Heat Transfer Analysis of heat pipes Using Self Rewetting Fluids

Radhakrishnan N[*1], Senthilkumar R[2],

[*]1 Assistant Professor, Department of Mechanical Engineering, Annamalai University, India
2 Associate Professor, Department of Mechanical Engineering, Annamalai University, India

Abstract: Generally, the electronic devices produce large amount of heat, to prevent the failure of the system and improve the reliability, the modern cooling devices are needed. The vital requirements of all heat transfer devices are compactness and high efficiency. The heat pipes are the one of the modern cooling devices which can be used as a cooling device for the electronic equipment for quick cooling with high effectiveness. In this work, the experiments on the heat pipes were conducted utilizing different working fluids such as DI water, aqueous solution of n-Butanol, aqueous solution of n-Pentanol, aqueous solution of n-Hexanol, aqueous solution of n-Heptanol and aqueous solution of n-Octanol for comparing the heat transport capacity of the heat pipe with capillary wick. Different heat inputs were indulged (30 W, 40 W, 50 W, 60 W and 70 W) under varied angle of inclinations (0°, 15°, 30°, 45°, 60°, 75°, 90°) of heat pipes. The results revealed that the heat transport capacity and thermal efficiency of the heat pipe was highest for aqueous solution of n-Octanol when compared to other working fluids utilized.

Index terms: heat pipe, heat input, angle of inclination, aqueous solution of alcohols.

1. Introduction

With the ever-growing requirement for thermal management mainly due to increasing heat flux requirements and thermal constraints, there emerges a revolutionized interest for the use of heat pipes mainly for industrial and commercial applications. Heat pipe is one of the innovative devices which has the capability for transferring huge quantities of heat through relatively small cross-sectional areas, with very little temperature differences (Peterson 1994; Faghri 1995). Heat pipes are considered reliable thermal device (Cotter, 1965). Heat pipes comprises of a sealed container with small quantity of working fluid which transfers the heat as latent heat energy by evaporating and cooling the working fluid in the heating zone and cooling zone respectively. The capillary structure which lines the inner wall of the container helps in return flow of the condensate by which circulation of the fluid is accomplished (Chi, 1976; Peterson, 1994). The heat pipes are more willful in heat recovery systems *viz.*, solar energy (Bloem, 1982; Cannavilo *et al.*, 1884; Littwin and Willis 1985), Audio amplification, liners for furnaces, geothermal conversion (Gruss, 1987), electronic cooling (Mariya *et al.*, 2006) and light water nuclear reactors (Kaminaga *et al*., 1997; Chandourene *et al*., 1987).

A major problem faced by majority of the heat pipes, including conventional heat pipes, flat heat pipes and micro heat pipes are heat transfer limitations. Generally, at normal working conditions, these cons determine the maximum possible heat transfer for a particular pipe. The continuous flow limit, frozen startup limit, viscous limit, condenser limit, boiler limit, sonic limit and capillary limit were the most common limitations of a heat pipe (Faghri, 1995; Sonan, 2008). The heat pipe utilizes the large latent heat associated with the phase change (Mughul and Plumb, 1996; Brautsch and Kew, 2002). Among the various limitations, capillary limit and boiling limit are the most important which determines the design and operation of heat pipe. The key factor for capillary limitation is surface tension; however, it generally decreases with increase in temperature. Moreover, working fluids presently utilized for heat pipes has negative gradients as of with temperature and hence they are unsuitable for further spreading and re-wetting the heated surface. Therefore, heat load and operating temperature are limited in heat pipes. The most rejuvenating solution to overdue these problems would be to identify a new working fluid which has a positive surface-tension gradient along the temperature in the operating region.

Water is the most commonly used working fluid for medium temperature applications mainly reasoned due to its amicability, cost, safety and even high surface tension. However, surface tension of the water decreases rapidly with increase in temperature. Vochten and Petre (1973) proved experimentally that, the aqueous solutions of alcohols, generally longer chains of more than four carbon atoms tend to have positive gradient with temperature. A wick structure can be utilized for achieving stable circulation of working fluid through capillary pressure head. In this analysis the heat pipes are fabricated with copper as the container material to conduct the experiments. The working fluids used for this experimentation are DI water, aqueous solution of n-Butanol, aqueous solution of n-Pentanol, aqueous solution of n-Hexanol, aqueous solution of n-Heptanol and aqueous solution of n-Octanol. The aqueous solution of alcohols is prepared by adding 2 ml of long chain alcohol with one litre of De-Ionized (DI water). These aqueous solutions of alcohols are called as self-rewetting fluids because of these fluids surface tension increases with increasing the temperature at elevated temperature range (when the operating temperature above 90^{o}C) (Zhang, 2001). The analysis are done for various heat inputs and angle of inclinations.

