ANALYSIS OF HEAT PIPE USING AQUEOUS SOLUTION OF n-PENTANOL WITH COPPER NANOFLUID

[1]Dr. R. Senthilkumar
Assistant professor, Department of Mechanical Engineering,
Annamalai University, Annamalai Nagar, India.

Abstract : This study utilizes an aqueous solution of n-Pentanol and copper nanoparticles in an aqueous solution of n-Pentanol on a heat pipe.. The copper nanoparticles used are 40 nm. The nanofluids are prepared and an aqueous solution of n-Pentanol is added to it at a concentration of 2 ml in one litre of DI water. From the comparison of the performance using both DI water and other fluids, it is found that, the thin porous coating layer formed by the nanoparticles suspended in nanofluids is a key effect of the heat transfer enhancement for the heat pipe using nanofluids. The results show the possibility of enhancing the thermal performance of heat pipe if copper nanoparticle in the aqueous solution of n-Pentanol is used as a working fluid. Finally, the thermal resistance of the nanofluid heat pipe tends to decrease by adding the aqueous solution of n-Pentanol in the copper nanofluid.

Index Terms - Heat pipe, copper nanofluid in the aqueous solution of n-Pentanol, heat input, angle of inclination.

I. INTRODUCTION

The heat pipe is a simple heat transfer device which can transport more heat from one place to other with an extremely higher thermal conductivity than the conventional pipes. Heat pipes are widely used for cooling electronic equipments in space vehicles and terrestrial applications such as high performance computers, laptops, heat recovery systems and solar energy. Higher amounts of heat can be transferred at very low temperature differences between a heat source and a heat sink [1-3], i.e., between the evaporator and condenser sections. Tien [4], Tien and Rohani [5] studied about the operational characteristics of a two-component working medium in heat pipe filled with different water/ethanol solutions. A theoretical framework has been performed to foresee the performances gained by this type of heat pipe and it is found that the performance depends on several factors like initial composition of two components mixture and heat pipe geometry.

Brommer [6] analyzed the two-component heat pipes using water/methanol binary mixture. It has been shown that, the startup behavior of heat pipes are enhanced by using these working fluids, when it is initially frozen and the freezing point of the working medium can be lowered by adding together with an appropriate liquid, like methanol in water for low temperature range. Kadoguchi et al. [7] examined the two-component heat pipes with the binary mixture working fluid which is a more advantageous heat transfer device than a gas-loaded variable- conductance heat pipe for controlling the temperature of electric device.

All of the conventional heat pipes endure from the common problem of heat transfer constraint. The maximum heat transfer rate of any particular heat pipe can be determined by these limitations under the typical operational circumstances. The capillary limits and the boiling limits are regarded as the most significant features in the heat pipe design. The capillary limit of a heat pipe can be persuaded by the surface tension of the working fluid. As the temperature increases, the surface tension of all the pure liquids generally reduces on account of the fact that the liquid travels along the interface towards the cooler condenser zone. The existing working fluids for the heat pipes have negative surface tension gradient with temperature, which is an unfavourable one for spreading or re-setting on a heated surface, and so the operating temperature as well as the heat load of heat pipe systems are limited. Besides, the heat pipe systems also suffer from operational instability problems because of the characteristics of the negative surface tension gradient with temperature.

The heat transfer capability of the all heat transfer devices including the heat pipe is restricted by the working fluid transport properties. To conquer these limitations, the thermo physical properties of the working fluid have to be enhanced. The heat transfer rate of heat transfer devices can be improved by adding additives to the working fluids to alter the fluid transport properties and flow features. One of the techniques is to use the aqueous solutions of alcohols, with chain lengths longer than four carbon atoms.

The aqueous solutions of long chain alcohols which have the carbon atom more than four have specific properties that the surface tension increases with temperature [8-9]. In the case of boiling phenomena, increasing surface tension at a higher temperature of such kinds of fluids causes supply of cooling liquid at dry patch on the heated surface. Therefore, using these kinds of fluids as heat pipe working fluids has led to the improvement in the heat transfer performance when compared with the conventional water heat pipe. It is sufficient that only a small amount of the long-chain alcohols, in the order of 10^{-3} mole per liter, is required to change the surface tension characteristics of water without affecting the other bulk properties of the water [10]. In addition, the heat pipe using the dilute solutions of long chain alcohols like aqueous solution of n-Pentanol yields both the high surface tension and the positive surface tension gradient with temperature, when the heat pipe operating temperature is at 90°C or above. Because of the high positive surface-tension gradient with temperature, the working fluid tends to move towards the evaporator in the heat pipe, reducing the liquid pressure drop, increasing the capillary limit and the boiling limit, and consequently, increasing the heat load.

