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Research Article

Boiling Heat transfer Enhancement of Heat Pipe using Nanofluid

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Abstract

A relatively new way for utilizing the thermal performance of heat pipes is to use nanofluids as working fluids in the heat pipes. Heat pipes are effective heat transfer devices in which the nanofluid operates in the two phases, evaporation and condensation. The heat pipe transfers the heat supplied in e.g. a laptop, from the evaporator to condenser part. Nanofluids are mixtures consisting of nanoparticles (e.g. nano-sized silver particles) and a base fluid (e.g. water). The aim of this project has been to examine the effect of nanofluids on heat pipes on the subject of temperature parameters and thermal resistance in the heat pies, through findings in literature and an applied model. The study, based on literature and an applied model, found that higher particle conductivity and higher concentration of nanoparticles consequently decrease the thermal resistance in the heat pipes, resulting in an enhanced thermal performance of the heat pipes with nanofluids as working fluids. It is however concluded that difficulties in finding the optimal synthesis of nanofluids, the concentration level of nanoparticles and the filling ratio of nanofluids in heat pipes, set bounds to the commercial use of nanofluids in heat pipes. It is suggested that, in order to enhance the heat transfer performance of nanofluids in heat pipes, to conduct further research concerning e.g. synthesis of nanofluids and concentration level of nanoparticles in nanofluids.

Keywords: *Heat transfer enhancement, nanofluids, nanoparticles, thermal resistance, flow rate, wall temperature resistance.*

1. Introduction

Since the 1990s, researchers began to apply nano-material technology to heat transfer field and have achieved many meaningful results on heat transfer enhancement. In 1995, Choi firstly proposed the concept of ‘‘nanofluid’’, which is a fluid with some kinds of nanometer-sized particles suspended into a base liquid. Some examples of applied nanoparticles are pure metals (Au, Ag, Cu,Fe), metal oxides (CuO, SiO_2, Al_2O_3, TiO_2, ZnO, Fe_3O_4), Carbides(SiC, TiC),Nitrides (AlN, SiN) and different types of carbon (diamond,graphite, single/multi wall carbon nanotubes). Traditional liquids, such as water, ethylene glycol and engine oil are some examples of base fluids. Under appropriate operating conditions, nanofluids will exhibit high thermal conductivity and stability and are increasingly being used in many heat transfer applications in industrial fields. In recent years, the studies on nanofluids mainly focused on its thermal conductivity, and on forced convection and boiling heat transfer mechanisms. Various mechanisms of the heat transfer enhancement have been proposed including the interface effect (liquid layering around the nanoparticle makes the atomic structure of the liquid layer more ordered than that of bulk liquid, due to higher thermal conductivity of the nanoparticle than liquid, the liquid layer at the interface would reasonably have a higher thermal conductivity than the bulk liquid), Brownian motion, ballistic transport of energy carriers (ballistic phonon transport through the nanoparticles, heat is carried by phonons, i.e., by propagating lattice vibrations), and thermo-phoresis with the rapid development of the IT industry, the heat flux in IC chips cooled by air has almost reached its limit by about 100 W/cm^2.Some applications in high technologies require heat fluxes well beyond such a limitation.

Therefore, the search for more efficient cooling technologies becomes one of the bottleneck problems for further development of the industry. Devices such as the thermosyphons and heat pipe cooling systems are candidates for solving this problem. Thermosyphon heat pipes are passive heat transfer devices with high effective thermal conductivity. The effective coefficient of thermal conductivity of a thermosyphon heat pipe can be orders of magnitude higher than those of highly conductive solid materials, such as copper the most frequently used coolants the heat transfer device study are air, water, and fluoro-chemicals. However, the heat transfer capability is limited by the working fluid transport properties. A relatively new way for utilizing the thermal performance of heat pipes is to use

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nanofluids as working fluids in the heat pipes. Heat pipes are effective heat transfer devices in which the nanofluid operates in the two phases, evaporation and condensation. The heat pipe transfers the heat supplied in e.g. a laptop, from the evaporator to condenser part. Nanofluids are mixtures consisting of nanoparticles (e.g. nano-sized silver particles) and a base fluid (e.g. water). (Zhen-Hua Liu *et al*., 2012).

