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Study of Heat Pipes Using Nanofluids in Heat Recovery and Energy Conservation Systems

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ABSTRACT
This work discusses about the energy conservation potential of the heat pipe using nanofluids like copper oxide and iron oxide as a working fluids. Heat pipes make available a two-phase consistent heat transfer system with passive operation and high effectiveness for energy conservation systems. Besides, gravity assisted heat pipes are used in a variety of energy conservation systems like data center cooling, agricultural products cold storage, bakery waste heat recovery and automotive dashboard cooling. The experiments are conducted for various heat inputs and inclination angle of the heat pipes. The energy conserved using nanofluids are compared with the De-Ionized water as a working fluid on the basis of thermal efficiency and thermal resistance. The thermal efficiency and thermal resistance of the heat pipes using nanofluids are nearly 40% higher and less than 50% of the DI water respectively. This shows that the energy transfer with nanofluids are better than the conventional working fluids.

KEYWORDS: Angle of inclination, Energy transfer, Heat input, Heat pipe, Nanofluids.

INTRODUCTION

The energy requirement of all the countries is increasing greatly in recent times. The maximum energy consumption occurs in the industrial sector, transport sector, residential applications and commercial sectors [1]. There are numerous heat recovery systems which are widely used to recuperate the waste heat, among them the heat pipe is of great importance. The heat pipe is an effective heat transfer device that can transport heat at high rates with a very small temperature gradient by utilizing the phase change of working fluid. The heat pipe is a simple device with very high thermal conductivity and no moving parts. It can transport large quantities of heat efficiently over large distances without requiring any external electricity input. The main features of heat pipes are passive operation, long life, isolated air streams, minimum maintenance and minimum size. A heat pipe is essentially a conserved slender tube containing a wick structure lined on the inner surface and a small amount of fluid such as water at the saturated state [2]. Heat transfer fluid shall be selected on the basis of operating temperature and compatibility with tube material. It is composed of three sections: the evaporator section at one end, where heat is absorbed and the fluid is vaporized; a condenser section at the other end, where the vapor is condensed and heat is rejected; and the adiabatic section in between, where the vapor and the liquid phases of the fluid flow in opposite directions through the core and the wick respectively, to complete the cycle with no significant heat transfer between the fluid and the surrounding medium. The operating pressure and the type of fluid inside the heat pipe depend largely on the operating temperature of the heat pipe. In the present study the condenser of the heat pipe is elevated so that the condensate returns to the evaporator with the assistance of gravity. When the heat pipe is operating in gravity assisted mode, a high heat transfer capability can be achieved. Further, no wick is required in the condenser since gravity drains the condensate from the wall to the paddle. However, a wick structure is required for circumferential distribution of liquid in the evaporator.