Another method is to use the nanofluid in the heat transfer equipments to enhance the thermal performance of heat transfer devices. An innovative way to improve the liquid thermal conductivity is the diffusion of highly conductive solid nanoparticles within the base fluid. This new creation of conductive fluids with nanoparticles is referred to as nanofluids. Nanofluids are becoming the fast emerging alternatives to the usual heat transfer fluids. The term ‘Nanofluids’ is used to indicate a newly introduced special class of heat transfer fluids that contain nanoparticles less than 100 nm of metallic or non-metallic substances uniformly and stably suspended in a conventional heat transfer liquid [11].

The thermo physical and transport properties of the conventional fluids are improved by adding the nanoparticles in base fluid. The effective thermal conductivity of nanofluids increases with increase in temperature [12]. This finding makes nanofluids even more attractive as a cooling fluid for heat transfer devices with high energy density. Some experimental investigations have revealed that the nanofluids have remarkably higher thermal conductivities and greater heat transfer characteristic than those of conventional pure fluids [13-14]. A theoretical model and an experimental procedure are proposed to describe the heat transfer performance of nanofluid flowing in a tube. The results obtained illustrate that the thermal conductivity of nanofluids remarkably increases with the volume fraction of ultra-fine particles [15]. The nanofluid consisting of copper nanoparticles dispersed in ethylene glycol has a much more effective thermal conductivity than the pure ethylene glycol or ethylene glycol containing the same volume fraction of dispersed oxide nanoparticles [16]. Tsai et al. [17] studied the thermal performance of the gold nanofluid in meshed heat pipe. The measured results show that the thermal resistance of the heat pipes with nanofluids is lower when compared with pure water. Kang et al. [18] discussed about the thermal enhancement of heat pipe using silver nanofluid as the working fluid. The experiments were conducted using DI-water dispersed with 10 nm and 35 nm silver particles, inside a 211 x10^{-6} m wide and 217 x10^{-6} m deep grooved circular heat pipe. The experimental results show that the thermal resistance of heat pipe filled with silver nanofluid reported a reduction of 10–80% compared to DI-water.

Kang et al. [19] employed the dilute dispersion of silver nanoparticles in DI water as a working fluid for a conventional 1 mm wick-thickness sintered circular heat pipe. The nanofluid is an aqueous solution with 10 nm and 35 nm diameter silver nanoparticles and the tested nanoparticle concentrations range from 1, 10, and 100 mg/ lit. At the same charge volume, it has been demonstrated that the temperature difference decreased to 0.56–0.65ºC when compared with DI water at an input power of 30–50 W. The nanofluids are having a higher heat transfer capacity than the conventional working fluids and also it reduces the overall thermal resistance between the evaporator and the condenser. It is in this direction, a working fluid which is the combination of copper nanoparticle and the aqueous solution of long chain alcohols has been explored in order to enhance the thermal performance of the heat pipe.

In the present analysis, heat pipe of copper container and the two strands of stainless steel wrapped screen are used as a wick material. The DI water, aqueous solution of n-Pentanol, copper nanofluid and copper nanoparticle in aqueous solution of n-Pentanol are used as working fluids in the heat pipe. The copper nanoparticle with a size of 40 nm and the aqueous solution of copper nanofluid prepared by adding the 2 ml/lit of n- Pentanol is used as working fluid. The concentration of copper nanoparticle in the DI water is 100 mg/lit. The nanofluids are prepared using the ultrasonic homogenizer for copper nanofluid and copper particle in the aqueous solution of n-Pentanol. The experiments are carried out for different inclinations of heat pipe to the horizontal with diverse heat inputs. The objective of this work is to study about the thermal efficiency improvement of heat pipe using copper nanofluid and the aqueous solution of n-Pentanol in copper nanofluid.

II. EXPERIMENTAL ARRANGEMENT AND TEST PROCEDURE

The experimental arrangement of heat pipe is shown in Fig. 1(a). The thermocouple positions are shown in Fig.1 (b). The evaporator section of heat pipe is excited by the circumferential electric heater which is linked in the evaporator section. The temperature distributions along the heat pipe are calculated with the help of fourteen sets of copper-constantan thermocouples. The wall temperature distribution of the heat pipe in adiabatic zone is measured using six evenly spaced copper constantan (T-type) thermocouples with an uncertainty of ±0.1ºC, at an equal distance from the evaporator. In addition, the thermocouples are also located in evaporator surface (three locations), condenser surface (three locations), inlet and outlet of the condenser jacket. The heat pipe is charged with 40 ml of working fluid, which approximately corresponds to the amount required to fill the evaporator. At the beginning of the experiment, the evaporator temperature is controlled at a temperature of 30°C.

The cooling water is circulated in the cooling jacket to remove the heat of the working fluid. This cooling jacket is attached to the condenser section which is located at the end of the heat pipe. The heat pipe has the capability to transmit the heat through the internal structure. Therefore, an abrupt increase in the wall temperature arises which could harm the heat pipe if the heat is not released at the condenser correctly. Consequently, the cooling water is dispersed first through the condenser jacket, before the heat is supplied to the evaporator. The condenser section of the heat pipe is cooled using water flow through a 150 mm long jacket with an inner diameter of 30 mm and outer diameter of 36 mm. The cooling water flow rate is measured by the floating rotameter with an uncertainty of ±1% and the flow rate is kept constant at 0.08 kg/min.