1.1 Classification of Enhancement Techniques:

Heat transfer enhancement or augmentation techniques refer to the improvement of thermo-hydraulic performance of heat exchangers. Existing enhancement techniques can be broadly classified into three different categories:

1.1.1 Passive Techniques

These techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficients by disturbing or altering the existing flow behavior (except for extended surfaces) which also leads to increase in the pressure drop. In case of extended surfaces, effective heat transfer area on the side of the extended surface is increased. Passive techniques hold the advantage over the active techniques as they do not require any direct input of external power. Heat transfer augmentation by these techniques can be achieved by using:

- Treated Surfaces: This technique involves using pits, cavities or scratches like alteration in the surfaces of the heat transfer area which may be continuous or discontinuous. They are primarily used for boiling and condensing duties.
- Rough Surfaces: These surface modifications particularly create the disturbance in the viscous sub-layer region. These techniques are applicable primarily in single phase turbulent flows.
- Extended Surfaces: Plain fins are one of the earliest types of extended surfaces used extensively in many heat exchangers. Finned surfaces have become very popular now days owing to their ability to disturb the flow field apart from increasing heat transfer area.
- Displaced Enhancement Devices: These inserts are used primarily in confined forced convection. They improve heat transfer indirectly at the heat exchange surface by displacing the fluid from the heated or cooled surface of the duct with bulk fluid from the core flow.
- Swirl Flow Devices: They produce swirl flow or secondary circulation on the axial flow in a channel. Helical twisted tape, twisted ducts & various forms of altered (tangential to axial direction) are common examples of swirl flow devices. They can be used for both single phase and two-phase flows.
- Coiled Tubes: In these devices secondary flows or vortices are generated due to curvature of the coils which promotes higher heat transfer coefficient in single phase flows and in most regions of boiling. This leads to relatively more compact heat exchangers.
- Surface Tension Devices: These devices direct and improve the flow of liquid to boiling surfaces and from condensing surfaces. Examples include wicking or grooved surfaces.
- Additives for Liquids: This technique involves addition of solid particles, soluble trace additives and gas bubbles added to the liquids to reduce the drag resistance in case of single phase flows. In case of boiling systems, trace additives are added to reduce the surface tension of the liquids.(Jay m. Ochterbeck)

1.1.2 Active Techniques

- These techniques are more complex from the use and design point of view as the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. It finds limited application because of the need of external power in many practical applications. In comparison to the passive techniques, these techniques have not shown much potential as it is difficult to provide external power input in many cases. Various active techniques are as follows:
- Mechanical Aids: Examples of the mechanical aids include rotating tube exchangers and scrapped surface heat and mass exchangers. These devices stir the fluid by mechanical means or by rotating the surface.
- Surface Vibration: They have been used primarily in single phase flows. A low or high frequency is applied to facilitate the surface vibrations which results in higher convective heat transfer coefficients.
- Fluid Vibration: Instead of applying vibrations to the surface, pulsations are created in the fluid itself. This kind of vibration enhancement technique is employed for single phase flows.
- Electrostatic Fields: Electrostatic field like electric or magnetic fields or a combination of the two from DC or AC sources is applied in heat exchanger systems which induce greater bulk mixing, force convection or electromagnetic pumping to enhance heat transfer. This technique is applicable in heat transfer process involving dielectric fluids.
- Injection: In this technique, same or other fluid is injected into the main bulk fluid through a porous heat transfer interface or upstream of the heat transfer section. This technique is used for single phase heat transfer process.

- Suction: This technique is used for both two phase heat transfer and single phase heat transfer process. Two phase nucleate boiling involves the vapor removal through a porous heated surface whereas in single phase flows fluid is withdrawn through the porous heated surface.
- Jet Impingement: This technique is applicable for both two phase and single phase heat transfer processes. In this method, fluid is heated or cooled perpendicularly or obliquely to the heat transfer surface.