2. Experimental setup:

In the proposed work, identical six heat pipes fabricated with copper were utilized as container materials. The different heat inputs used for this experiment include 30w, 40w, 50w, 60w and 70w whereas the angle of inclinations was 0°, 15°, 30°, 45°, 60°, 75° and 90°. 0.08 kg/min was the constant flow rate of the coolant in the condenser section. The experimental setup is shown in Fig 1. The specifications of heat pipe are tabulated in Table 1.

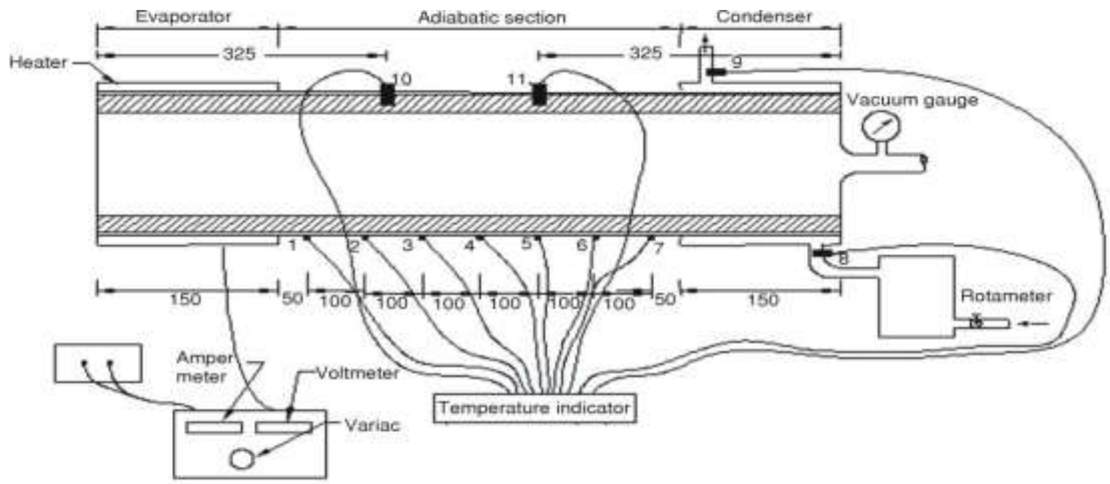


Fig. 1 Experimental setup

Table 1. Specifications of heat pipe

Specifications	**Dimensions**
Outside diameter, m	0.020
Inside diameter, m	0.0176
Evaporator length, m	0.150
Condenser length ,m	0.150
Adiabatic length, m	0.300
Working fluid,	DI Water, n-Butanol, n-Pentanol, n-Hexanol, n-Heptanol, n-Octanol
Wick mesh size	80 per sq. inch
No of layers of wick	2

3. Result and Discussion

3.1 Effect of heat pipe inclination on thermal efficiency:

In the present study, the thermal performances of cylindrical heat pipes utilizing different working fluids such as DI water, aqueous solution of n-Butanol, aqueous solution of n-Pentanol, aqueous solution of n-Hexanol, aqueous solution of n-Heptanol and aqueous solution of n-Octanol are used. The ratio between the cooling capacity rate of water at the condenser section to the power supplied (heat supplied) at the evaporator section is noted for calculating the thermal efficiency of the heat pipe.

$$\text{Cooling capacity rate} = mC_p\,(T_{co}\text{-}T_{ci})$$

where, ‘m’ is the flow rate of water in the condenser section in kg/s,
C_p is the specific heat of water in J/kg.K,
$T_{c,o}$ is the cooling water outlet temperature in the condenser section in K, and
$T_{c,i}$ is the cooling water inlet temperature in the condenser section in K.