The initial temperature of cooling water is maintained at 28ºC. The inlet and outlet temperatures of the cooling water are computed using two copper constantan thermocouples. The experimental part consists of a 20 mm outer diameter copper-water heat pipe with a length of 600 mm and a wall thickness of 1.2 mm. The wick consists of two wraps of stainless steel wire mesh with a wire diameter of 0.183 mm and 2365 strands per meter. The adiabatic section of the heat pipe is entirely shielded with the glass wool. The amount of heat loss from the evaporator and condenser surface is negligible. The experiments are performed using four identical heat pipes which are manufactured as per specified dimensions. One of the heat pipes is filled with de-ionized water, second one with copper nanofluid, third one with the aqueous solution of n-Pentanol and the fourth one with the aqueous solution of n-Pentanol with copper nanofluid. The power input to the heat pipe is slowly increased to the preferred power level.

The surface temperatures at six different locations along the adiabatic section of heat pipe are measured at regular time intervals until the heat pipe attains the steady state condition. Concurrently, the evaporator wall temperatures, condenser wall temperatures, water inlet and outlet temperatures in the condenser zone are also measured.

Once the steady state is reached, the input power is turned off and cooling water is permitted to flow through the condenser to cool the heat pipe and to make it ready for further experimental purpose. The steady state is defined as the variation in temperature which is less than ±0.1ºC for 10 min. Then the power is increased to the next level and the heat pipe is tested for its performance. Experimental procedure is repeated for different heat inputs (30, 40, 50, 60 and 70 W) and different inclinations of pipe (0º, 15º, 30º, 45º, 60º, 75º and 90º) to the horizontal and observations are traced. The output heat transfer rate from the condenser is calculated by applying an energy balance to the condenser flow. The vacuum pressure in the inner side of the heat pipe is monitored by vacuum gauge, which is attached in the condenser end of the heat pipe.

