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Thermal Characteristics of a Cylindrical Heat Pipe using Multi-Layer Screen Mesh Wick

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ABSTRACT:

Heat pipe is the most widely used heat exchanging device in removal of heat from any given system at a faster rate. The thermal characteristics of heat pipe with single and multi-layered screen mesh wicks have been observed with two working fluids water and acetone. Heat pipe of length 250 mm and 12.7 mm outer diameter, made of copper material is used in all the trials of with and without wick structure. A 100 mesh stainless steel screen wire mesh is chosen as wick structure. Experiments were conducted at different heat loads and various inclinations with 100% fill ratio in evaporator. The performance is measured based on total thermal resistance and overall heat transfer coefficient. The heat pipe is found effective at 60^o inclination with acetone as a working fluid and with four layered screen mesh wick. Uncertainty in thermal resistance and heat transfer coefficient is calculated for a heat input of 10W at 0° and 60° inclinations.

KEYWORDS:

Heat pipe; Screen wire wick; Multi-layer screen mesh; Uncertainty

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ACRONYMS AND NOMENCLATURE:

A	Surface area at evaporator (m^2)
h	Heat transfer coefficient ($W/m^2.K$)
Q	Power or heat Input (W)
R	Total thermal resistance (°C / W)
T_c	Average condenser temperature (°C)
T_e	Average evaporator temperature (°C)

1. Introduction

There are different ways to extract heat from electronic gadgets or instruments by using different cooling devices. Heat pipe is one of the most effective and fastest ways of removing heat from any device in many applications [1, 4]. The performance of any heat pipe depends on various factors like the geometry of the heat pipe, material of heat pipe, working fluid and its fill ratio, type of wick structure and orientation or inclination of the heat pipe. Literature review for majority of the configurations (like dry run, wet run with and without wick structure) showed that at the inclination of 60°, heat pipe shows a better performance [2]. Material and the working fluid are chosen based on the compatibility and the application [3]. Even the fill ratio in the evaporator helps in enhancing the heat transfer. For Acetone as working fluid the results showed better performance at 100% fill ratio in the evaporator [7, 12]. Working fluids with low boiling point like Acetone is more preferable since they start evaporating earlier than water at a given temperature or heat input [5, 6].

Even though there are several wick structures available screen mesh wick is chosen for study in this paper since it is easy to design a heat pipe with screen mesh wick than sintered powder and groove wick structures. The porosity or mesh size as well as the screen mesh wick material will decide the performance of heat pipe. The total number of layers of screen mesh wick (multi-layer) may vary the resistance and heat transfer coefficient in a given heat pipe. The following assumptions were made for the experiment:

(a) container and working fluid will not react and not form any non-condensable gases
(b) vapour and liquid flows will be laminar
(c) the compressibility will be negligible
(d) the vapour considered to be saturated at 273.15 K
(e) all the thermo physical properties are considered to be constant
(f) the body forces are considered to be negligible.

2. Experimental set up

The schematic of experiment is shown in Fig.1. It includes a heat pipe (evaporator section, adiabatic section and condenser sections) with wick structure. A control panel is used to measure heat input in terms of voltage (V) and current (I), thermocouple readings of temperature (°C). An autotransformer dimmer is used along with the panel in order to vary the heat input. The heat pipe is fabricated using copper tube with 250 mm length, 10.3 mm inner and 12.7 mm outer diameter. An electric heater of 230V AC and 400W capacity is inserted into the evaporator section on one end of the heat pipe. The other end of the heat pipe is submerged in a water filled container which will act like a heat sink. Thermocouples of K-type are used for recording temperatures along the length of the heat pipe.