1.1.3 Compound Techniques

A compound augmentation technique is the one where more than one of the above mentioned techniques is used in combination with the purpose of further improving the thermo-hydraulic performance of a heat exchanger. The advent of high heat flow processes has created significant demand for new technologies to enhance heat transfer. For example, microprocessors have continually become smaller and more powerful, and as a result heat flow demands have steadily increased over time leading to new challenges in thermal management. Furthermore, there is increasing interest in improving the efficiency of existing heat transfer processes. An example is in automotive systems where improved heat transfer could lead to smaller heat exchangers for cooling resulting in reduced weight of the vehicle. Many methods are available to improve heat transfer in processes. The flow of heat in a process can be calculated based on:

$Q = h A \Delta T$

where Q is the heat flow, h is the heat transfer coefficient, A is the heat transfer area, and T is the temperature difference that results in heat flow. It can be stated from this equation that increased heat transfer can be achieved by

(i) Increasing A, (ii)Increasing ΔT, (iii) Increasing h.

A grater temperature difference ΔT lead to increase in heat flow, but ΔT is often limited by process or materials constraints. For example, the maximum temperature in a nuclear reactor must be kept below a certain value to avoid runaway reactions and meltdown. Therefore, increased T can only be achieved by decreasing the temperature of the coolant. However, this would reduce the rate of the nuclear reaction and decrease the efficiency

Maximize the heat transfer area A is common strategy to improve heat transfer, and many heat exchangers such as radiators and plate-and-frame heat exchangers are designed to maximize the heat transfer area. However, this strategy cannot be employed in microprocessors and micro electromechanical systems (MEMS) because the area cannot be increased. In aerospace and automotive systems, increasing the heat transfer area can only be achieved by increasing the size of the heat exchanger which can lead to unwanted increases in weight. (Godson *et al* 2010)

Heat transfer improvements can also be achieved by increasing the heat transfer coefficient h either by using the more efficient heat transfer method or by improving the transfer properties of heat transfer material. For example, heat transfer systems which employ forced convection of a gas exhibit a greater heat transfer coefficient than systems which employ free convection of a gas. Alternatively, the heat transfer coefficient can be increased by enhancing the properties of the coolant for a given method of heat transfer. Additives are often added to liquid coolants to improve specific properties. For example, glycols are added to water to depress its freezing point and to increase its boiling point. The heat transfer coefficient can be improved via the addition of solid particles to the liquid coolant (i.e. nanofluid).(Jay m. Ochterbeck)

2. Nanofluid Concepts

The concept of nanofluids is developed at Argonne National laboratory is directly related to trends in miniaturization and nanotechnology. Nanotechnology in the U. S., China, Europe, and Japan show that nanotechnology will be an emerging and exciting technology of the 21st century and that universities, national laboratories, small businesses, and large multinational companies have already established nanotechnology research groups or interdisciplinary centers that focus on nanotechnology (Choi *et al*. 1995). It is estimated that nanotechnology is at a similar level of development as computer/information technology was in the 1950s. Solids have orders-of-magnitude higher thermal conductivities than those of conventional heat transfer fluids. For example, the thermal conductivity of copper at room temperature is about 3000 times greater than that of engine oil. Therefore, solid particles in fluids are expected to enhance the thermal conductivities of fluids. In fact, numerous theoretical and experimental studies of the effective thermal conductivity of dispersions that contain solid particles have been conducted since Maxwell's theoretical work was published more than 100 years ago (Maxwell, 1873). Fig 1. Shows the thermal conductivity of typical materials. Solids have thermal conductivities that are orders of magnitude greater than those of traditional heat transfer fluids.

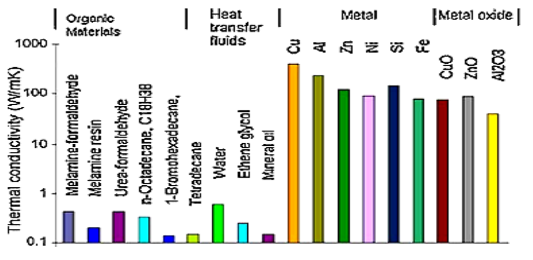

Fig. 1 Thermal conductivity of typical materials

However, all of the studies on thermal conductivity of suspensions have been confined to millimeter- or micrometer-sized particles. The major problem with these particles is their rapid settling in fluids. In recent years, nanotechnology has enabled the production of nanoparticles with average sizes below 50 nm. Nanoparticles at this scale have unique properties. Applying this emerging nanotechnology to established thermal energy engineering, Argonne developed the concept of nanofluids, a new and innovative class of heat transfer fluids that are engineered by suspending Nanoparticles in conventional heat transfer fluids.Maxwell's concept of enhancing the thermal conductivity of fluids by dispersing solid particles is old, but what is new and innovative with the concept of nanofluids is the idea of using the nanometer-sized particles that have become available only recently. These very small particles remain in suspension almost indefinitely and also provide high surface area densities. Because of the "square/cube law," the surface-area-to-volume ratio of nanoparticles is three orders of magnitude greater than that of micro particles. They show that "size does matter" in the concept of nanofluids. For this reason, nanofluidsare a rapidly emerging field in which nano science and thermal engineering meet. (Maxwell *et al*., 1873)