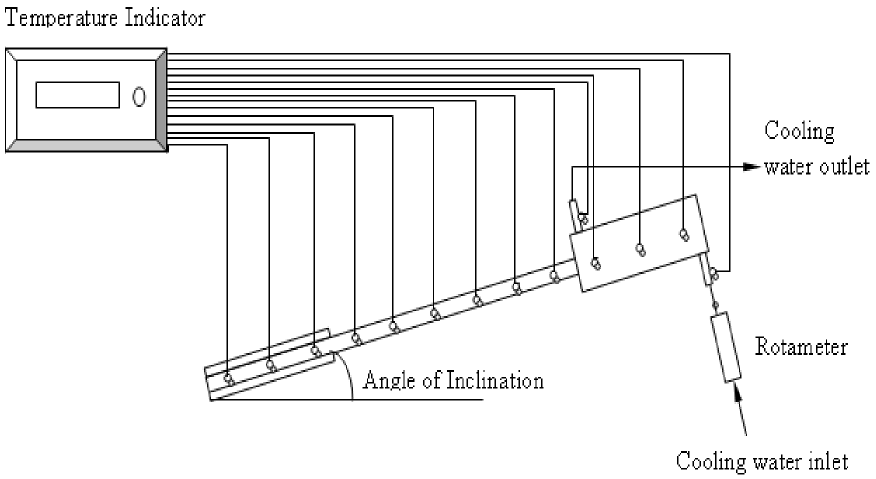


Fig. 1(a) Experimental arrangement

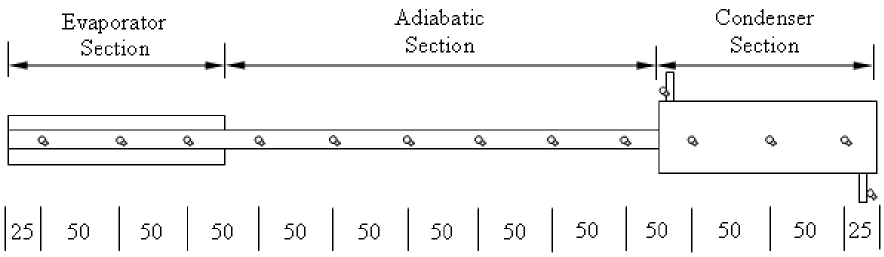


Fig. 1(b) Thermocouple locations of heat pipe

III. RESULTS AND DISCUSSIONS

3.1 Effect of heat pipe inclination in thermal efficiency

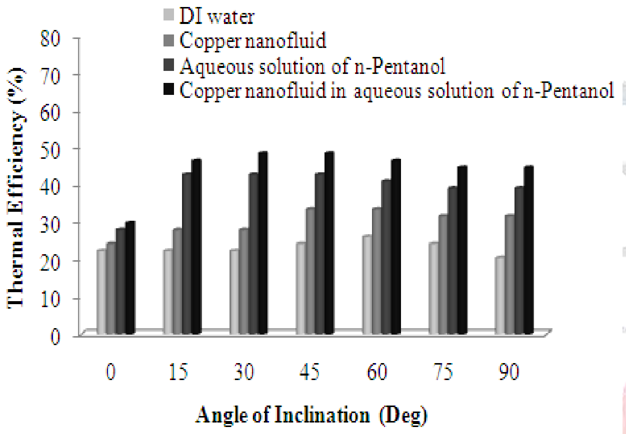
The thermal performances of the cylindrical heat pipe with various working fluids such as DI water, copper nanofluid, aqueous solution of n-Pentanol and copper nanoparticle in aqueous solution of n-Pentanol are compared. The heat pipe thermal efficiency is calculated by the ratio between the cooling capacity rate of water at the condenser section to the power supplied at the evaporator section [20].

$$\text{Cooling capacity rate} = \acute{m} C_p (T_{c,o} - T_{c,i})$$

Where ‘ḿ’ is the flow rate of water in the condenser, C_p is specific heat of water, $T_{c,o}$ is the outlet temperature of cooling water in the condenser and $T_{c,i}$ is the inlet temperature of cooling water in the condenser. Figures 2 - 6 show the variations of heat pipe thermal efficiency for DI water, copper nanofluid, aqueous solution of n-Pentanol and copper nanoparticle in aqueous solution of n-Pentanol with various tilt angles for 30 W, 40 W, 50 W, 60 W and 70 W heat inputs respectively. From all the figures, it has been observed that the efficiency of the heat pipe increases with increasing values of the tilt angle. This is due to the fact that the gravitational force has a significant effect on the flow of working fluid between the evaporator section and the condenser section along with the capillary action of wick. However, when the heat pipe inclination angle exceeds 30° for de-ionic water, aqueous solution of n-Pentanol and copper nanoparticle in aqueous solution of n-Pentanol and 45° for copper nanofluid, the heat pipe thermal efficiency tends to decrease. The efficiency of the heat pipe seems to decrease since the formation of the liquid film is at higher rate inside the condenser due to the deposition of coolant in the bottom side of the condenser resulting in the increased value of the thermal resistance. Therefore the thermal efficiency decreases when the angle exceeds 30° for DI water, aqueous solution of n-Pentanol and copper nanofluid in the aqueous solution of n-Pentanol and 45° for copper nanofluid. The maximum heat input for the heat pipe using DI water can be calculated from the available equations [2] and it is found to have a value of 74 W for this study. Therefore, for comparative study the maximum heat input of the heat pipe is limited to 70 W.

In this analysis, the thermal efficiency of heat pipe increases about 8% with copper nanofluid as a working fluid when compared with the DI water. Besides, the heat pipe which uses copper nanoparticle with aqueous solution of n-Pentanol increases the thermal efficiency to nearly about 20% as compared to that of DI water due to the positive surface tension gradient possessed by n-Pentanol.

The heat pipes filled with DI water and the copper nanofluid takes 60 to 70 min to attain the steady state. The steady state time for aqueous solution of n-Pentanol and copper nanoparticle in the aqueous solution of n-Pentanol are 40 to 50 minutes. The maximum temperatures of heat pipes using various working fluids are ranging from 110ºC to 120ºC for DI water, 90ºC to 115ºC for copper nanofluid, 65ºC to 80ºC for the aqueous solution of n-Pentanol and 70ºC to 85ºC for copper nanoparticle in aqueous solution of n-Pentanol. The maximum temperature of the heat pipes depends on the heat input and the angle of inclination.



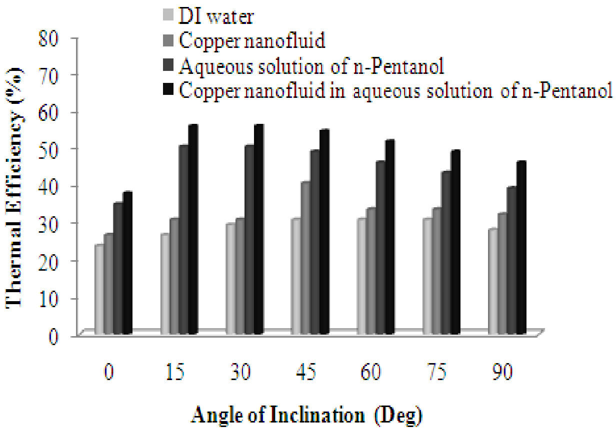
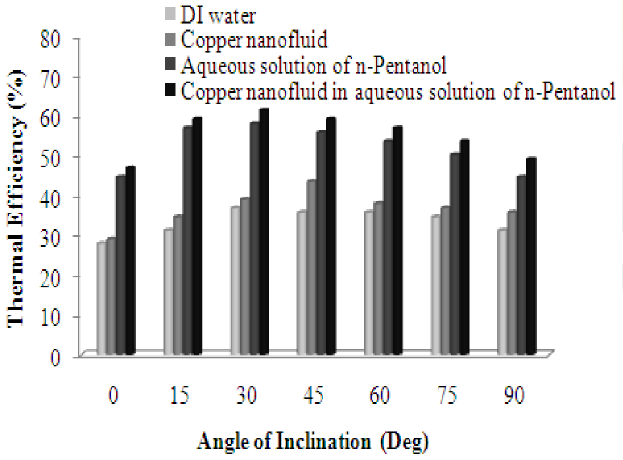