Figures 2 to 6 represents the thermal efficiency of the heat pipe for different working fluids, namely DI water, aqueous solution of n-Butanol, aqueous solution of n-Pentanol, aqueous solution of n-Hexanol, aqueous solution of n-Heptanol and aqueous solution of n-Octanol. The aqueous solution of alcohols are prepared by proper mixing of pure alcohol (99.9% pure) with an amount of one litre of DI water. The experiments comprising with different tilt angles 0°, 15°, 30°, 45°, 60°, 75°, 90° and 30W, 40W, 50W, 60W and 70W as heat inputs. Considering all the figures 2-6, it is evident that there is a positive association between the tilt angle and thermal efficiency whereby, increase in tilt angle results in increased thermal efficiency. This may be reasoned due to the gravitational force which plays a significant role for the flow of working fluid between the evaporator section and condenser section along the capillary action of the wick. The point to be noted that, whenever the angle of inclination oversees 30° for de-ionic water, aqueous solution of n-Butanol, aqueous solution of n-Pentanol, aqueous solution of n-Hexanol, aqueous solution of n-Heptanol and 45° aqueous solution of n-Octanol the thermal efficiency of the heat pipe decreases. The reason for lessening of the thermal efficiency may be due to the development of liquid film inside the condenser, which is reasoned due to the deposition of coolant at the bottom of the condenser resulting in the increased value of the thermal resistance of heat pipe. It may be interpreted that there is decrease in thermal efficiency whenever the angle exceeds 30° in case of DI water, aqueous solution of n-Butanol, aqueous solution of n-Pentanol, aqueous solution of n-Hexanol, aqueous solution of n-Heptanol and 45° for aqueous solution of n-Octanol. The maximum heat input is fixed as 70 W for comparative study.

In this experiment, when aqueous solution of n-Octanol is used as the working fluid, the thermal efficiency of the heat pipe increases about 33% compared to DI water. While using aqueous solution of n-Heptanol, thermal efficiency is found to be increased to about 25% as when compared to DI water. This is main reason behind that is the positive surface tension gradient of aqueous solution of alcohol. The maximum surface temperature of the heat pipes depends the heat input in the evaporator section, coolant flow rate and angle of inclination.

