronic equipments. Heat pipe working under gravity with the condenser above the evaporator is known as gravity assisted heat pipe [3] as shown in Fig. 1. Gravity assisted heat pipe has found numerous application in heat recovery [4,5], solar energy [6] and recently in light water nuclear reactors [7].Bilegan and Fetcu[8] worked on performance characteristics of gravity assisted aluminium extruded heat pipe considering the effect of operating temperature,tilt angle and the length of the heat pipe.They concludedthat relatively high rates of heat transfer can be achieved with heat pipes containing simple and inexpensive wick and Freon-12(R-12) as working fluid. Andros and Florschetze [9] and Nguyen-Chi and Abhat [10] observed the flow behavior at the evaporator section while Shirashi et al. [11] studied the flow behavior at the evaporator and adiabatic regions for both vertical and inclined gravity assisted wickless heat pipe. They all reported that the counter flowing vapor affects the condensate return to the evaporator, developing a disturbance wave which will lead to entrainment or a flooding limit at higher heat flux.

The purpose of our study is to investigate the performance of a gravity assisted water filled heat pipe containing steel net mesh as wick material

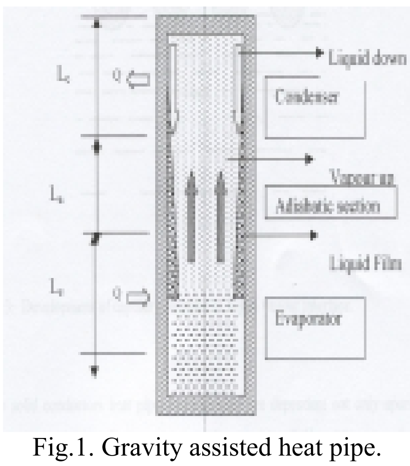


Fig.1. Gravity assisted heat pipe.

2. EXPERIMENTAL APPARATUS AND TEST PROCEDURE

The schematic diagrams of the heat pipe used in the experiment and the experimental set up are shown in Figs. 2(a) and 2(b), respectively. A stainless steel tube having inner diameter of 12.5 mm and length of 0.50 m was used as a heat pipe for this experiment. A screen or mesh made of stainless steel net was rolled and inserted inside the pipe as wick material. Inside volume of the evaporator section was filled with water, both ends of the pipe was closed by welding. Eighteen calibrated K- type thermocouples were attached at the outer surface of the heat pipe by heat proof tape. Ten units of thermocouples were attached to the evaporator wall each at an interval of 10mm, five units were at adiabatic section each at an interval of 40 mm and three units were at condenser section. Mica sheet was wound around the evaporator section for electrical insulation. Ni-Cr thermic wire was wound around the evaporator wall for heating. The evaporator section and adiabatic section was thermally insulated with glass wool to minimize the heat loss from the wall.

To perform forced cooling a water jacket was built around the condenser section through which water coolant flows. The vertical position of heat pipe was marked as zero degree and by rotating the test rig, heat pipe was set to various angle of inclination. Heater was switched on and water line for the coolant opened simultaneously. Heat was supplied to the evaporator section electrically through AC power supply starting from 25 watt with an increase of 5 watt step reaching up to 40 watt finally. Wall Temperatures of the evaporator, adiabatic and condenser sections were recorded at steady state condition. These operations were repeated for other inclination angles of 10, 20, 30, 45 and 60 degrees.

Experimental parameters and their ranges for the performance test of the heat pipe are shown in Table 1:

Table 1: Experimental parameters and their ranges

Parameters	Condition
Diameter of pipe	12.5 mm
Length of pipe	500 mm
Length of evaporator section	200 mm
Length of adiabatic section	100 mm
Length of condenser section	200 mm
Kind of working fluid	Water
Inclination angle	0^o,10^o,20^o,30^o,45^o,60^o
Charging ratio	20%
Heat input	25w,30w, 35w, 40w

Heat pipe thermal resistance, R was calculated by using the measured mean wall temperature in the evaporator and condenser sections and heat input, i.e.

$$R = (T_e - T_c) /Q \qquad (1)$$

Where T_e is the wall temperature of the evaporator section of heat pipe, T_c is the wall temperature of the condenser section and Q is the thermal load imposed on the evaporator. The overall heat transfer coefficient, U_t is obtained from the following equation:

$$U_t = Q / A_e (T_e - T_c) \qquad (2)$$

Where, A_e is the surface area of the evaporator while Q, T_e and T_c are as above.