Fig. 2 Variations of heat pipe efficiency for various inclinations at 30 W heat input

Fig.3 Variations of heat pipe efficiency for various inclinations at 40 W heat input



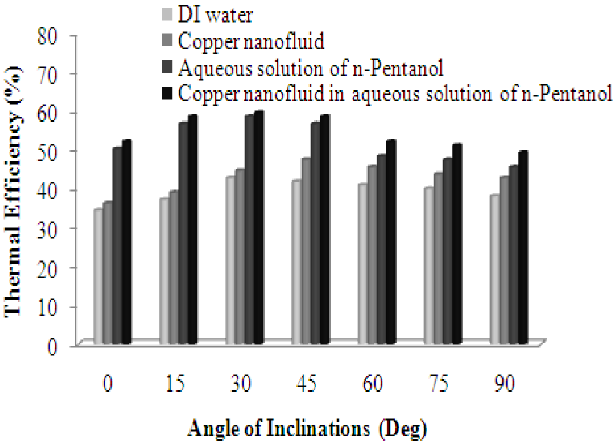


Fig. 4 Variations of heat pipe efficiency for various inclinations at 50 W heat input

Fig. 5 Variations of heat pipe efficiency for various inclinations at 60 W heat input

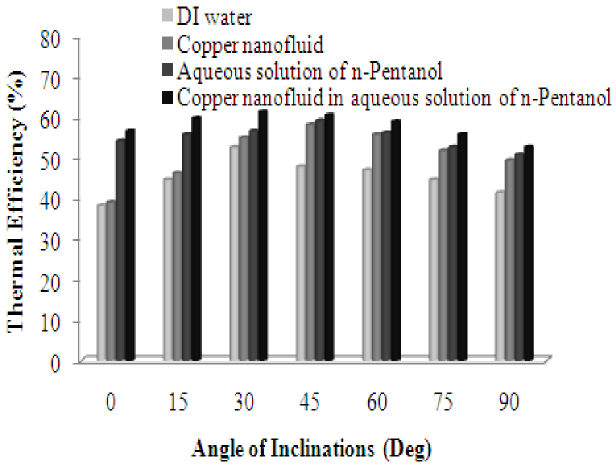


Fig. 6 Variations of heat pipe efficiency for various inclinations at 70 W heat input