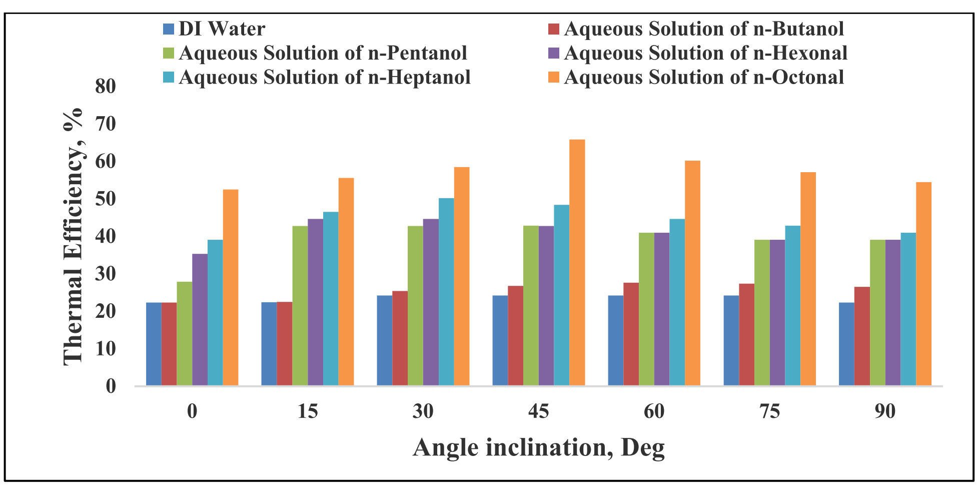


Fig. 2 Effect of heat pipe inclination on thermal efficiency for 30W heat input

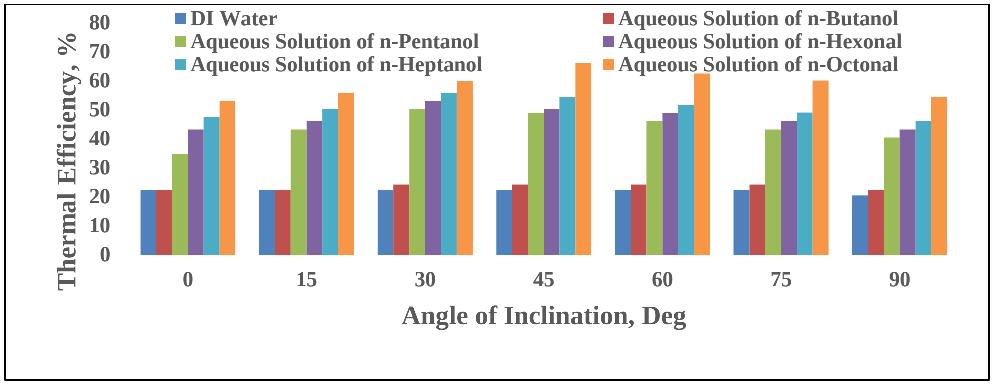


Fig. 3 Effect of heat pipe inclination on thermal efficiency for 40W heat input

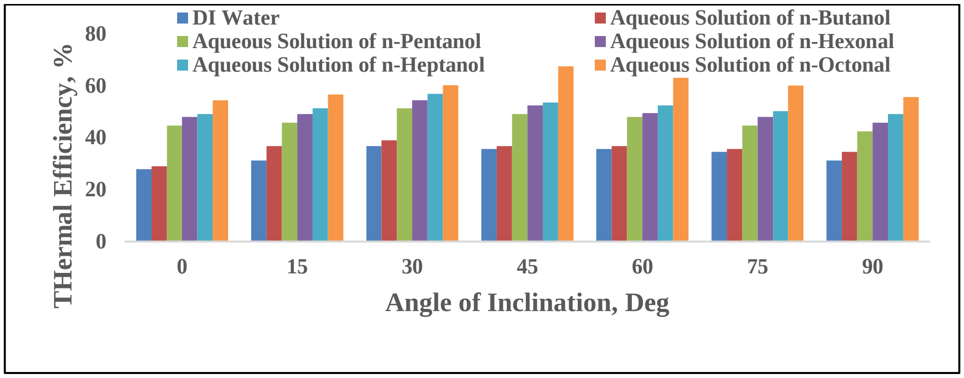


Fig. 4 Effect of heat pipe inclination on thermal efficiency for 50W heat input

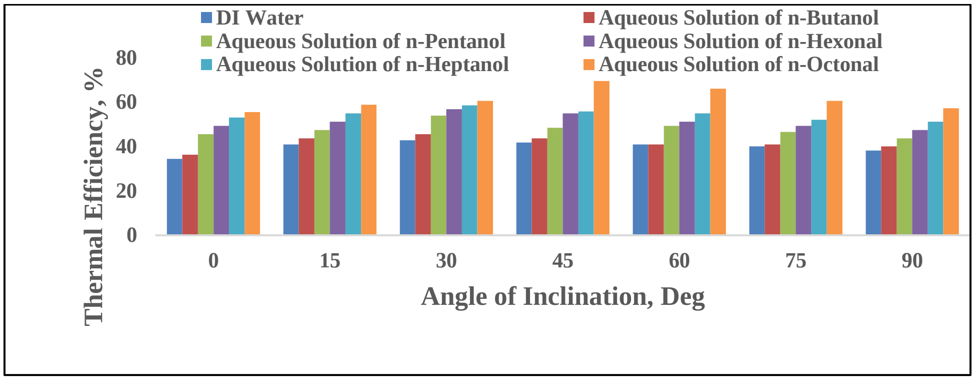


Fig. 5 Effect of heat pipe inclination on thermal efficiency for 60W heat input

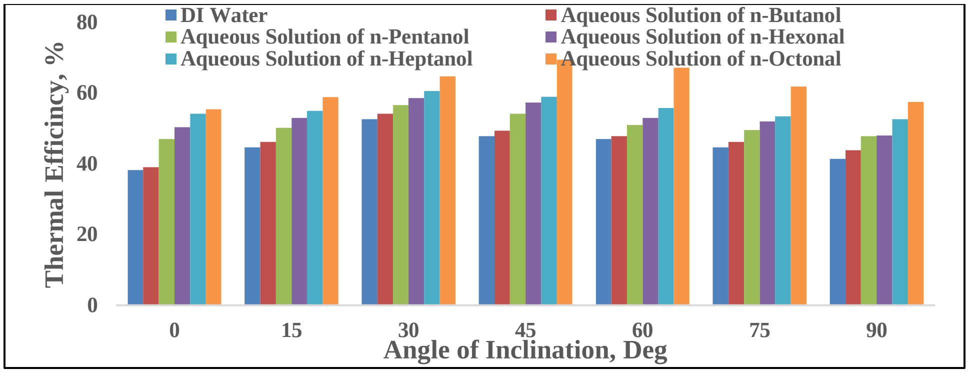


Fig. 6 Effect of heat pipe inclination on thermal efficiency for 70W heat input

3.2 Effect of thermal resistance

The thermal resistance of the heat pipe is studied for various range of heat pipes, different angle of inclinations. Figure 7-13 represents the wide range of thermal resistance with respect to heat inputs like 30 W, 40 W, 50 W, 60 W & 70 W and angle of inclinations of 0°, 15°, 30°, 45°, 60°, 75°, 90° with respect to horizontal position of heat pipe for different working fluids utilized.