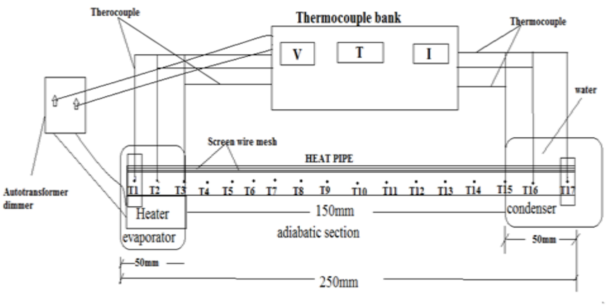

Fig. 1: Experimental set up of heat pipe

Initially the experimentation is carried out by taking heat pipe without (w/o) wick structure, filled with water and acetone separately. The fill ratio is 100% of evaporator section volume which is equal to 4.17 ml. For both the configurations performance is measured at various heat inputs as well as at different inclinations of heat pipe. Later the experiments are repeated by introducing screen mesh wick inside the heat pipe. A Stainless steel screen mesh of 0.15 mm porosity, 0.1 mm thickness is used as wick structure inside the heat pipe. First the experiments are conducted with single layer of screen mesh wick and then continued with two and four layers. Heat transfer at the condenser is taking place by natural convection as there is no external source used outside the heat sink.

3. Mathematical equations

The performance of heat pipe observed in this study is total thermal resistance and overall heat transfer coefficient. They are presented by the following equations:

$$R = \frac{Te - Tc}{Q} \quad (1)$$

$$h = \frac{Q}{A(Te - Tc)} \quad (2)$$

4. Results and discussion

The experiment is conducted at various heat inputs i.e., at 10W, 15W, 30W and 45W and at various inclinations of 0°, 30°, 45° and 60°. As mentioned before the trails are conducted both with water, acetone as working fluids, with and without wick structure (single and multi-layer screen mesh wick). Fig. 2 shows the temperature distribution along the length of the heat pipe at various heat inputs. It is observed that temperature drops along the length of the heat pipe. Higher is the heat input, higher is the temperature drop. Fig. 3 shows the variation of temperature along the length of heat pipe at an input of 10W, with and without screen mesh wick. Fig. 4 shows the total thermal resistance against the heat input or power at various inclinations. It is observed that heat pipe at 60° inclination has the lowest resistance when compared to other orientations.

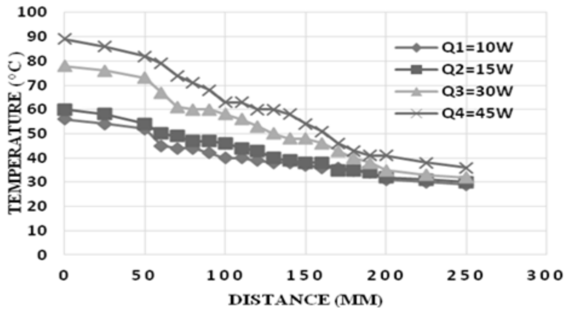

Fig. 2: Temperature distribution along the length of the heat pipe (w/o wick)

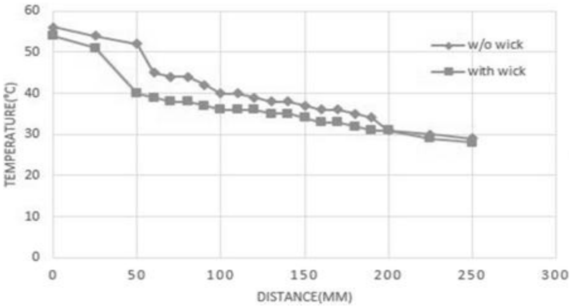

Fig. 3: Temperature distribution along the length of heat pipe at Q = 10W (with and w/o wick) – water

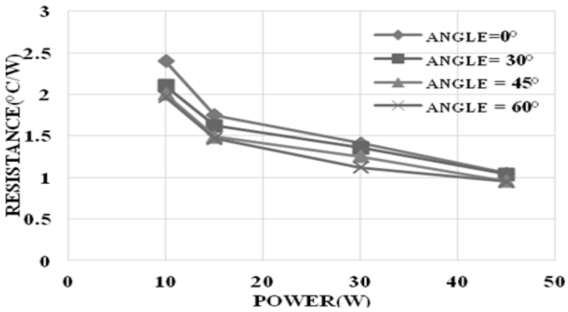

Fig. 4: Variation of thermal resistance against power at different inclinations (w/o wick) - water

Fig. 5 shows that lower the resistance, higher is the heat transfer and the overall heat transfer coefficient. Fig. 6 and Fig. 7 shows the variations in resistance and the heat transfer coefficient at different heat inputs respectively. The comparison is made with water as working fluid and both with and w/o wick structure. Since 60° inclination of heat pipe gave a better result, the comparison is shown only between 0° and 60°. As expected heat pipe with wick showed a better performance than w/o wick at 60° inclination.