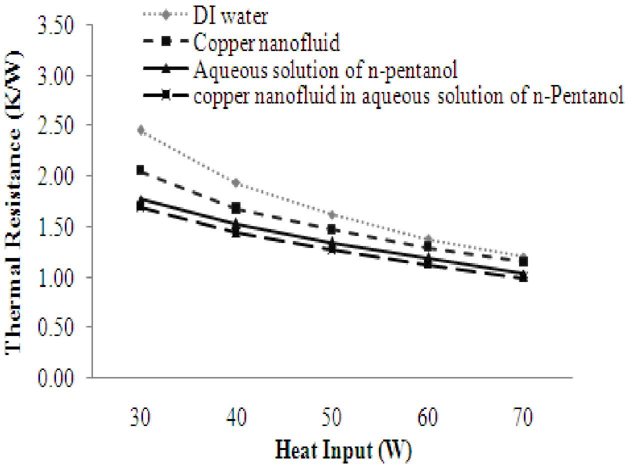


Fig.7 Thermal resistance of heat pipe for 0° inclination

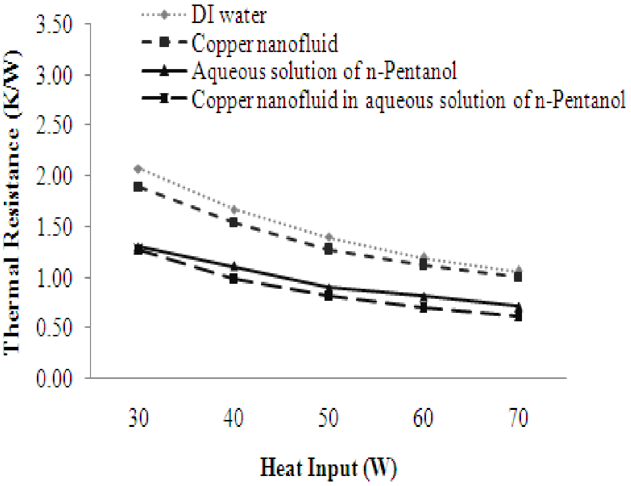


Fig. 8 Thermal resistance of heat pipe for 15° inclination

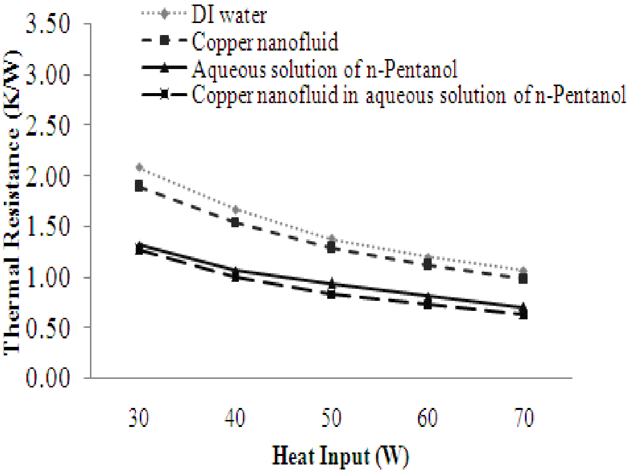


Fig. 9 Thermal resistance of heat pipe for 30° inclination

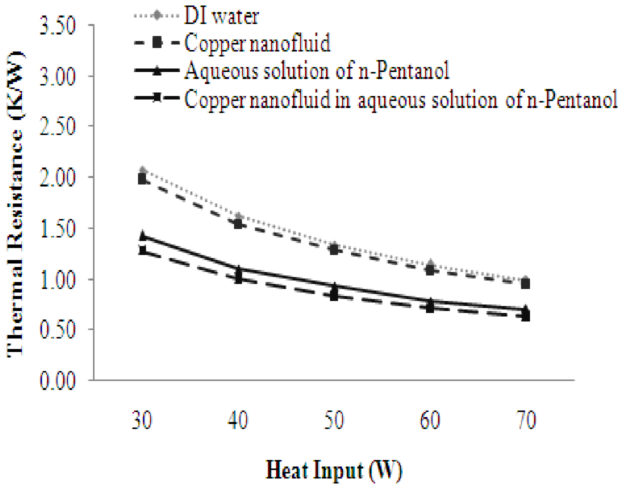


Fig. 10 Thermal resistance of heat pipe for 45° inclination

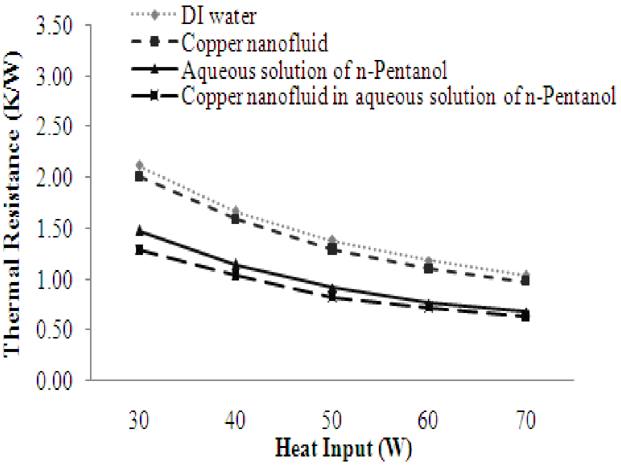


Fig. 11 Thermal resistance of heat pipe for 60° inclination

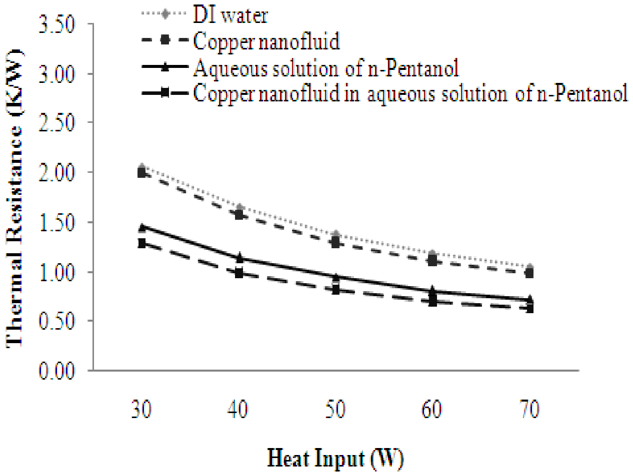


Fig. 12 Thermal resistance of heat pipe for 75° inclination

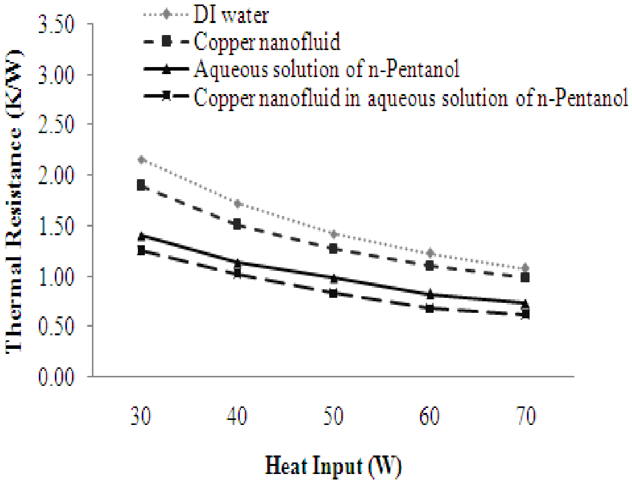


Fig. 13 Thermal resistance of heat pipe for 90° inclination

3.2 *Effect of thermal resistance*

Figures 7-13 show the relative results of thermal resistance of heat pipe with DI water, copper nanofluid, aqueous solution of n-Pentanol and copper nanoparticle in aqueous solution of n-Pentanol. The thermal resistance (R) of the heat pipe is defined as

