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A Study on the Heat Transfer Enhancement of Miniature loop Heat Pipes by Using the Cu Nanofluids

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Abstract : An experimental study was carried out to understand the heat transfer performance of a miniature loop heat pipes using water-based copper nanoparticles suspensions as the working fluid. The suspensions consisted of deionized water and copper nanoparticles with an average diameter of 80 nm. Effects of the cupper mass concentration and the operation pressure on the average evaporation and condensation heat transfer coefficients, the critical heat flux and the total heat resistance of the mLHPs were investigated and discussed. The pressure frequency also depends upon the evaporator temperature which has been maintained from 60^{o}C to 90^{o}C. The Investigation shows 60% filling ratio gives the highest inside pressure magnitude of highest number pressure frequency at any of setting of evaporator temperature and 5wt% results the lowest heat flow resistance.

Key Words : Miniature loop Heat Pipe, Pressure Fluctuation, Heat flow resistance, Nanofluid

1. Introduction

A Loop heat pipes (LHPs) is a type of heat transfer system used in heat recovery systems. LHP is preliminarily used for cooling and controlling the temperature of electronic devices which may be classified in special category of heat pipes. The complexity of microchip has been increasing at the rate of factor of 2 per year over the past several decades. The number of transistors on a chip has increased to as many as 500 billion transistors packed on a single chip. The further miniaturization of electronic devices is leading to greater chip packing densities and thus higher chip power densities. The new challenge in the field is on removal of large quantities of heat quickly and efficiently from chip in order to keep chip temperature within an operational range. LHPs phenomena carry a great role in the field of heat transfer to control heat transfer into micro cavity. The LHPs that is driven by the fluctuation of pressure waves occurs much more and quick heat transfer from one end to another. The pressure fluctuation occurs because of nucleate boiling by evaporative section and condensation of the working

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fluid. The article shows all about vertical orientation of miniature loop heat pipes. The research concentrates on the pressure characteristics inside the miniature loop heat pipes. Extended investigations of LHPs have been investigated since the first development of Loop heat pipes (LHPs) originates from 1972, when the first such device with a length of 1.2 m and capacity of about 1 kw, with water as working fluid, was created and tested successfully by the Russian scientists Gerasimov and Maydanik from the Ural Polytechnical Institute[1-2]. Loop heat pipes (LHPs) are highly efficient heat-transfer devices with a considerable potential for development and application in various fields. At present LHPs are successfully employed in space engineering[3]. Past works over LHPs can be concluded within several features like heat transfer characteristics and capability with different filling ratio, flow visualization inside LHPs, effects of length ratio and diameter on performance of LHPs, nanofluid and other applicable fluids has been used as working fluid for developing LHPs performance.

Gi et al. conducted flow visualization for closed-loop PHP made from Teflon tube of 2 mm internal diameter and partially filled with R142b. The PHP consisted of 10 meandering turns and it is 400 mm from the evaporator to condenser. The evaporator was heated by a hot bath and the condenser was cooled by a cold bath. It was concluded that the best thermal performance for the PHP is achieved when the FR is from 0.5 to 0.6[4].

In S. Suresh et al. using Al_2O_3-Cu/ water hybrid nanofluids with volume concentration from 0.1 to 2%[5]. 1998 Chandratilleke et al. developed the cryogenic loop heat pipes. The development of cry cooler cooled superconducting magnets applications, where heat transport distance is large, and the heat conduction by a copper block will be constrained by its cross section transport capacity[6]. Q. Mo et al. shows that the heat transport capacity of loop heat pipe with liquid nitrogen as working fluid is very low- only 26 W hen it operates in horizontal direction and its lowest thermal resistance reaches 1.3 K/W, which is too high for most of cryogenic heat transport system[7-8]. V. G Pastukhov et al. The first of them had as its aim demonstration of the limiting possibilities of mLHP with design characteristics suitable for application in PC and Analogous electronic devices[9]. Yu. F. Maydanik loop heat pipes a decrease in pressure losses in the adiabatic section of LHPs is ensured by the fact that for the motion of a working fluid here use is made of separate smooth-walled pipe-lines, which exclude both the thermal and the viscous interaction between counter flows of vapor and liquid[10].

The work has much more new investigations about mLHP comparing previous works. The pressure characteristics and the influence of nanoflud concentration on pressure fluctuation into mLHP has been. It is well known that the heat transfer by miniature loop heat pipe occurs for quick fluctuation of pressure intensity but it can be hardly found some works over pressure distribution inside mLHP. The work with copper nanofluid and pressure behaviors drag a different dimension to this article.