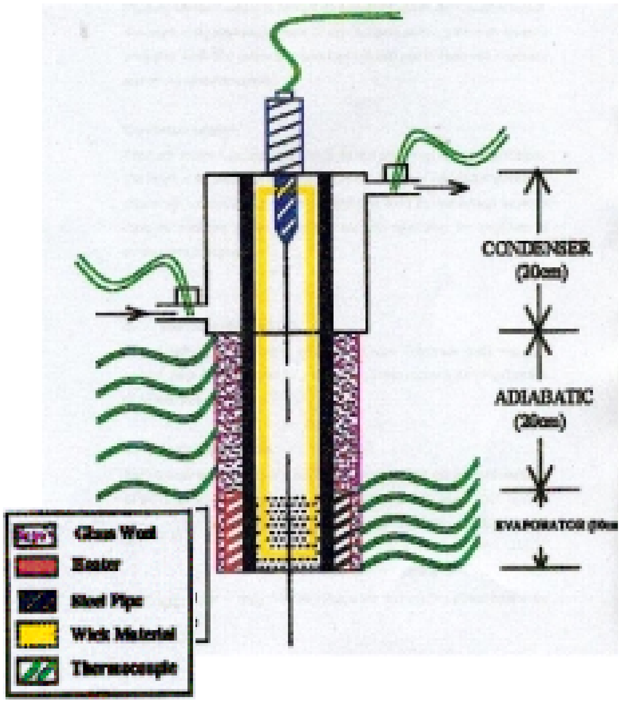


Fig. 2(a). Schematic Diagram of model heat pipe

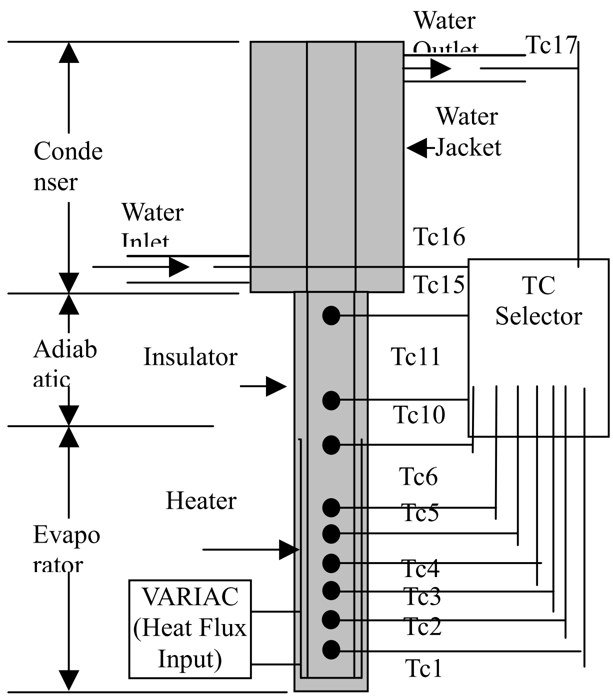
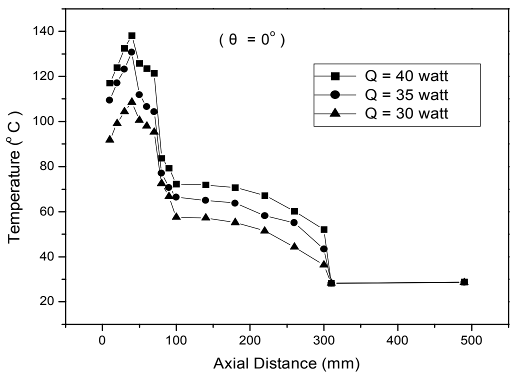


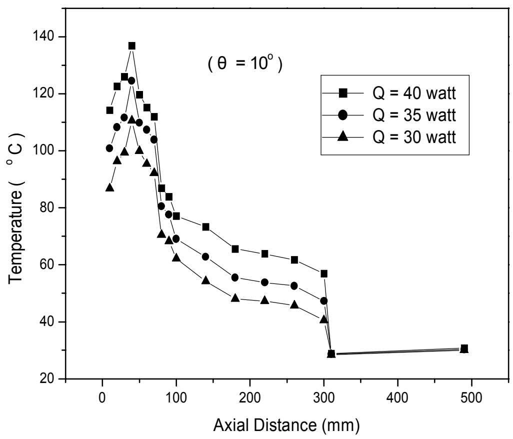
Fig. 2(b) Schematic diagram of experimental set-up