$$R = \frac{(T_e - T_c)}{Q}$$

where T_e and T_c are average values of temperatures at the evaporator and condenser sections respectively and Q is the heat supplied to the heat pipe in the evaporator section. From all the figures, it is clear that the thermal resistance of heat pipe decreases for all the four working fluids with increasing values of angle of inclination and the heat input. The figures show that the thermal resistance of the heat pipes with nanofluid solution is lower than that with base working fluids. The reason for reducing the thermal resistance of the nanofluid heat pipe is the convective heat coefficient of nanofluid is higher than pure water [21] and the suspended nanoparticles in a fluid can increase the thermal conductivity of fluid. Therefore, it is expected that the thermal performance of heat pipe will be enhanced. However, the thermal resistances of heat pipes using both the base fluid and nanofluids are comparatively high at low heat loads for the reason that a relatively solid liquid film resides in the evaporator section.

On the other hand, these thermal resistances condense quickly to its minimum value when the heat load is increased because of the sudden collapse of the solid liquid film in the evaporator section. The difference between the thermal resistance of DI water & copper nanofluid is nearly 10% and the thermal resistance of the copper nanofluid and the aqueous solution of n-Pentanol is less than the DI water and copper nanofluid for all the variables and the value is nearly 30% less than the copper nanofluid. The decreasing value of thermal resistance between the aqueous solution of n-Pentanol and copper nanofluid is nearly 8% .The reason behind it is the fact that the surface temperature of the self rewetting fluids (aqueous solution of n-Pentanol) heat pipe is less than that of the DI water and copper heat pipe, i.e., more amount of heat is carried away by the self rewetting fluids in the evaporator section. For the high-temperature heat source, a large amount of the aqueous solution of n-Pentanol could be vapourized in the heat pipe and that vapour moves to the condenser section quickly and powerfully. It results in an increase in the condenser section temperature, subsequently lower thermal resistance for higher heat input than the lower heat input. The thermal efficiency reaches its maximum value when the value of the resistance is minimum. For DI water and aqueous solution of n-Pentanol the thermal efficiency is high at the angle of 30° and the value of thermal resistance is lower than other inclinations. Similarly copper nanofluid and copper nanoparticle in the aqueous solution of n-Pentanol gives higher efficiency and lower thermal resistance at 45^0. The variations of thermal resistance are within 8 to 10% only for all fluids at all inclinations expect for horizontal position.

Recently, Do and Jang [22] mathematically presented that the key effect of the heat transfer enhancement of a heat pipe using nanofluids is not due to the thermo physical properties of nanofluids but it is owing to the thin porous coating layer formed by nanoparticles in the evaporation region. Besides, Yang et al. [23] and Kim et al. [24] indicated that the coating layer formed by nanoparticles improves the surface wettability by reducing the contact angle and increasing the surface roughness, which in turn increases the critical heat flux. This not only improves the maximum heat transport rate but also, significantly reduce the thermal resistance of the heat pipe using nanofluids. This may be due to the formation of the thin porous coating layer by nanoparticles suspended in nanofluids. The coating layer on the mesh wick surface provides an additional evaporating surface where high heat transfer rates occur. This drastically reduces the thermal resistance of the mesh wicked heat pipe and also it increases the capillary pumping ability to pull the liquid to the mesh wick surface. The uncertainties of both thermal efficiency and the thermal resistance are within ±1%

The heat transfer coefficient of the heat pipe increases due to the presence of nanoparticles in the base fluid and its effective properties. In addition, the particle relocation is also one of the reasons for this enhancement in efficiency which led to the non-uniform distribution of thermal conductivity and viscosity of flow field.

IV. CONCLUSION

This experimental study investigated that the effect of angle of inclination in thermal performance of cylindrical heat pipe using DI water, copper nanofluid, aqueous solution of n-Pentanol and copper nanoparticle in aqueous solution of n-Pentanol. From the experimental study it is found that the thermal efficiency of copper nanoparticle in aqueous solution of n-Pentanol is higher than the base fluids like DI water, copper nanofluid and aqueous solution of n-Pentanol. Also the thermal resistance of copper nanoparticle in aqueous solution of n-Pentanol reduces to three fourth of DI water. The results show that the thermal performances of the heat pipe may be enhanced by adding a very small amount of long chain alcohol which gives the better performance than the conventional working fluid and also nanofluid. This may be due to the reason that, the dilute aqueous solution of n-Pentanol which is having a positive surface tension gradient with temperature gives rise to an increased value of the capillary limit and the boiling limit of the heat pipe along with the nanofluid.