2. Experimental setup

2.1 Experimental Apparatus and Procedure

The experimental apparatus (shown in Fig. 1) consists of a miniature loop heat pipe, water heater, cooling bath and data acquisition system. The heat pipe is made by copper and acrylic tube with the same inner diameter of 8 mm having the loop length of 725 mm. The mLHP setup was oriented vertically and the downward loop section with the length of 100 mm was submerged into the evaporative section. Evaporative temperature was kept constant by flowing hot water heated by tube type heater with digital control system. Similarly the 100 mm of upper loop section was inserted through the condensing tank and kept sealed. Condenser temperature was maintained within 18℃ to 20℃ by using isothermal cooling unit. In the middle of this mLHP 525 mm acrylic adiabatic section was covered by 2 cm thick glass wool to insulate this section thermally. T-type thermocouple was soldered to the outer wall of mLHP in both condensing and evaporative sections to measure the wall temperature of mLHP. After setting temperature of evaporative section temperature of evaporative fluid gets stable. One piezoresistive absolute pressure sensor (Model-Kistler 4045A5) is set with another small by pass tube coming out from condensing section of mLHP to catch the pressure characteristics inside the tube.

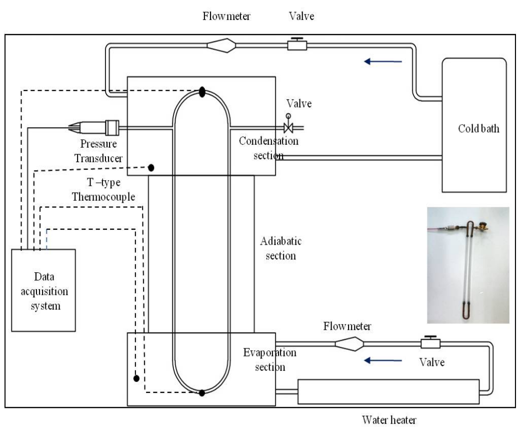
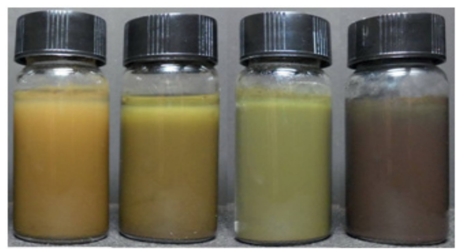


Fig. 1 Schematic diagram of Experimental Setup and Real Experiment photo.

The sensor was perfectly sealed and tested several times. Using lab view program with the help of computer all the pressure data has been acquired after getting the system stable. Data acquisition rate was 100 data /sec and data taking duration was about 10 min. To find out the frequency distribution FFT analysis has been with 10240 data and the experimental measurement error 2%. For the convenience of understanding a part of real experimental setup has been shown.

2.2 Preparation of Nanofluid

The copper nanoparticles with mean diameter of 80 nm was (collected from NTi Npowder, Daejeon South Korea) used to make nanfluid suspension. The purity of Dark brown copper nanofluid was 99.9% and two step method is used to disperse nanoparticle into base fluid. Base fluid was distilled water and no pH changers or surfactants were used to make dispersion. Ultrasonic vibrator (Sonic Vibra-Cell VC-130PB) generating ultrasonic pulses of 130 W at 20 kHz were used for 2 hr in every individual dispersion process.



a) 1wt%　b) 3wt%　c) 5wt%　d) 7wt%

Fig. 2 Photo of different wt% nanofluids sample

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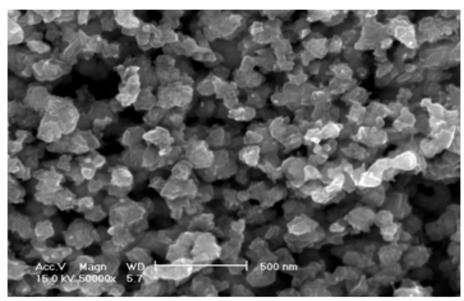

Fig. 3 SEM image of copper particle with average diameter(80-100) nm

The percentage of nanoparticles in the base fluid was in the range of 1% to 7% in weight. Fig 2. Shows the physical observation of different weight percentage nanofluid. It can be seen that with increasing particle concentration the color of nanofluids gets more darker. Fig 3. shows a SEM (Scanning Electron Microscope) image containing copper nanoparticles with average size of 80nm-100nm.Table 1 shows 30℃ thermo physical propertics water and Cu nanofluids.