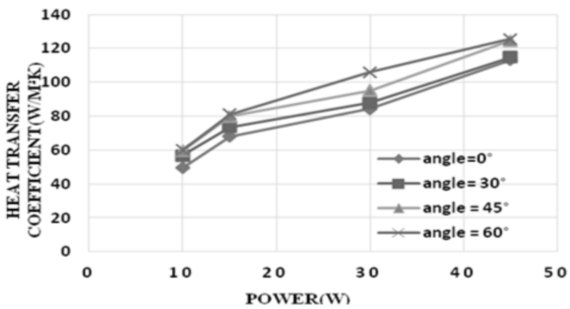

Fig. 5: Variation of heat transfer coefficient against power (w/o wick) – water

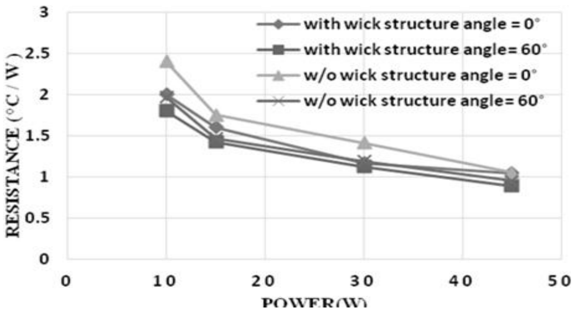

Fig. 6: Variation of thermal resistance against power (with and w/o wick) – water

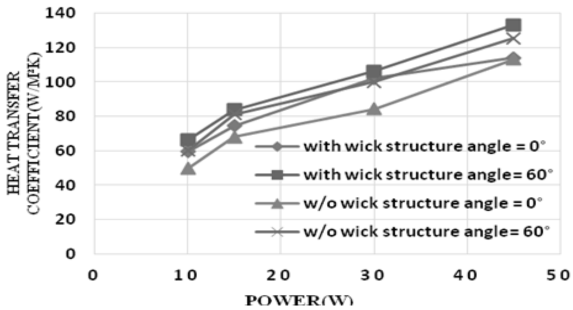

Fig. 7: Overall heat transfer coefficient against power (with and w/o wick) – water

Now the experiment is repeated with acetone as working fluid. Heat transfer coefficient for acetone is higher than water as the thermal resistance is lower, which can be seen in Fig. 8 and Fig. 9. The reason behind which is the lower boiling point of acetone. Both the trials are done using wick structure. The uncertainty in the thermal resistance at a heat input of 10W is found to be ±3.58%, ±3.06% at inclination angles of 0^o and 60^0 respectively. The uncertainty in the overall heat transfer coefficient at heat input of 10W is found to be ±8.9%, ±9.1% at 0° and 60°inclinations respectively.

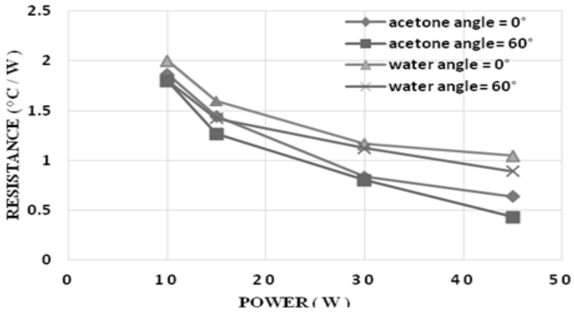

Fig. 8: Variation of thermal resistance against power for water and acetone - with wick