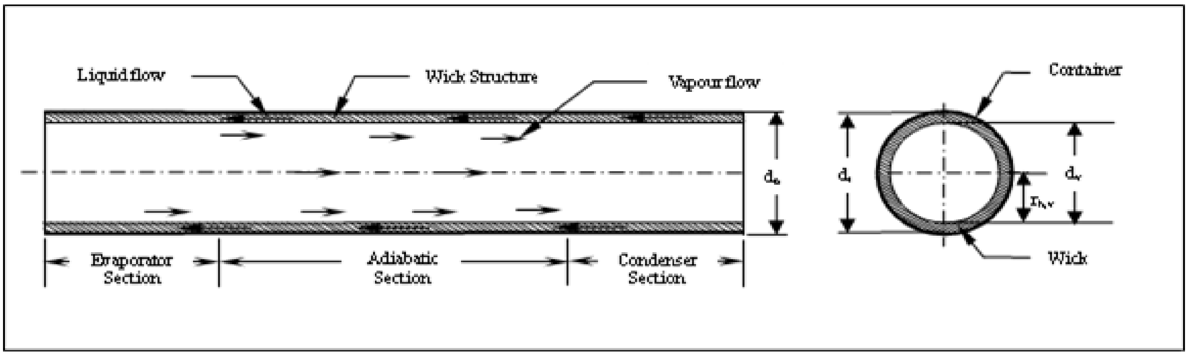

Fig. 1: Working of heat pipe

The position of condenser in the heat pipe is not restricted to any specific orientation and it may be utilized in any direction. Gravity-assisted heat pipes are unidirectional conductors which behave as thermal diode. If they are properly oriented, heat is transferred only from the evaporator to the condenser but never in the reverse direction. Also, since heat pipes are sealed, by selecting suitable working fluids, compatible with wick and pipe materials, corrosion can be minimized. Riffat *et al.* [3] studied thermal performance of a thin membrane heat pipe solar collector and hybrid heat pipe solar collector/CHP system to provide electricity and heating for a building [4] to conserve the energy from the solar. Mathioulakis and Belessiotis [5] experimentally studied the performance of a new solar hot water system with an integrated heat-pipe. They reported that the developed model can be used for the optimization of the system design. Feng Yang *et al* [6] analyzed the feasibility of using heat pipe heat exchangers to utilize waste heat from the automotive exhaust gas. The experimental results indicate the benefits of exhaust gas heating in addition to revealing good agreement with numerical results. Noie-Baghban and Majideian [7] worked on the design and build of a heat pipe arrangement to be installed in a heat pipe heat exchanger for the purpose of heat recovery in hospital and laboratory buildings where high air change is a primary requirement. Joudi and Witwit [8] carried out work to improve the thermal performance of gravity assisted conventional wickless heat pipes with the introduction of an adiabatic separator. The investigation concluded that the addition of an adiabatic separator eradicated the effect of inclination angles above 45◦ and decreased the heat pipe working temperature respectively. The performance of these conventional heat transfer fluids is limited due to low thermal conductivities**.** To improve the thermal performance of the heat pipes, advanced heat transfer fluids with substantially higher conductivities are used. The use of solid particles as an additive suspended into the base fluid is a new technique for enhancing the heat transfer performance. The innovative heat transfer fluids suspended by nanometer-sized solid particles are called 'Nanofluids'[9]. The nanoparticles of typical length scales of 1–100 nm with high thermal conductivity are suspended in the base fluids to enhance effective thermal conductivity and the convective heat transfer coefficient of the base fluid like water or ethylene glycol. The thermal conductivity of the particle materials, metallic or nonmetallic such as Al_2O_3, CuO, Cu, SiO, TiO, FeO are typically order-of-magnitude higher than the base fluids even at low concentrations, resulting in significant increases in the heat transfer coefficients than the conventional heat transfer fluids [10]. Yang and Liu [11] performed an experimental study on the thermal performance of a thermosyphon using nanofluids under steady operating pressures. The experimental results showed that the evaporating heat transfer coefficient of functionalized nanofluid increases maximally by 17% at the operating temperature of 40°C. Parametthanuwat et al. [12] studied the heat transfer of nanofluid in a thermosyphon for economizer. Water, water-based silver nanofluid with silver concentration 0.5 w/v%, and the nanofluid mixed with 0.5, 1.0, and 1.5 w/v% of oleic acid were used as working fluids. Thermosyphon for economizer consists of evaporation, adiabatic and condensation sections. The results showed that the thermosyphon efficiency can be enhanced by 30% at the volumetric flow rate of 1 lit/min, the filling ratio of 50%, and the operating temperature of 80°C. Lu et al. [13] performed an experimental study on the thermal performance of the open thermosyphon using the deionized water and water-based CuO nanofluids as the working liquid. The experimental results showed that adding nanoparticles to the base fluid significantly improved the thermal performance of the thermosyphon at the mass concentration of 1.2 wt.% and the filling ratio of 60% for maximal heat transfer enhancement. In this study, the heat pipes are fabricated with copper as the container material with two layers of stainless steel wrapped screen as a wick material. The mesh size is 80 strands per square inch. The working fluids are DI water, copper oxide nanofluid and iron oxide nanofluid. The size of the nanoparticle is 50 nm for both copper oxide and iron oxide. The nanofluids are prepared using the ultrasonic homogenizer for nanofluids. The experiments are conducted for various inclinations of heat pipe to the horizontal (0^o, 15^o, 30^o, 45^o, 60^o, 75^o