Table 1 Thermo physical propertics

Materials	Thermal Conductivity W.$m^{-1}k^{-1}$	C.P J/kg.K
water	0.6176	4.179387
Cu	401	387

3. Data Reduction

Receiving thousands of raw data signal in the form of voltage it has been converted into pressure and analyzed to find mean and RMS value in following way

Mean Pressure, $$P_{mean} = \frac{\sum_{i=1}^{N} P(t)}{N} \quad (1)$$

N is total number of data recorded in a period of time (i =1.2.3………………N)

Pressure fluctuation (Prms) or rms value of u component expressed in eq. (2)

RMS value, $$P_{rms} = \sqrt{\overline{P}^2} = \sqrt{\frac{\sum_{i=1}^{N} [P_{mean} - P(t)]^2}{N}} \quad (2)$$

Where N=10240

The overall heat flow resistance ($R_{T/T}$) has been calculated for constant wall temperature following the equation given below

$$R = \frac{\overline{T_e} - \overline{T_c}}{\overline{T_{we}}} \quad (3)$$

Where R is a dimensionless parameter and it expresses the thermal resistance and $\overline{T_e}$, $\overline{T_c}$, $\overline{T_{we}}$ are average mLHP wall temperature in evaporator, average mLHP wall temperature in condenser and average hot water temperature supplied to evaporative section respectively.

4. Results and discussion

The heat input in the evaporator, filling ratio of working fluid as well as the shape, diameter, angle of installation have great influences on performance of miniature loop heat pipe. The influence of particle weight fraction on heat transfer is also concern to study nanofluids. The all above mentioned parameters are interrelated with inside pressure fluctuation for the best performance of mLHP.

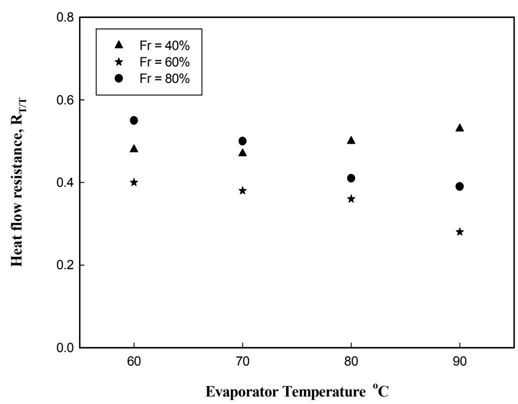

Fig. 4 Water heat flow resistance of heat pipe at different filling ratio

Fig. 4 presents the effect of different filling ratio on thermal resistance at various operating evaporative temperatures where the working fluid is distilled water. Here it can be shown that the lowest heat flow resistance has been achieved at 60% filling ratio at any evaporative temperature. With increasing the evaporative temperature heat flow resistance is decreasing for 60% and 80%

filling ratio. But in case of 40% filling ratio heat flow resistance increases with increasing evaporative temperature because of low volume ratio that does not capable to carry more heat until the pick of condensing section of mLHP. Besides the mass of fluid is too small in amount that brings only less amount of heat to condenser that's why the temperature difference between evaporator and condenser is so small. In case of 80% filling ratio more fluids makes much vapor plug on the pick and did not have a feasible space to ease the heat transfer. Because of more vapor plug in case of 80% filling ratio the driving force for the oscillation and transportation of heat from the evaporator to the condenser is decreased.

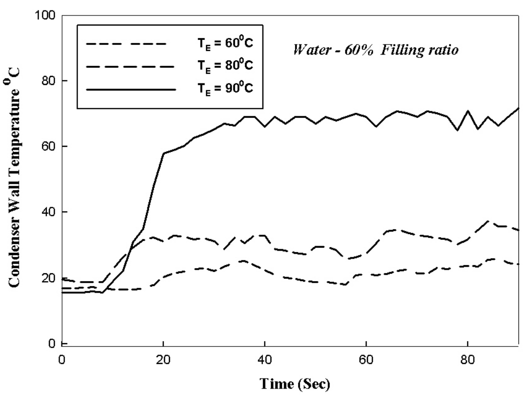

Fig. 5 Temperature distribution of condensing wall at various evaporative temperature

So 60% filling ratio facilitates the optimum conditions in mass and in volume to transport more heat from evaporative section that minimizes thermal resistance and maximizes heat transfer through mLHP. For 60% filling ratio, Fig. 5 shows temperature distribution at condensing section gets higher with increasing evaporative temperature. Pressure and temperature increases with passing time and with increasing evaporative temperature. Similarly in fig. 6 – It can be shown that pressure

