Enhancement of thermal performance of a loop heat pipe using alumina – water nanofluid: An experimental investigation

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Abstract: The thermal performance of a loop heat pipe (LHP) with alumina – water nanofluid is experimentally investigated. The experiments are carried out in a LHP, in which the setup consists of condenser, evaporator, two transport lines (vapour and liquid lines), rotameter, power supply, thermocouples. The experiments are conducted for heat input ranging from 30 – 310 W using deionised water (baseline) and alumina – water nanofluid. Alumina nanoparticles with 2% mass concentration and water are used as working fluids. The experimental results indicate that the nanofluid can enhance the thermal performance of loop heat pipe and lower the evaporator temperature by 12% from the baseline case. The experimental results prove the capability of loop heat pipe with alumina – water nanofluid for various applications.

Key words: Loop heat pipe, nanofluid, thermal performance

1. Introduction

The loop heat pipe (LHP) is a device that operates on a multi phase fluid-flow cycle, maintained by a capillary medium in the evaporator. It is a heat transfer device which can transport a large amount of heat over a long distance with negligible temperature difference. In steady state operation these heat pipes have high thermal conductance. Thus LHPs are also known as super thermal conductors. Their advantages include electricity free operation, reliability and ability to work even with negligible temperature difference and transfer heat over long distances with small pressure drop [1,2].

The performance of an LHP is greatly affected by characteristics of working fluid in the heat pipe. Gunnasegaran et al. [3,4] conducted experimental and numerical investigations on LHPs with alumina and silica as nanofluids. It was found that the thermal resistance decreases when using silica-water nanofluid. The LHP charged with alumina-water nanofluid yielded lower wall temperature difference between evaporator and condenser and steady state is attained faster. Zhenping et al. [5] experimentally investigated the influence of a nanofluid on the heat transfer characteristics of a miniature loop heat pipe. It was concluded that performance improvement of the LHP using the nanofluid resulted in the reduction of the contact angle, the enhancement of boiling heat transfer and a deposited nanoparticle coating on the boiling surface. The thermal performance of a miniature loop heat pipe was investigated with graphene nanofluid by Trijo et al. [6]. The results showed an increase in the thermal conductivity and thermal efficiency of the device. The thermal performance of a loop heat pipe had been experimentally investigated by many researchers. Pauken et al. [7] experimentally
studied the thermal performance of LHP with two working fluids i.e., ammonia and propylene. The constant conductance performance of the LHP was found to be 170 W/K with ammonia and 44 W/K for propylene. The thermal performance of an LHP with acetone as working fluid was experimentally investigated by Riehl et al. [8]. It was concluded that the system could present reliable performance in all situations with power level as low as 1 W. Also higher operating temperatures could be obtained when evaporator is above the condenser. Zhao et al. [9] also studied the thermal performance of a double compensation chamber LHP for anti icing system in aircrafts. Results showed an increase in surface temperature of the aircraft wing with increase of heat load on the evaporator.

The application of nanofluid in LHP is a challenging area of research, which is still in its initial stages. Also only a few researchers have considered nanofluids as the working fluid in LHP. The present study deals with the experimental investigations of LHP with alumina nanoparticles. Heat input ranges from 30 to 310 W in steps of 40 W. The experiments are conducted in an LHP which is of new design. The thermal performance of the LHP using nanofluid is compared with that of deionised water (baseline case).

2. Nanofluid preparation
In the present study, the working fluids used are alumina – water nanofluid and deionised water. The nanofluid is prepared by using a two-step method. Deionised water is taken as the base fluid for the preparation of nanofluid. The alumina nanoparticles having an average size of 13 nm and density 3.95 g/cm³ are used to prepare the nanofluid with 2 % mass concentration. The particle mass concentration of the nanofluid is calculated using the equation (1) [10]

\[
\text{Percentage mass concentration} = \frac{W_n}{W_{bf}} \times 100\%
\]

Where,

\[
W_n = \text{Amount of nanofluid in gram}
\]
\[
W_{bf} = \text{Amount of base fluid in gram}
\]

3. Experimental setup
The LHP has six parts: evaporator, compensation chamber, wick, condenser, liquid and vapour line. All parts of the heat pipe are made with copper. The figure 1 shows the schematic diagram of LHP indicating the thermocouple positions used in the present study. Figure 2 shows the photograph of compensation chamber and the wick which is placed inside the evaporator. The detailed specifications of the loop heat pipe are given in the table 1.

The evaporator area is same as that of the area of heater top surface. In order to reduce contact resistance between evaporator and heater, a flat evaporator is employed. The wick with a porosity of 63 % is used. Wick is used to produce the capillary force which is required to overcome pressure losses in the LHP. The compensation chamber acts as the reservoir of working fluid. After placing the wick inside the evaporator the compensation chamber and evaporator are brazed together.

The schematic diagram of experimental setup LHP is shown in figure 3. It consists of LHP, thermocouples, rotameter, pump, chilling unit, voltmeter, ammeter, data logger, heater and computer. The heater block consists of a copper block fitted with two cartridge heaters. Arrangement of heaters are made such that the evaporator surface is maintained at uniform temperature. The heaters are connected to a dimmerstat to give different heat inputs which are measured using voltmeter and ammeter.