2.1 Hybrid Nanofluids

Nano composites, i.e., composites containing dispersed particles in the nanometer range, are significant part of nanotechnology and one of the fastest growing areas in material science and engineering. Alumina (Al_2O_3) is a ceramic material that exhibit several excellent properties such as very good stability and chemical inertness. But Al_2O_3has lower conductivity compared to metallic nanoparticles. Metallic nanoparticles such as copper (Cu), aluminum (Al) possess very high thermal conductivities. But stability and reactivity are two important factors that always impede the use of metallic nanoparticles in the nanofluid applications. The incorporation of small amount of metal particles into an ammonia matrix can significantly improve the thermal properties. (J. Sarkar *et al*.)

2.2 Particle Material and Base Fluid

Many different particle materials are used for nanofluid preparation. Al_2O_3, CuO, TiO_2, SiC, TiC, Ag, Au, Cu, and Fe nanoparticles are frequently used in nanofluid research. Carbon nanotubes are also utilized due to their extremely high thermal conductivity in the longitudinal (axial) direction. Base fluids mostly used in the preparation of nanofluids are the common working fluids of heat transfer applications; such as, water, ethylene, glycol and engine oil. In order to improve the stability of nanoparticles inside the base fluid, some additives are added to the mixture

2.3 Particle Size

Nanoparticles used in nanofluid preparation usually have diameters below 100nm. Particles as small as 10 nm have been used in nanofluid research. When particles are not spherical but rod or tube-shaped, the diameter is still below 100nm, but the length of the particles may be on the order of micrometers. It should also be noted that due to the clustering phenomenon, particles may form clusters with sizes on the order of micrometers.

2.4 Particle Shape

Spherical particles are mostly used in nanofluids. However, rod-shaped, tube-shaped and disk-shaped nanoparticles are also used. On the other hand, the clusters formed by nanoparticles may have fractal-like shapes.

2.5 Advantages of Nanofluids

Nanofluids offers following advantages than other methods to improve heat transfer in conventional fluids.

- Simple Manufacturing Methods. The availability of simple manufacturing methods enables to produce nanofluids that meet the needs of a wide variety of current and future applications. Researchers can choose the most appropriate material to be added to a fluid currently in use. (For example, the two-step method works best with fluids that have high vapor pressure, like water.) The two-step method first produces nanoparticles and then disperses them in a base fluid. It is simple, and it is less costly and works with more fluids than the one-step method. But the one-step method, employs a direct evaporation-condensation method that results in very small, essentially no agglomerating nanoparticles that disperse well.
- Can Use Many Particle Materials. One can choose from a variety of nanoparticle materials, which is most compatible with an already existing base fluid. One can use nonmetals when the use of metals would not be appropriate (for example, because they oxidize), and can exploit the enhanced heat transfer capabilities and stability of metal nanoparticles.
- Works With A Variety Of Base Fluids. Nanofluids work with a variety of base fluids. This feature enables them to be used in many current applications. Existing fluids can be easily improved instead of being replaced. Examples include radiators that use an ethylene glycol/water mixture and thermal systems that use synthetic fluids. (Heris *et al*., 2006)
- Does Not Require Dispersants. Nanofluids remain stable almost indefinitely without the use of dispersants. An additional benefit is that using

nanofluids eliminates any time, cost, or effort that would be associated with using dispersants. (A small quantity of thio-glycolic acid was added to Boron Nitride nanofluids to enhance conductivity, not stability.)