Figure 7-13 reveals the relative results of thermal resistance of heat pipe with DI water, aqueous solution of n-Butanol, aqueous solution of n-Pentanol, aqueous solution of n-Hexanol, aqueous solution of n-Heptanol and aqueous solution of n-Octanol. The thermal resistance (R) of the heat pipe is defined as,

$$\text{Thermal Resistance} = \frac{(T_E - T_C)}{Q}$$

Where T_E and T_C are average values of temperature at the evaporator and condenser section respectively in K and Q is the heat supplied to the heat pipe in the evaporator section in W. It can be interpreted from the figures, the thermal resistance decreases with increase of angle of inclination and heat input with respect to all the working fluids used. It is clear to be noted that the thermal resistance of the heat pipes is the lowest while using aqueous solution of n-Octanol.

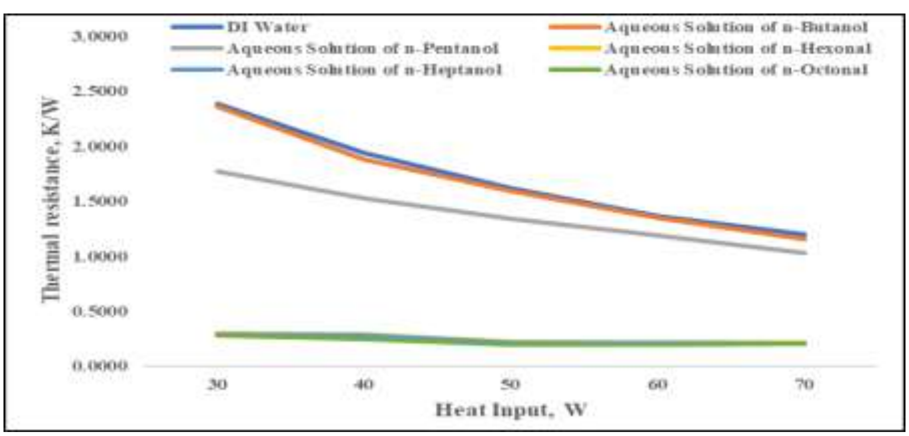


Fig. 7 Thermal resistance of heat pipe for 0° inclination