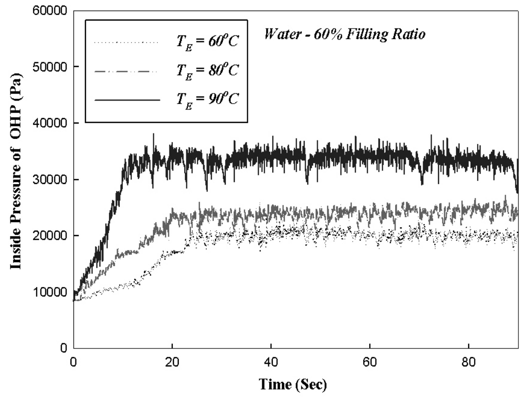

Fig. 6 Pressure distribution into OHP at various evaporative temperatures

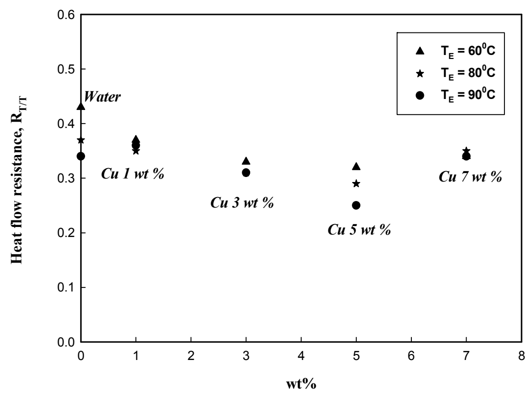

Fig. 7 Heat flow resistance with different particle wt% at 60% filling ratio

increasing evaporative temperature inside pressure of mLHP increases and at the temperature near boiling point, the value of pressure distribution becomes multiple of 60℃ or 80℃ It takes almost 30 sec to get thermal stability. Both of pressure and temperature gives higher magnitude at 90℃ and it gets down at lower evaporative temperature. Pressure and temperature distribution profile having a great similarities and temperature distribution depends upon pressure distribution inside mLHP. It is recommended to use evaporative temperature near boiling point of working fluid to get high thermal efficiency for mLHP. Fig. 7 shows, heat flow resistance decreases with the addition of copper nanoparticle into nano-fluids for all of three examined evaporative temperature but suddenly heat flow resistance gets higher than all other mass fraction at 7 wt%. It means there must have an optimum weight fraction of nano particles for internal operation of mLHP and the present experimental optimum mass fraction is 5wt%. Thermal conductivity increases with the particle addition into base fluids that facilitates more heat transfer to the condensing section. Inside mLHP there are several movements of fluid like oscillation, circulation as well as plugging make nanoparticles suspended and enables to excite nanoparticles to increase the rate of convective heat transfer into mLHP. If particle fraction gets higher there may occur particle deposition or sedimentation at both the evaporative and condensing section that causes higher heat flow resistance. Fig. 8 is much more comprehensive to understand the influence of mass fraction on heat transfer into mLHP. Pressure frequency distribution for optimum filling ratio (60%) shows the higher frequency at condensing part is about 13 Hz for 5wt% where the others are showing very low frequency at same evaporative temperature. So the pressure frequency distribution is one of basic phenomena to understand the heat transfer phenomena into mLHP. If Pressure fluctuation gets higher with higher magnitude heat transfer must happen at high rate which is interrelated with filling ratio and mass fraction of nanoparticles. Fig. 9 shows that the RMS value of pressure gives higher magnitude at 5 wt% that implies the intensity of pressure is also more. It happens because the plug inside mLHP significantly reduces at 5 wt% and makes it free to transport heat from evaporative section as a result pressure near condenser increases. So the fluctuation value from mean pressure is much more at 5 wt% because of creating more slugs into heat pipe.