- Does Not Settle Rapidly. Nanofluids outperform existing heat transfer fluids containing solid particles in terms of long-term stability. Such stability is a requirement for enhancing heat transfer, since heat transfer occurs at the surface. Particles also need to stay suspended to ensure that the properties of the fluid do not change. Moreover, if particles settle, more particles need to be added to replace them, which represent extra time, expense, and effort.
- The best known capillary-driven two-phase system is the heat pipe, where a schematic of a conventional heat pipe. The concept of the heat pipe was first presented by Gaugler and Trefethen, but was not widely publicized until an independent development by Grover *et al*. at the Los Alamos Scientific Laboratories. Heat pipes are passive devices that transport heat from a heat source (evaporator) to a heat sink (condenser) over relatively long distances via the latent heat of vaporization of a working fluid. As shown, a heat pipe generally has three sections: an evaporator section, an adiabatic (or transport) section, and a condenser section. The major components of a heat pipe are a sealed container, a wick structure, and a working fluid. The wick structure is placed on the inner surface of the heat pipe wall and is saturated with the liquid working fluid and provides the structure to develop the capillary action for liquid returning from the condenser to the evaporator section. With evaporator heat addition, the working fluid is evaporated as it absorbs an amount of heat equivalent to the latent heat of vaporization, while in the condenser section; the working fluid vapor is condensed. The mass addition in the vapor core of the evaporator section and mass rejection in the condenser end results in a pressure gradient along the vapor channel which drives the corresponding vapor flow. Return of the liquid to the evaporator from the condenser is provided by the wick structure.
- As vaporization occurs in the evaporator, the liquid meniscus recedes correspondingly the wick structure, similarly, as vapor condenses in the condenser region, the mass addition results in an advanced meniscus. The difference between the capillary radii in the evaporator and condenser ends of the wick structure results in a net pressure difference in the liquid-saturated wick. This pressure difference drives the liquid from the condenser through the wick structure to the evaporator region, thus allowing the overall process to be continuous. (G. Huminic *et al*., 2011)
- Due to the two-phase characteristics, the heat pipe is ideal for transferring heat over long distances with a very small temperature drop and for creating a nearly isothermal surface for temperature stabilization. As the working fluid operates in a thermodynamic saturated state, heat is transported using the latent heat of vaporization instead of sensible heat or conduction where the heat pipe then operates in a nearly isothermal condition. This nearly isothermal condition offers benefits of transporting large amounts of heat efficiently, decreasing the overall heat transfer area and saving system weight. The amount of heat that can be transported through the use of latent heat is typically several orders of magnitude greater than transported by sensible heat for geometrically equivalent system. Additionally, no mechanical pumping systems are required due to the capillary-driven working fluid. Given the wide range of operating temperatures for working fluids, the high efficiencies, the low relative weights, and the absence of external pumps in heat pipes, these systems are seen as attractive options in a wide range of heat transfer applications.
- Theoretically, heat pipe operation is possible at any temperature between the triple state and the critical point of the working fluid utilized, albeit at significantly reduced transport capabilities near the two extremes due to the fluid property characteristics of surface tension and viscosity., along with the corresponding triple point, critical point, and most widely utilized temperature range for each individual fluid. Classification of heat pipes maybe in terms of geometry, intended applications, or the type of working fluid utilized. Each heat pipe application has a temperature range in which the heat pipe is intended to operate. Therefore, the working fluid must be chosen to take into account this operating temperature (along with the pressure condition), but also its chemical compatibility with the container and wick materials. (J Lee *et al*., 2007).

2.6 Study of aspects of different nanofluids on thermal performance

By studying the temperature difference between evaporator and condenser an evaluation of on the thermal efficiency of the heat pipe can be made. It also enables studies on the incremental heat dissipation enhancement of the heat pipe without increasing the wall temperature of the heat pipe (Shafahi *et al*., 2010a). The working fluids studied in Figure 2 are:

pure water, silver *(Ag),* silicon carbide *(SiC)* and aluminum oxide *(*Al_2O_3*)* based working fluids with 10 % volumetric concentration. (Mousa *et al*)

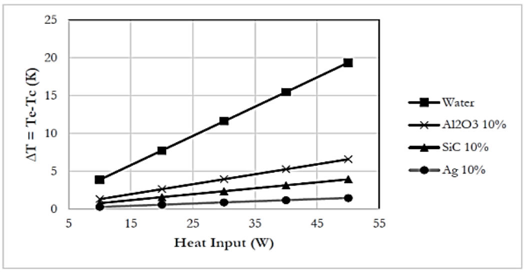

Fig.2 Temperature difference between evaporator and condenser depending on nanofluid and heat input.