4. RESULTS AND DISCUSSION

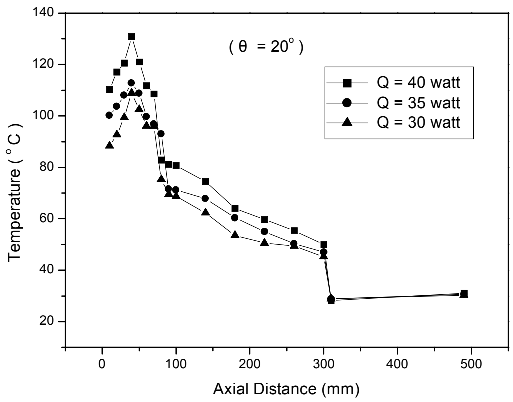
Figs. 3(a) to 3(e) show the axial wall temperature distribution of the heat pipe at various heat input and inclination angle. The figures indicate that at a particular heat input the temperature of evaporator section is lowest when the heat pipe is placed vertically and the temperature of the evaporator increases as the inclination angle of the heat pipe increases. This result is consistent with the finding of Well and Yuan [13]. At the same heat input, cooling water flow rate and inclination angle the wall temperature of the evaporator section is higher at higher power input.



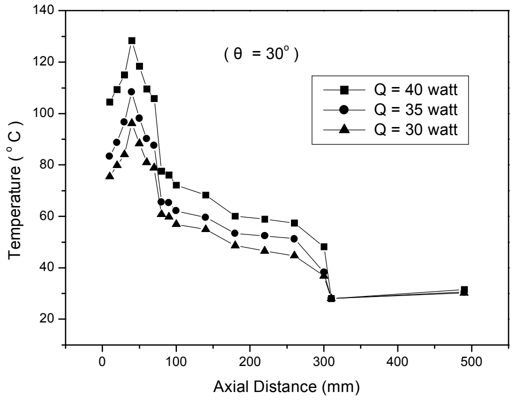
(a)



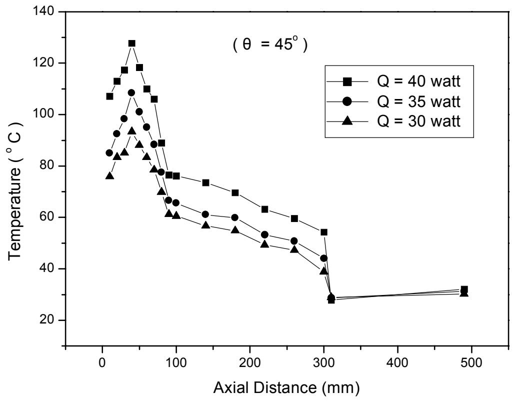
(b)



(c)



(d)



(e)

Fig 3: Axial Temperature distribution along the heat pipe (a) $\theta = 0^o$, (b) $\theta = 10^o$, (c) $\theta = 20^o$, (d) $\theta = 30^o$, (e) $\theta = 45^o$

Fig.4 shows the effect of inclination angle on the thermal resistance of heat pipe at various power input. From the figure it is clear that thermal resistance increases with increase in inclination angle at all heat input. This implies that the action of gravity, which serves to speed up the flow of liquid from condenser to evaporator, decreases with increase in inclination angle. It should be noticed however that up to an inclination angle of about 20 degree the rate of increase of thermal resistance is very slow after which it rises abruptly up to