and 90^o) with different heat inputs (30, 40, 50, 60 and 70 W) The thermal efficiency and thermal resistance of the heat pipes are evaluated and discussed elaborately to investigate the working characteristics and the heat transfer performance of heat pipes.

II. Experimental analysis:

The schematic diagram of experiment is shown in fig. 2. The heat pipes are constructed using copper tube of diameter 20 mm and the two ends are brazed with copper end caps with a thickness of 2 mm. The heat pipe is partially charged with working fluid. The surface temperature of evaporator section (3 locations), adiabatic section (6 locations) and condenser section (3 locations) are measured using 10 evenly spaced copper constantan (T-type) thermocouples. The inlet and outlet temperature of the water at the condenser jacket also measured using copper constant thermocouples (T type). The heat input is given at the evaporator section in the form of cylindrical electrical heater which is energized by the AC supply and the heat input is measured using a power transducer. The tubular type condenser is used to remove the heat from the heat pipe. The condenser section of the heat pipe is cooled using water flow through a jacket with an inner diameter of 30 mm and outer diameter of 36 mm. The flow rate of water in the condenser is maintained as constant at 0.08 kg/min. The surface of the heat pipe is fully insulated with the glass wool in order to reduce environmental impact. The experiments are conducted for 30 W, 40 W, 50 W, 60 W and 70 W heat inputs and various inclinations of the heat pipes (0^o, 15^o, 30^o, 45^o, 60^o, 75^o and 90^o) with respect to the horizontal direction with different working fluids. The power input to the heat pipe is gradually raised to the desired power level. The surface temperatures at all locations like evaporator, adiabatic, condenser, water inlet and outlet temperatures in the condenser jacket are measured at regular time intervals until the heat pipe reaches the steady state condition. Once the steady state is reached, the input power is turned off and cooling water is allowed to flow through the condenser to cool the heat pipe and to make it ready for further experimental purpose. Then the power is increased to the next level and the heat pipe is tested for its performance. This procedure is repeated for different heat inputs and different inclinations of heat pipe and observations are recorded. The output heat transfer rate from the condenser is computed by applying an energy balance to the condenser flow.

RESULTS AND DISCUSSIONS

3.1. Effect of heat input and angle of inclination on thermal efficiency:

The thermal efficiency of the heat pipe is defined as the ratio of cooling capacity rate of water at the condenser section and the power supplied at the evaporator section [14]. The thermal efficiency of heat pipe using DI water, copper nanofluid and iron oxide nanofluid as a working medium are computed and compared in fig. 3 - 7 for various tilting angles and heat inputs. From all the figures, it is found that the heat pipe efficiency increases with increasing values of the angle of inclination. This is due to the fact that the gravitational force has a significant effect on the flow of working fluid between the evaporator and the condenser sections along with the capillary action of wick structure. From the figures, it is evident that the heat pipe efficiency increases with the increase in the tilt angle up to certain angle and then decreases. 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 in addition to capillary action of wick structure. The thermal efficiency of the heat pipe for nanofluids reaches a maximum value at 45^o inclination angle and DI water at 30^o afterwards the heat pipe thermal efficiency tends to decrease. This may be due to the strong formation of the liquid film at the inner side of condenser section resulting in the high thermal resistance between the vapour of the working fluid and the cooling medium in the condenser. The thermal efficiency of the heat pipe increases with increase in heat flux, due to the fact that the temperature gradient between the evaporator section and condenser sections increases. For higher values of heat input in the evaporator section, the heat generated in the surface is more and the working medium which is in the form of vapour moves vigorously into the condenser section. The cooling water in the condenser absorbs this excessive heat and as a result, the efficiency of the heat pipe increases. The thermal efficiency of the heat pipe filled with copper nanofluid is 10 to 12% higher than the DI water filled heat pipe. The heat pipe filled with iron oxide is 30 to 35% higher than the copper oxide. It is due to the fact that energy consersion of the iron oxide is more than the copper oxide nanofluid.