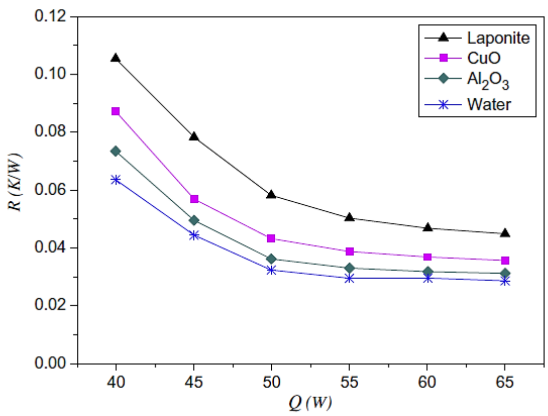

Fig. 3 Heat resistance of closed two-phase heat pipe with different nanofluidsas compared to pure water

2.7 Advantages of Al_2O_3 *Nanofluid*

Aluminium and aluminium oxide nanoparticles are used for corrosion, scratch and wear resistance and display high thermal barrier properties as well as being super hydrophobic; in composites they provide high barrier, durability, fire retardancy, stiffness, thermal fatigue resistance, fracture toughness, creep resistance and wear resistance.

3. Experimental setup and test methodology

This work is fabricated to study the heat transfer enhancement of a heat pipe using Al_2O_3/water nanofluid. The experimentation work is done using a circular heat pipe with the following objectives:

1) Effect of different concentration of nanofluid /water on thermal
    a. Resistance of heat pipe
2) Effect of heat input on thermal resistance rate of heat pipe.
3) Effect of cooling water flow rate

In order to achieve the above objectives the experimental system designed with the following specifications, provision is made to vary the heater input by changing the voltage, 3%, 5%, 7% volume fraction of nanofluid are prepared.

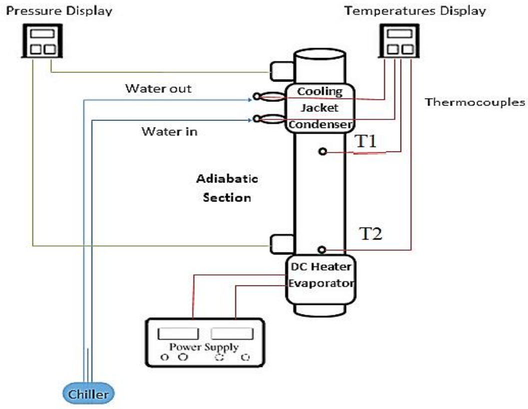

Fig. 4 Schematic Experimental Setup (Hassan *et al.*, 2015)

3.1 Specification of Experimental System

- Four heat pipes of 150 mm length, one with inner fluid as water and three with 3% , 5%, 7% aluminium oxide nanofluid respectively.
- Heater Capacity:-200 W with variation in 25W.
- Rota meter:-0-10 LPM.
- RTD:-8 Nos.3 for evaporator section, 2 for adiabatic section and 3 for condenser section.

3.1.1 Heat pipe

Heat pipe has the following dimensions

- Material of Heat pipe – Copper
- Total length-150 mm
- Evaporator length-25 mm
- Adiabatic length-100 mm
- Condenser length-25 mm
- Outer diameter of pipe-25.4 mm
- Inner diameter of pipe-23.5 mm

3.2 Test Methodology

1. The heat pipe body is made up of copper, with a length of 150 mm, outside and inside diameter of 25.4 mm and 23.5 mm respectively.
2. The heat pipe is charged with 400 ml of working fluid, which approximately corresponds to the amount required to fill the evaporator. The distance between the evaporator and the condenser is normally called as the adiabatic section with a length of 100 mm.
3. The wall temperature distribution of the heat pipe in adiabatic zone is measured using five evenly spaced, at an equal distance from the evaporator.
4. The adiabatic section of the heat pipe is completely insulated with the asbestos material layer. The amount of heat loss from the evaporator and condenser surface is negligible.