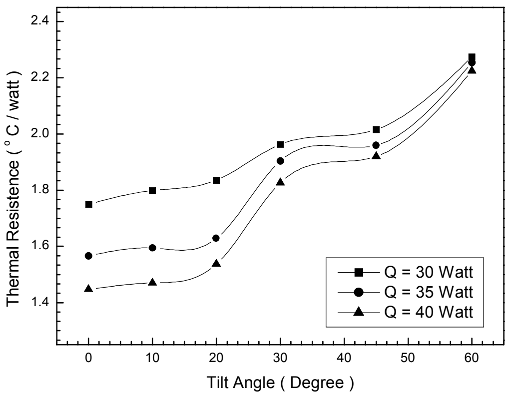


Fig 4. Effect of inclination angle on thermal resistance of heat pipe

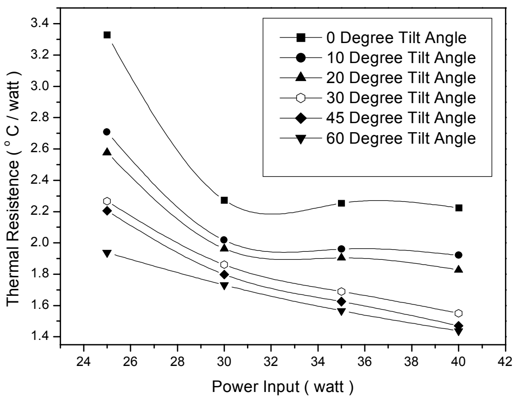


Fig.5.Effect of power input on thermal resistance of heat pipe

60 degree inclination angle within our experimental range. The reason behind this may be explained as follows: As the inclination angle increases the vapor comes in contact of the pipe wall before reaching the condenser section, hence condensation occurs in adiabatic section and the rate of condensation is slower which results in a low heat transfer rate i.e. high thermal resistance.

Fig.5 shows the effect of varying power input on thermal resistance of heat pipe at various tilt angle. It is evident that thermal resistance of heat pipe is high at low input power and it decreases with increase in heat flux input at the evaporator

Fig.6 shows the effect of varying power input on overall heat transfer coefficient of heat pipe at various tilt angles. The figure indicates that the overall heat transfer coefficient increases with increase in power input at any inclination angle. Fig.7 shows the effect of inclination angle on overall heat transfer coefficient. It shows that overall heat transfer coefficient of a gravity assisted heat pipe is highest at any power input within our experimental range when it is placed in vertical position, and is inversely proportional to the inclination angle from vertical position.

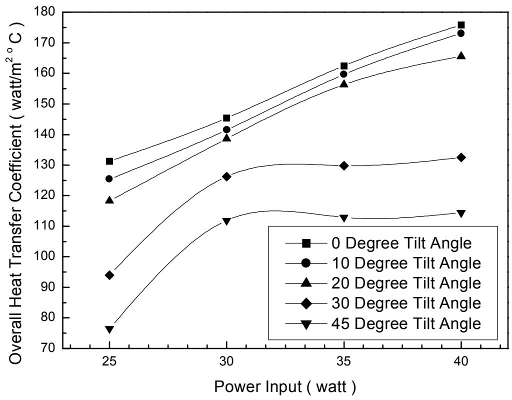


Fig 6. Effect of power input on overall heat transfer coefficient of heat pipe

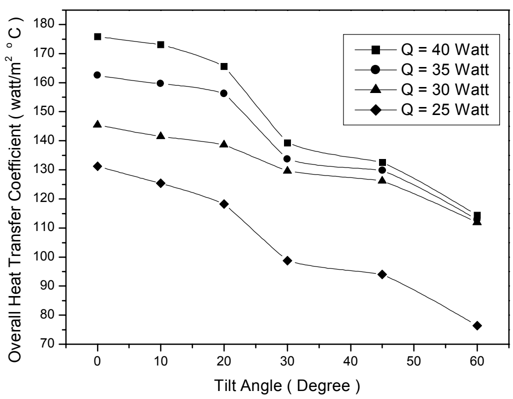


Fig 7. Effect of inclination angle on overall heat transfer coefficient of heat pipe

5. CONCLUSIONS

The results of the performance test for the gravity assisted heat pipe having diameter of 10 mm and length 0.5 m are summarized as follows:

a. At a particular heat input the wall temperature of the evaporator section is lowest when the heat pipe is placed vertically; It is highest when heat pipe is horizontal and the wall temperature of the evaporatorsection increases as the inclination angle from vertical position increases.

b. The thermal resistance increases with the increase of inclination angle. The rate of change of thermal resistance within the inclination angle 20 degree from vertical position is very slow. However, between 20 degree and 30 degree the thermal resistance increases sharply. At an angle around 45 degree another boost up in thermal resistance is noticed for the heat pipe used in this experiment.

c. The overall heat transfer coefficient decreases as the inclination angle from the vertical position of the heat pipe increases.

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