A thick layer of glass wool insulation is given at the heater so that heat loss can be minimised. The chilling unit is used to maintain the cooling water at constant temperature. Rotameter and pump are used to measure and maintain constant cooling water supply to condenser. Cooling water enters the condenser at bottom left corner and leaves at top right corner. The uncertainty in measurement of temperature, voltage and current are ± 0.2 °C, ± 0.1 V and ± 0.01 A respectively. Fifteen calibrated T-Type thermocouples are used to measure temperatures at different locations of the heat pipe assembly. The thermocouples are fixed to the outer surface of heat pipe.
Table 1. Specification of LHP

| Specification     | Dimension/material |
|-------------------|--------------------|
| **Evaporator**    |                    |
| Dimension (mm)    | L45 × W45 × H22    |
| **Compensation chamber** |                |
| Dimension (mm)    | L45 × W38 × H22    |
| Material          | Copper             |
| **Condensor**     |                    |
| Dimension (mm)    | L315 × W96 × H60   |
| Material          | Acrylic            |
| **Vapour line**   |                    |
| Outlet diameter (mm) | 13                |
| Inlet diameter (mm) | 11                |
| Length (mm)       | 490                |
| **Liquid line**   |                    |
| Outlet diameter (mm) | 13                |
| Inlet diameter (mm) | 11                |
| Length (mm)       | 490                |
| **Pump**          |                    |
| Performance (litres/hour) | 40              |

Figure 1. Schematic diagram of the loop heat pipe indicating the thermocouple positions
Figure 2. A photograph of compensation chamber and wick used in the present study

The joint of thermocouple is strengthened with fast curing epoxy compounds (M-seal and araldite). T_1 and T_2 measure the heater temperature and interface temperature between heater and evaporator. Two thermocouples (T_3 and T_4) measure the temperature of evaporator: one on vapour line side and one on liquid line side. T_5 and T_9 give the vapour temperatures at evaporator and condenser. Vapour line (T_6 and T_7) and liquid line (T_12 and T_13) have two thermocouples each. The average condenser temperature is measured by T_8, T_{10} and T_{11}. Cooling water inlet and outlet temperatures are measured using W_i and W_o. The computer connected to data logger stores all the data which are used for data analysis.

Figure 3. Experimental setup

4. Experimental procedure
The loop heat pipe is tested with deionised water and alumina–water nanofluid to study its thermal performance for the heat load range of 30 - 310 W. The LHP is fabricated and working fluid is filled.
Then evaporator is connected to heater block and the whole assembly is covered with a thick layer of glass wool insulation. For all the experiments LHP is kept in vertical orientation i.e. condenser is above the evaporator. The condenser is connected to cooling water inlet and outlet. The cooling water with a constant flow rate of 40 litres per hour is allowed to flow through the condenser with a temperature of 20 °C. The thermocouples are connected to the data logger. Heater wires are connected to the dimmerstat and power supply is switched on. An initial heat load of 30 W is applied to the evaporator base and the heat pipe is allowed to reach steady state. Then heat input is increased in steps of 40 W. The above procedure is repeated until the heat load becomes 310 W. The thermocouples measure the temperature of various locations in every 5 s and the values are noted. After the experiment, the heat input is reduced to zero and waited till the loop heat pipe is allowed attain the room temperature. Later cooling water supply is cut off and loop heat pipe is removed from the experimental set up.

5. Results and discussions

5.1. Effect of heat input on evaporator temperature

Figure 4 plots the evaporator temperature versus heat loads. When heat load is applied to the evaporator base, the temperature increases and vapour is formed in the vapour line. In this experiment the reservoir is maintained at ambient temperature. The LHP shows a very good response to the change in the heat load from 30 to 310 W and reaches steady state within a short time period. It can be seen that LHP is able to maintain the evaporator temperature within a range of 43.28 °C to 54.98 °C and 46.302 °C to 61.35 °C for alumina–H₂O nanofluid and deionised water respectively. The LHP exhibits very efficient control over the operating temperature of the evaporator for the entire range of input power. The temperature at the evaporator of the LHP using alumina – H₂O nanofluid is lower by 12 % than that of the deionised water, since alumina – H₂O nanofluid has higher thermal conductivity and high heat transfer rate.

5.2. Temperature analysis

The transient temperature distribution of LHP with deionised water and alumina–H₂O nanofluid at heat load of 30 W is shown in figure 5 and figure 6 respectively. Here temperatures considered are average values of evaporator (Tₑ), vapour line (Tᵥ), condenser (Tₓ) and liquid line (T₁) temperatures.
It can be seen from figure 5 that the temperatures of all points increase gradually until 23 min and become almost steady thereafter. It is also observed from figure 6 that the temperatures at all points have been reduced due to the enhanced heat removal in the LHP by higher thermal conductivity and convective heat transfer of alumina–H₂O nanofluid. As a result, the higher thermal characteristics of the nanofluid have proved its potential as alternative for conventional deionised water in the LHP.

**Figure 5.** Transient temperature distribution of LHP using deionised water at \( Q = 30 \) W

**Figure 6.** Transient temperature distribution of LHP using alumina–H₂O nanofluid at \( Q = 30W \).

6. **Conclusion**

A loop heat pipe is experimentally studied to determine its thermal performance for a heat load range of 30 – 310 W in steps of 40 W. The use of alumina–water nanofluid in LHP enhances the thermal performance. The transient temperature distributions are also obtained from experiment. The LHP using alumina–H₂O nanofluid yields lower evaporator temperature and attains its steady state faster
than LHP using deionised water. The evaporator temperature of LHP reduces by 12 % when nanofluid is used. The experimental results show that nanofluid can enhance the thermal performance of the loop heat pipe. Thus loop heat pipes using nanofluids are highly promising in the thermal management of electronic devices.

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