REFERENCES

[1] Petersen, G. P. ; (1995). *An Introduction to Heat Pipes*, Wiley Publications, New York.
[2] Chi, S. W.; (1976). *Heat Pipe Theory and Practice*, McGraw-Hill Publications, Washington.
[3] Faghri, A.; (1995). *Heat Pipe Science and Technology*, Taylor & Francis, Washington.
[4] Tien. C.L. (1970). Two-Components Heat Pipes, Thermo physics: Application to Thermal Design of Spacecraft, Academic Press,
New York.
[5] Tien, C.L.; Rohani, A.R. (1973): Theory of two-component heat pipes. Journal of Heat Transfer, 94, pp. 479–484.
[6] Brommer H.J. (1974): Theoretical and experimental investigation of two-component heat pipes. Proceedings of the Thermo physics and Heat Transfer Conference, American Institute of Aeronautics and Astronautics and American Society of Mechanical Engineers, Boston.
[7] Kadoguchi, K.; Fukano, T; Emi, Y. (1994): Heat-transfer characteristics in the heating section of a closed two-phase thermosyphon working with a binary mixture. Heat Transfer Japanese Research, 23, pp. 128–140.
[8] Vochten, R.; 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. Journal of Colloidal and Interface Science, 42, pp. 320-327.
[9] Villers, D,; Platten. J. K. (1988): Temperature dependence of the interfacial tension between water and long- chain alcohols. Journal of Physical Chemistry, 92, pp. 4023-4024.
[10] Oron, A.; Rosenau, P. (1994): On a nonlinear thermo capillary effect in thin liquid layers. Journal of Fluid Mechanics. 273, pp. 361-374.
[11] Choi, S.U.S. (1995): Enhancing thermal conductivity of fluids with nanoparticles, developments and applications of non-Newtonian flows. FED, 231, pp. 99 – 105.
[12] Das, S.K.; Putra, M.; Thiesen, P., Roetzel, W. (2003): Temperature dependence of thermal conductivity enhancement for nanofluids. Journal of Heat Transfer, 125, pp. 567 – 574.
[13] Lee, S.; Choi, S.U.S.; Eastman, J.A. (1999): Measuring thermal conductivity of fluids containing oxide nanoparticles. Transaction of ASME, 121, pp. 280-289.
[14] Choi, S.U.S.; Wang, X.; Xu, W. (1999): Thermal conductivity of nanoparticle-fluid mixture. Journal of Thermodynamics and Heat Transfer, 13(4), pp. 474-480.
[15] Xuan, Y.; Li, Q. (2000): Heat transfer enhancement of nanofluids. International Journal of Heat and Fluid Flow, 21, pp. 58 – 64.
[16] Choi, S.U.S.; Eastman, J.A.; Li, S.; Yu, W.; Thompson, J. (2001): Anomalously increased effective thermal conductivities of ethylene glycol-based containing copper nanoparticles. Applied Physics Letters, 8, pp. 718 – 720.
[17] Tsai, C.Y.; Chien, H.T.; Ding, P.P.; Chan, B,; Luh, T.Y.; Chen, P.H. (2004): Effect of structural character of gold nanoparticles in nanofluid on heat pipe thermal performance. Material Letters, 58, pp. 1461-1465.
[18] Kang, S.W.; Wei, W.C.; Tsai, S.H.; Shih-Yu Yang. (2006): Experimental investigation of silver nano-fluid on heat pipe thermal performance. Applied Thermal Engineering, 26, pp. 2377-2382.
[19] Kang, S.; Wei, W,; Tsai, S.; Huang, C. (2009): Experimental investigation of nanofluids on sintered heat pipe thermal performance. Applied Thermal Engineering, 29, pp. 973-979.
[20] Naphon, P.; Assadamongkol, P.; Borirak. T. (2008): Experimental investigation of titanium nanofluids on the heat pipe thermal efficiency. International Communications in Heat and Mass Transfer, 35, pp. 1316–1319.
[21] Wen, D.; Ding, Y. (2007): Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions. International Journal of Heat and Mass Transfer, 47, pp. 5181-5188.
[22] Do, K.H.; Jang, S.P. (2010): Effect of nanofluids on the thermal performance of a flat micro heat pipe with a rectangular grooved wick. International Journal of Heat and Mass Transfer, 53, pp. 2183–2192.
[23] Yang, X.F.; Liu, Z,; Zhao, J. (2008): Heat transfer performance of a horizontal microgrooved heat pipe using cuo nanofluid. Journal of Micromechanics Micro engineering, 18, pp. 035038 -1-035038-6.
[24] Kim, H.D.; Kim, J.; Kim, M.H. (2007): Experimental studies on CHF characteristics of nano-fluids at pool boiling. International Journal of Multiphase Flow, 33, pp. 691-709.