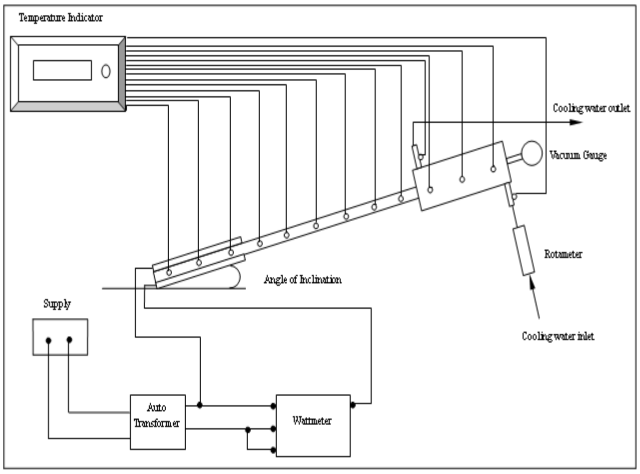

Fig. 2: Schematic diagram of experimental setup

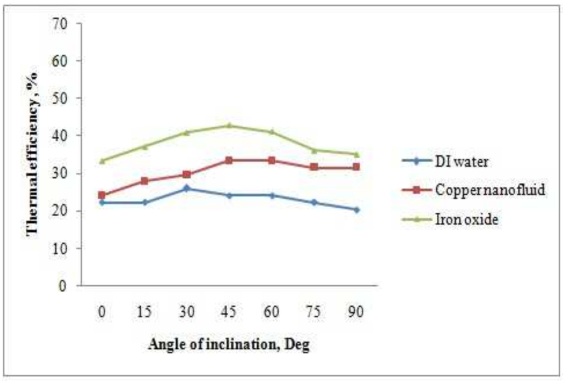

Fig. 3: Variations of thermal efficiency for 30 W

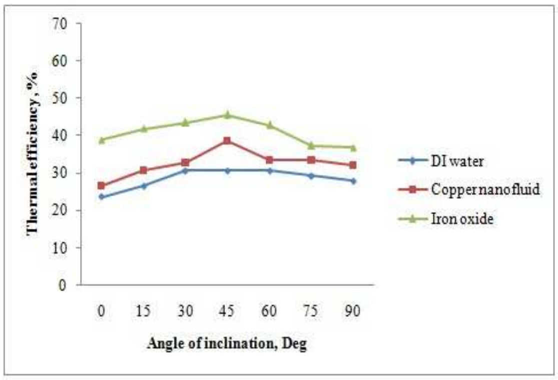

Fig. 4: Variations of thermal efficiency for 40 W

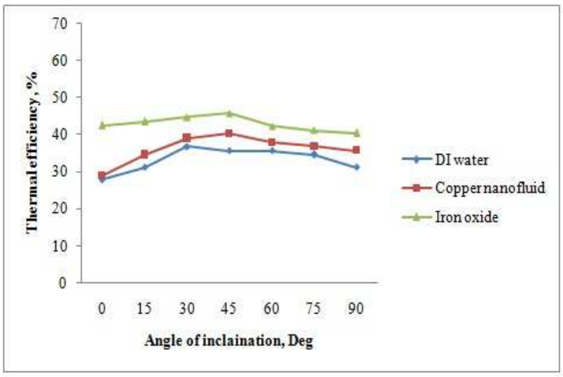

Fig. 5: Variations of thermal efficiency for 50 W

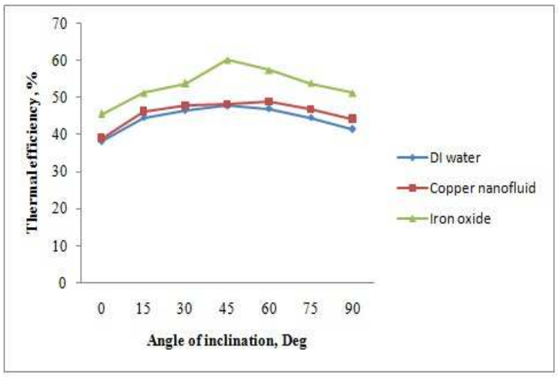

Fig. 6: Variations of thermal efficiency for 60 W

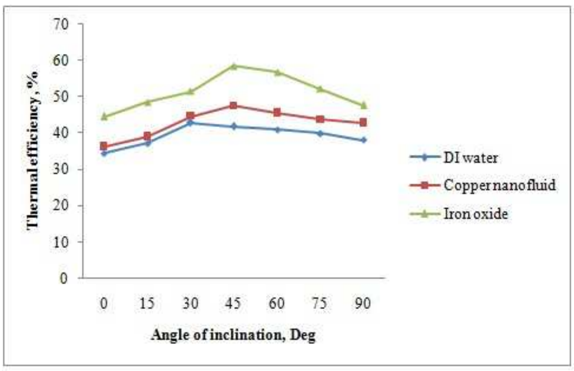

Fig. 7: Variations of thermal efficiency for 70 W

3.2. Effect of heat input and angle of inclination on thermal resistance:

The thermal resistance (TR) of the heat pipe is defined as

$$TR = \frac{T_e - T_c}{Q}$$

where Te and Tc are the average surface temperatures of the heat pipe at the evaporator section and the condenser section respectively and Q is the heat supplied to the heat pipe. Figures 8 to 11 show the comparative results of thermal resistance of heat pipe with DI water, copper nanofluid and iron oxide nanofluid. From all the figures, it is clear that the thermal resistance of heat pipe decreases for all the working fluids with its increasing values of angle of inclination and the heat input. However, the thermal resistances of heat pipes using both the base fluid (DI water) 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 fall quickly to its minimum value when the heat load is increased. The thermal resistance of copper nanofluids are nearly 50 % less than the DI water and for iron oxide is nearly 70 to 75% less than the DI water. Tsai et al. [15] and Liu et al. [16] stated the major reduction in the thermal resistances of the heat pipes using nanofluids is on the thermal resistance from the evaporator section to the adiabatic section at higher heat loads. This tendency for the variation of thermal resistance according to the heat input is a common characteristic of the heat pipe as indicated by Hopkins et al. [17]. The main reason for the decreasing values of the thermal resistance of heat pipe is due to the formation of vapour bubble at the liquid–solid interface. A larger bubble nucleation size creates a higher thermal resistance that prevents the transfer of heat from the solid surface to the liquid. As a result, the higher thermal performances of the new coolant have proved its potential as a substitute for conventional DI water in circular meshed heat pipe. Yang et al. [18] and Kim et al. [19] indicated that the reduction in thermal resistance 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.