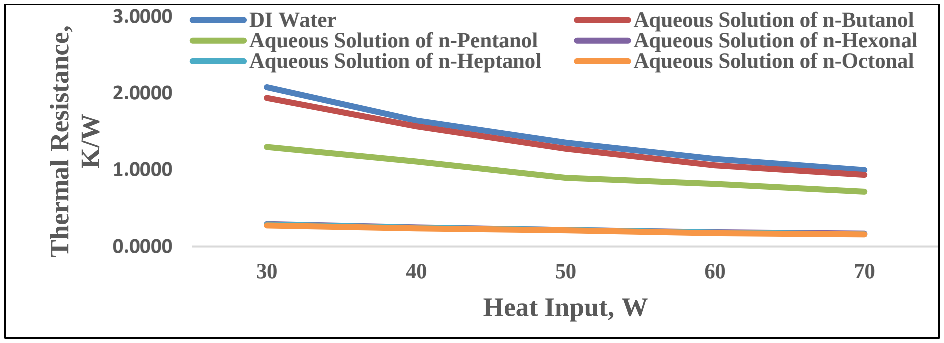


Fig. 8 Thermal resistance of heat pipe for 15° inclination

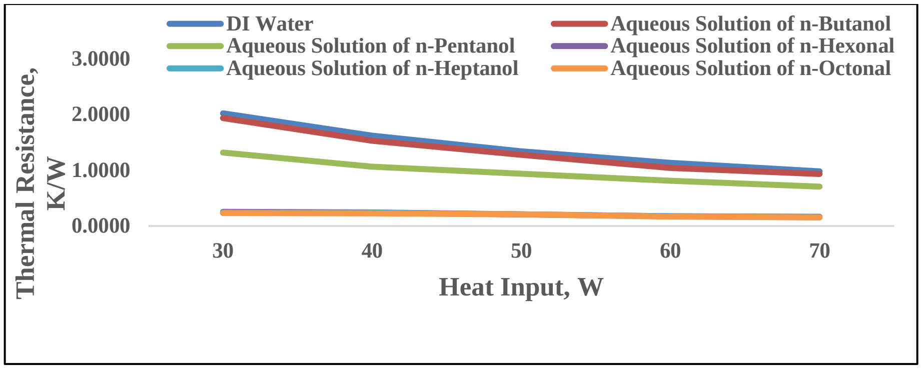


Fig. 9 Thermal resistance of heat pipe for 30° inclination

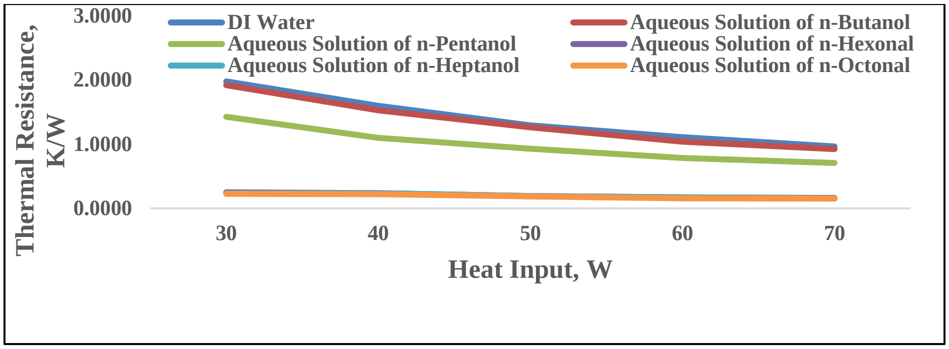


Fig. 10 Thermal resistance of heat pipe for 45° inclination

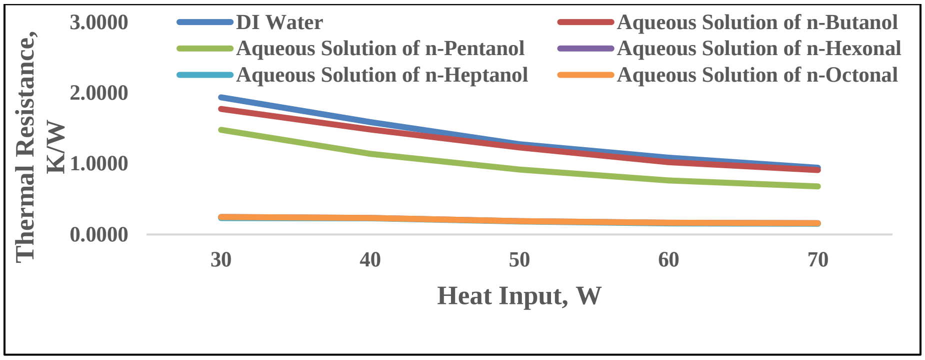


Fig. 11 Thermal resistance of heat pipe for 60° inclination

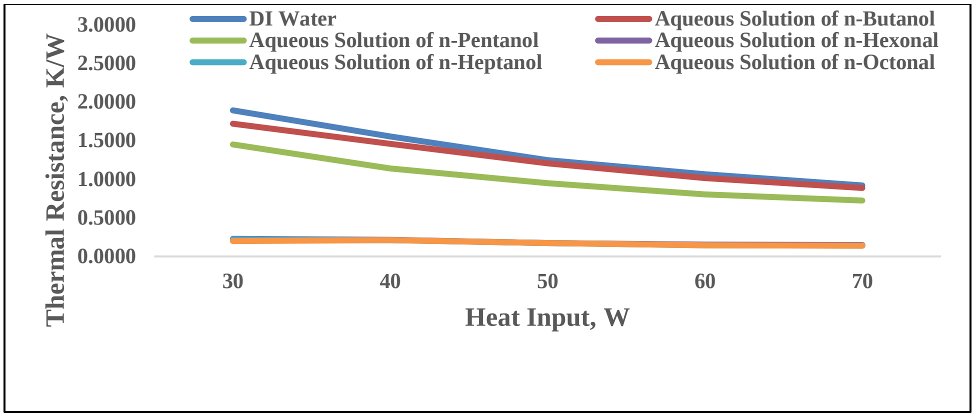


Fig.12 Thermal resistance of heat pipe for 75° inclination

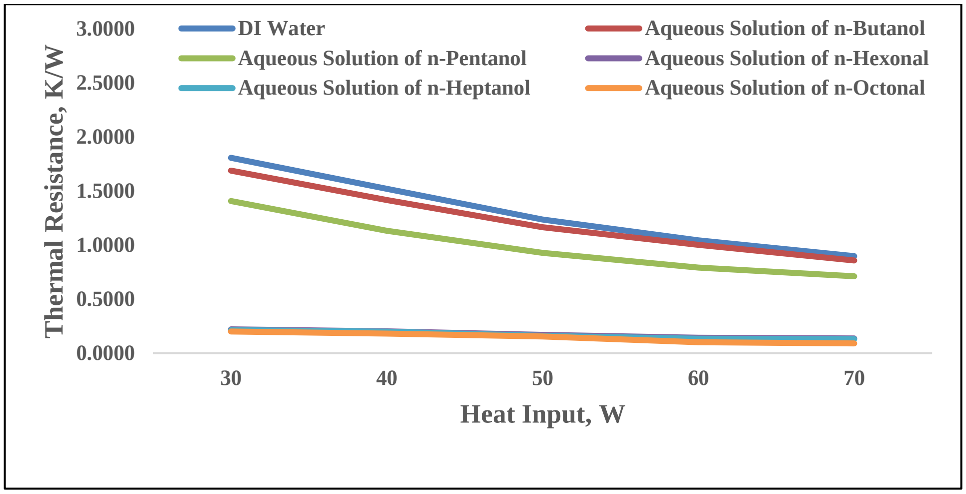


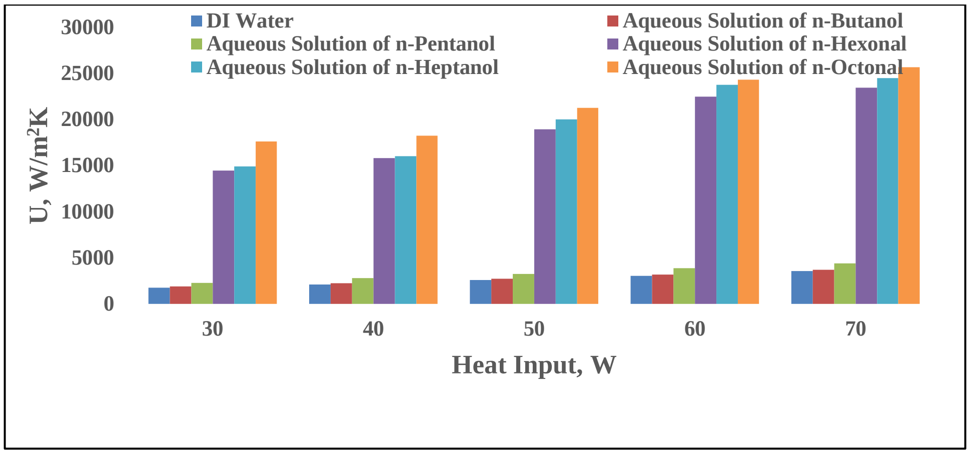
Fig.13 Thermal resistance of heat pipe for 90° inclination

4. Overall heat transfer coefficient

The overall heat transfer co-efficient under varied conditions are studied and evaluated for different heat inputs and angle of inclination. Figure 14 denotes the pictorial representation of heat input vs Overall heat transfer coefficient for 30 W, 40 W, 50 W, 60 W, 70 W as heat inputs and 90° as angle of inclinations in the heat pipe for DI water, aqueous solution of n-Butanol, aqueous solution of n-Pentanol, aqueous solution of n-Hexanol, aqueous solution of n-Heptanol and aqueous solution of n-Octanol. While using DI water as a working fluid, the overall heat transfer coefficient had a value range of 1530 to 3500 W/m^2K. However, when using aqueous solution of n-Butanol, aqueous solution of n-Pentanol, aqueous solution of n-Hexanol, aqueous solution of n-Heptanol and aqueous solution of n-Octanol as working fluid, the overall heat transfer coefficient of aqueous solution of n-Butanol ranges from 1600 to 3700 W/m^2K; aqueous solution of n-Pentanol had a value range of 3100 to 4400 W/m^2K; aqueous solution of n-Hexanol ranging from 10600 to 23400 W/m^2K; aqueous solution of n-Heptanol ranging from

15200 to 24500 W/m^{2}K and aqueous solution of n-Octanol ranging from 11500 to 25600 W/m^{2}K.