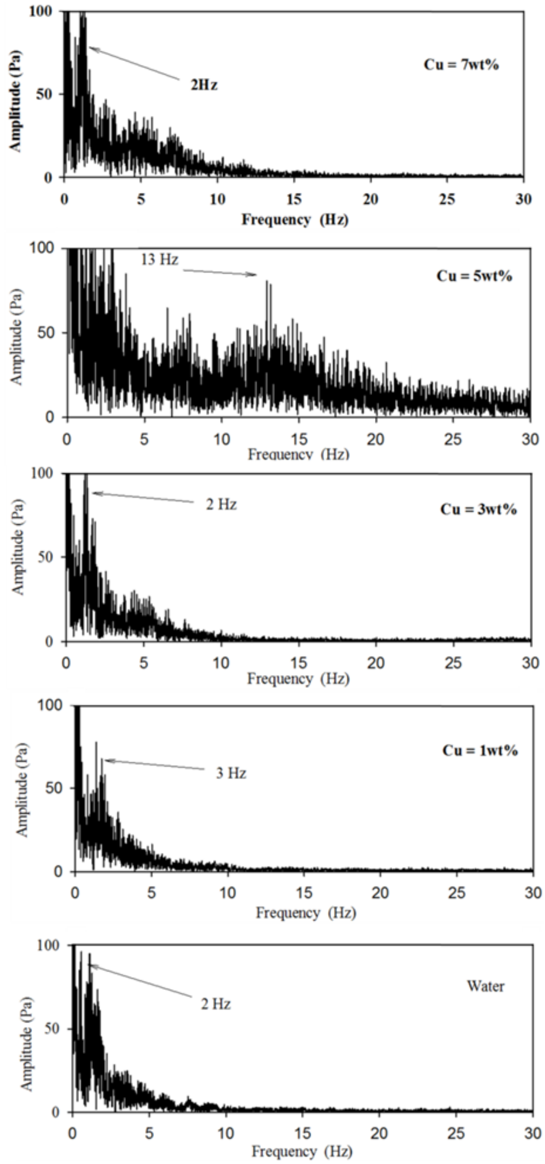

Fig. 8 Frequency distribution with different particle wt% at 60% filling ratio and 80℃ evaporative temperature

Fig. 10 describes mean pressure for different particle wt% at different evaporative temperature. Among all particle weight fraction, 5 wt% shows higher magnitude of mean pressure at all of set evaporative temperatures. The pressure increases gradually with increasing evaporative temperature.

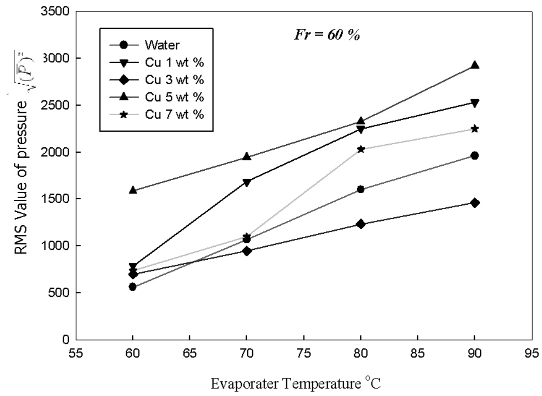

Fig. 9 RMS value of pressure into mLHP at different particle wt%

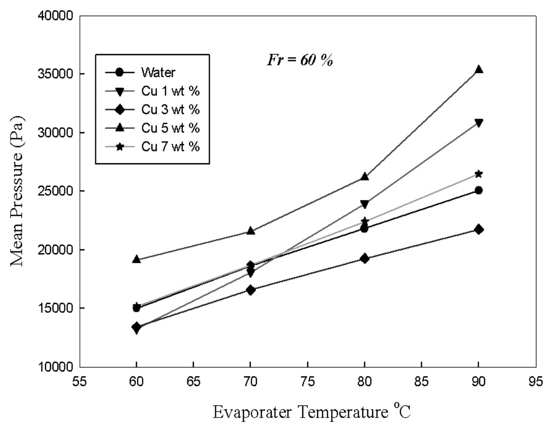

Fig. 10 Mean value of pressure into mLHP at different particle wt%

In miniature loop heat pipes heat transfer occurs because of repeated pressure fluctuation and the more repetition of pressure fluctuation means more heat transfer. The higher number of pressure frequency has been achieved at 5 wt% at any evaporative temperature calculated by FFT analysis using at least 10240 data for each case.

5. Conclusions

The optimum filling ratio is about 60% for creates more slugs into mLHP that drives more heat from evaporative section to condensing section. So the thermal performance surely will be much more at 60% filling ratio.

Copper nanofluid can perform better than pure water as working fluid into mLHPs. The optimum concentration of copper nanofluid has been investigated as the best performance in terms of lowest heat flow resistance is 5 wt%.

Repeated Pressure fluctuation reduces heat flow resistance and higher pressure frequency has been calculated at 60% filling ratio as well as at 5 wt% of nanofluid.

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