5. The electrical power input is applied at the evaporator section using cylindrical electric heater attached to it with proper electrical insulation and the heater is energized with 230V AC supply and measured using a voltmeter and ammeter connected in parallel and series connections respectively.
6. The evaporator and condenser have a length of 25 mm. In order to measure the average temperature of the evaporator, two RTDs are distributed along the length of evaporator.
7. Water jacket has been used at the condenser end to remove the heat from the pipe. 8. The heat pipe has the ability to transfer the heat through the internal structure. As a result, a sudden rise in wall temperature occurs which could damage the heat pipe if the heat is not released at the condenser properly. Therefore, the cooling water is circulated first through the condenser jacket, before the heat is supplied to the evaporator.
9. The condenser section of the heat pipe is cooled using water flow through a jacket with an inner diameter of 25.4 mm and outer diameter of 30 mm. The water flow rate is measured using a rotameter on the inlet line to the jacket, the flow rate is kept constant at 6.6 lpm, to measure the average temperature of the condenser, three equally spaced RTD distributed along the length of condenser.
10. The inlet and outlet temperatures of the cooling water are measured using two RTDs.
11. The experiments are conducted using three identical heat pipes which are manufactured as per mentioned dimensions. One of the heat pipes is filled with distilled water, second one with 3% aqueous solution of nano fluid (Al_2O_3), third one with aqueous solution of 5% nano fluid, fourth with 7% nano fluid.
12. The power input to the heat pipe is gradually raised to the desired power level. The surface temperatures at five different locations along the adiabatic section of heat pipe are measured at regular time intervals until the heat pipe reaches the steady state condition. Simultaneously the evaporator wall temperatures, condenser wall temperatures, water inlet and outlet temperatures in the condenser zone are measured.
13. 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.
14. The steady state condition is defined as a state in which the variation of temperature is within 1^0C for 10 min. Then the power is increased to the next level and the heat pipe is tested for its performance.
15. Experimental procedure is repeated for different heat inputs (25, 50, 75 and 100 W) and the output heat transfer rate from the condenser is computed by applying an energy balance to the condenser flow.

4. Results

Fig. 5shows adiabatic section upper temperature versus the evaporator temperature. The adiabatic section upper temperature, T1, increased as the evaporator temperature, T2, increases for all working fluids. Nanofluids showed an enhancement in the heat pipe performance as it lowers the T1 and therefore increases the temperature difference across the adiabatic section; which in turn increases the heat transfer across the heat pipe. This enhancement increases as the nanoparticles concentration is increased. After several use of the nanofluids in one month time span, the heat pipe performance proved to be inconsistent as shown in Fig. 4. It can also be seen from this figure that T1 values are higher at the corresponding T2 compared tosimilar inconsistence has been reported by and, however no clear explanation has been revealed. (Hassan *et al*. 2015).

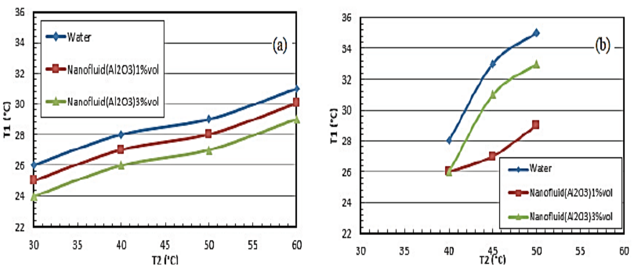

Fig.5 Results from experimentation. (Hassan *et al*., 2015)

Conclusions

By charging Al_2O_3nanofluid as the working fluid inside a 1 mm wick-thickness sintered circular heat pipe, following are the outcomes.
• More is the dispersion of Al_2O_3nanoparticles, better is the heat transfer enhancement
• Results indicate that the Al_2O_3nanofluid has remarkable potential as a working fluid for heat pipe.
• The thermal resistance of the heat pipes with the nanoparticle solution is lower than that of pure water in grooved heat pipes.
• A significant performance enhancement was observed, up to 50%, and then followed by performance inconsistencies after repetitive experiments. It is investigated that the nanoparticles, wick and surface of porous media of heat pipe revealed increased nanoparticle sizes, deposits on the wick as well as particle agglomerations, which accounts for now developing blockage and performance inconsistencies of heat pipe.
• The lowest temperature in the heat pipe can be observed in the curved zone and this temperature decreases from the evaporator to the curve and then increases after returning back to the evaporator.

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