The aqueous solution of n-Octanol heat pipe has recorded high overall heat transfer coefficient due to the high heat transport capacity. With respect to angle of inclination, 90° has recorded with high overall heat transfer coefficient, since it has the high temperature difference between the evaporator and condenser sections. The overall heat transfer coefficient has recorded the maximum value of 25600 W/m^{2}K.



s

Fig. 14 Overall heat transfer co-efficient comparison for 90° inclination

5. Conclusion

This experiment was investigated with the objective of studying the effect of angle of inclination on thermal performance of cylindrical heat pipe using for DI water, aqueous solution of n-Pentanol, aqueous solution of n-Hexanol, aqueous solution of n-Heptanol and aqueous solution of n-Octanol as working fluids. The experiment revealed that the aqueous solution of n-Octanol has shown highest thermal efficiency than all other working fluids utilized in the study. Moreover, thermal resistance of aqueous solution of n-Octanol found to be the lowest of all working fluids. Hence, the thermal performance of the heat pipe may be increased by the addition n-Octanol. It shows better performance and efficiency than all other used working fluids. The reason behind this is reasoned to that,n-Octanol have a positive surface tension gradient along the temperature which gives rise to increased value of the capillary limit and the cooling limit of the heat pipe with n-Octanol ans also god oxidation property. The surface temperature distribution along the adiabatic section of the heat pipe was found to be within permitted limit and uniform. The heat transfer coefficient also higher for aqueous solution for n-Octanol and the value is high when heat pipe kept under vertical position.

Acknowledgment

The authors thank the authorities of Annamalai University for providing the necessary facilities in order to accomplish this piece of work.

References

1. A. Brautsch and P. A. Kew, Examination and visualization of heat transfer processes during evaporation in capillary porous structures, Appl. Therm. Eng., 22 (2002) 815-824.
2. Bloem H, De-Grijis JC and Devaan RLC (1982) An evacuated tubular solar collector incorporating a heat pipe. Philips Tech. Rev. 40, 181-191.
3. Cannavilo M, Caaarosa C, Latrofa E, Martorano L and Reale F (1981) Gravity heat pipes as geothermal convectors. Proc. 4th Int. Heat Pipe Conf. p: 759.
4. Chandourene S, Gruss A, Theoretical and experimental study of high temperature heat pipe heat exchanger application to 1300kW respirator, Sixth international heat pipe Conference Grenoffle France, 1987.
5. Chi SW (1976) Heat pipe theory and practice. McGraw-Hill, Washington
6. Cotter, T.P., Theory of Heat Pipes, Los Almos Scienctific Laboratory Report No. LA-3246-MS, 1965.
7. Faghri A (1995) Heat pipe science and technology. Taylor & Francis, Washington
8. F. Kaminaga, H. Hashimoto, C. Feroz, K. Goto and K. Masumura, Heat transfer characteristics of evaporation and condensation in a two-phase closed thermosyphon, Proc. 10th Int. Heat pipe Conf., Germany (1997).
9. Littwin D.A, Willis D.B, The use of heat pipes to conserve energy in petroleum refineries, Energy Process, pp 198-202, (1985).
10. Mariya Ivanova, Yvan Avenas, Christian Schaeffer, Jean-Bernard Dezord, and Juergen Schulz-Harder, Heat Pipe Integrated in Direct Bonded Copper (DBC) Technology for Cooling of Power Electronics Packaging, IEEE Transactions on Power Electronics, 21, (6), pp 1541, (2006)
11. M. P. Mughal and O. A. Plumb, An experimental study of boiling on a wicked surface, Int. J. Heat Mass Transfer, 39 (1996) 771-777.
12. Peterson (1994) An introduction to heat pipes, Wiley & Sons.
13. Sonan R, Harmand S, Pellé J, Leger D and Fakès M (2008) Transient thermal and hydrodynamic model of flat heat pipe for the cooling of electronics components. Int. J. Heat Mass Transfer. 51, 6006– 6017.
14. Vochten R and Petre G (1973) Study of the heat of reversible adsorption at the air-solution interface, II. Experimental determination of the heat of reversible adsorption of some alcohols. J. Cillid Interface. Sci. 42,320-327.
15. Zhang N (2001) Innovative heat pipe systems using a new working fluid, Inl. Comm. Heat Mass Transfer. 28(8), 1025-1033.