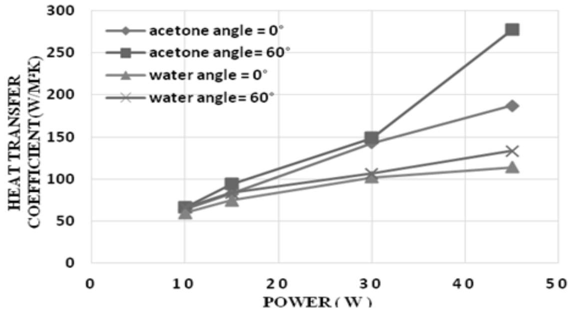

Fig. 9: Overall heat transfer coefficient against power with wick – (water and acetone)

Till now the experimentation is carried out with a single layer of screen mesh wick and the results are plotted to correlate the thermal characteristics at various heat inputs. Now let us see how the heat pipe performance enhances with the increase in number of layers of screen mesh wick within the heat pipe. Fig. 10 shows the thermal resistance of heat pipe at 0°, 60° inclination, with acetone as a working fluid and with 3, 4 layers of screen mesh wick. It can be noticed that 4-layer wick in heat pipe gives less thermal resistance than the 3-layer wick and at 60° inclination. Lesser the resistance, higher should be the heat transfer coefficient which can be seen in Fig. 11. Resistance decreases with increase in number of layers from 1 to 4 layers. Even though the thermal resistance is decreasing with increase in number of screen mesh wick layers from 1 to 4 layers, but still optimum number of layers has to be found because beyond certain number of layers resistance will increase[8, 10].

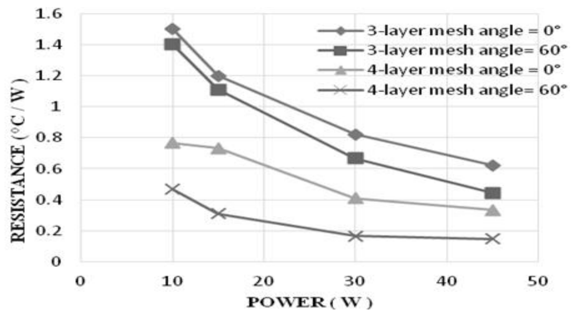

Fig. 10: Thermal resistance against the power with 3 and 4-layers screen mesh wick at 0° and 60° inclination with acetone as working fluid.

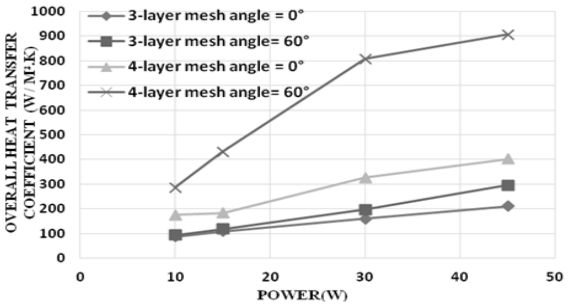

Fig. 11: Overall heat transfer coefficient against heat input with 3 and 4 - layers screen mesh wick at 0° and 60° inclination using acetone

5. Conclusions

The thermal characteristics of a cylindrical copper heat pipe are investigated experimentally. The effects of heat input, inclination angle and number of layers for 100 % fill ratio in the evaporator on the temperature distribution, thermal resistance and heat transfer coefficient of the heat pipe were observed. The following conclusions are drawn:

- Increase in heat input resulted in decrease of the thermal resistance and increase in overall heat transfer coefficient.
- Acetone can be the better working fluid than water as all the results showed better performance of the heat pipe.

- Heat pipe at 60^o inclination angle gave the better result at various heat inputs, for both water and acetone and for single and multi-layer wick structures.
- Multi-layer screen mesh wick with 4-layers in the heat pipe showed better performance than single layer screen mesh wick, but optimum number of layers are yet to be finalized for better performance.
- At an input of 10W, the uncertainty in the thermal resistance and the overall heat transfer co-efficient is found to be ± 3.58 % and ±8.9 % respectively, when the heat pipe is in horizontal position.

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