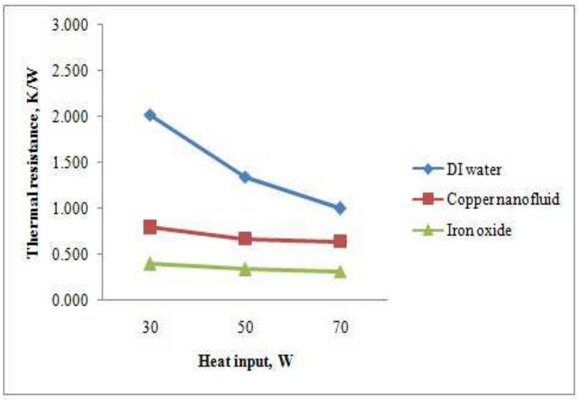

Fig. 8: Thermal resistance of the heat pipe at 0^o Inclination

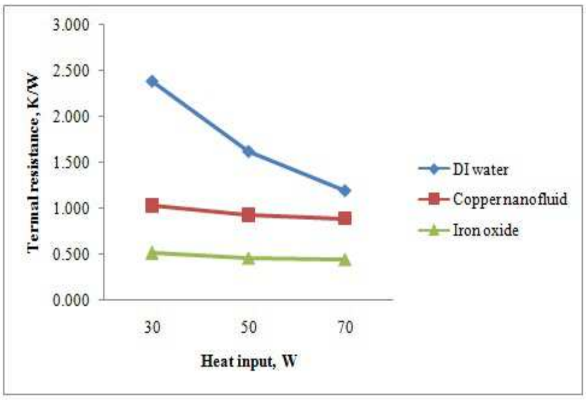

Fig. 9: Thermal resistance of the heat pipe at 30^o Inclination

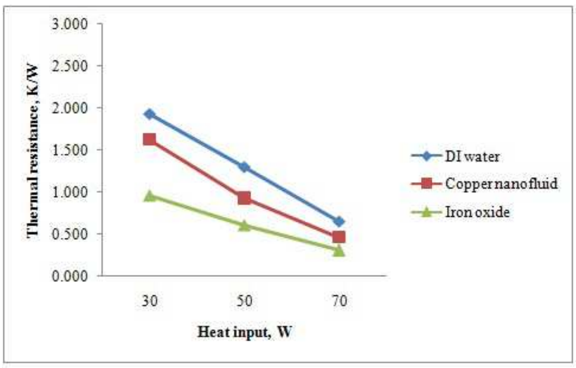

Fig. 10: Thermal resistance of the heat pipe at 60^o Inclination

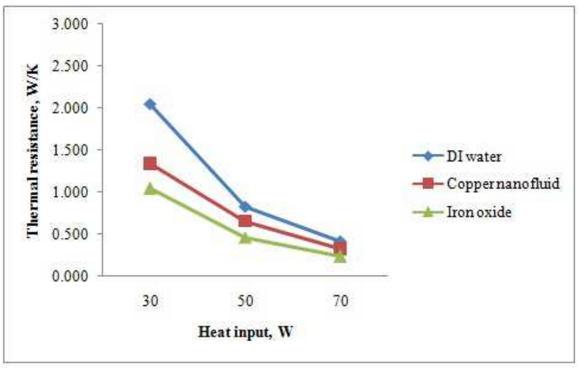

Fig. 11: Thermal resistance of the heat pipe at 90^o Inclination

Conclusion:

The technological development of research into the utilization of heat pipes for efficient and passive heat transport is rapidly increasing through the experimentation techniques. From this experimental analysis of the heat pipe using copper nanofluid and iron oxide nanofluid the following results are obtained.

- The experimental results show that the thermal efficiency and thermal resistance of heat pipe is a function of working fluid, inclination angle and heat input.
- The heat pipe thermal efficiency enhanced by 30 to 35% when compared with the base fluid like DI water.
- The thermal resistance of the heat pipe is decreased by using nanofluid 50% than the DI water.
- The surface temperature of the heat pipes using nanofluids are 30 to 50^{o}C less than the base fluid filled heat pipes. It is due to the more energy transfer characteristics of the nanofluids.
- The temperatures at adiabatic regime are almost uniform for all the experiments.
- The trial results reveal that the heat pipe efficiency gets reduced when the heat pipe is kept in vertical direction. The gravitational forces which assist the flow of working fluid back to the evaporator may accelerate the process which may hinder the heat transfer process at the condenser end and the fluid might have returned to the evaporator section with higher temperature end.

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