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Thermal performance of miniature loop heat pipe with graphene–water nanofluid

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ABSTRACT

The heat transfer performance of miniature loop heat pipe with graphene–water nanofluid is experimentally analysed. The miniature loop heat pipe used in the study consisted of a square flat evaporator having a size of 20 mm × 20 mm, a compensation chamber placed above the evaporator and transport lines having different diameters. The difference in diameter prevents reverse flow of vapour through liquid line and also increases the flow rate of condensed liquid through liquid line. An optimum filling ratio of 30% of the total volume of the heat pipe is used in all the experiments. The experiments are conducted for a heat load range of 20–380 W using water and graphene–water nanofluid in vertical orientation. The graphene nanosheets having 1–5 nm thickness with very low volume fractions of 0.003%, 0.006% and 0.009% are mixed with distilled water to prepare nanofluid. The experimental results indicate that the nanofluids improve the thermal performance of the miniature loop heat pipe and lower the evaporator interface temperature compared to distilled water. An optimum concentration of 0.006% provides the maximum improvement in heat transfer. The lowest thermal resistance value (0.083 K/W at 380 W) is observed for the optimum concentration and it is 21.6% below the value of distilled water. The evaporator interface temperature reached only 106.3 °C at 380 W which shows a decrease of 10.3 °C compared to distilled water. The experimental results confirm suitability of miniature loop heat pipe filled with graphene–water nanofluid for cooling applications.

1. Introduction

The miniaturization and rapidly increasing heat loads of the new electronic devices put forward the challenge of efficient cooling in these devices because the life of electronic components decreases as their operating temperature increases [1]. Miniaturized heat pipes are one of the possible solutions to this problem. Since heat pipes work on the principle of boiling and condensation, large heat removals are possible with them. The other advantages of heat pipes include electricity free operation, reliability, and ability work with small temperature difference and transfer of heat over significant distances with small pressure drop [2,3]. These benefits make the heat pipe the best candidate for increased cooling demands of electronic devices.

The performance of heat pipe is greatly decided by the properties of the fluid used in the heat pipe. Godson et al. [4] after reviewing many publications concluded that the nanofluids can be used to increase the heat transfer performance in many practical applications including heat pipes. The major reason for this improvement is credited to increase in thermal conductivity and turbulence due to nanoparticles. Asirvatham et al. [5] and Godson et al. [6] also reported enhancements in the convective heat transfer coefficient and effective thermal conductivity for different nanofluids. In this context, nanofluid becomes a promising working fluid for the heat pipe.

Many researchers have used nanofluid in different types of heat pipes to get better heat transfer performance as mentioned in the review articles [7–10]. Most of them observed an improvement in heat transfer with nanofluid even though a few reported negative result. Only a few researchers have considered nanofluids as working fluid in loop heat pipes. Li et al. [11] analysed the steady and transient operation of a miniature capillary pumped loop (CPL) using CuO–water nanofluid (average nanoparticle size = 50 nm) in different mass concentrations ranging from 0.5% to 2.0% at a

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Nomenclature

CPU	central processing unit
GPU	graphics processing unit
mLHP	miniature loop heat pipe
SS	stainless steel
Cu	copper
CC	compensation chamber
HP	heat pipe
OD	outer diameter (mm)
ID	inner diameter (mm)
LPH	litres per hour
T	temperature (°C)
V	voltage (V)
I	current (A)
Q_a/Q	applied heat load (W)
Q_c	heat rejected at condenser (W)
q	heat flux (W/m^2)
R_t	thermal resistance of heat pipe (K/W)
h	heat transfer coefficient (W/m^2 K)
A	area exposed to heat transfer (m^2)
L	length of heat pipe from evaporator to condenser (m)
K_{eff}	effective thermal conductivity of heat pipe (W/m K)
m	mass flow rate of cooling water (kg/s)
c	specific heat of cooling water (J/kg K)

Greek symbols

η_t	thermal efficiency of heat pipe (%)
φ	volume fraction (%)
Δ	change

Subscripts

e	evaporator
c	condenser
ve	vapour at evaporator
vc	vapour at condenser
c/s	cross sectional

filling ratio of 55% of total volume. The use of nanofluids reduced the evaporator temperature, improved the start-up time of CPL and increased the heat transfer coefficient by 45% for 1.0% optimal mass concentration. But nanofluid could not improve the minimum and maximum starting power. Riehl [12] used water–nickel nanofluid in a miniature loop heat pipe. The results showed a lower heat transfer coefficient at the evaporator side and higher operating temperatures throughout the loop compared to pure water. The presence of nanoparticles in capillary wick structure, small diameter of transport lines and increase in density and viscosity of nanofluid have resulted in poor performance of the miniature loop heat pipe.

Gunnasegaran et al. [13] and Gunnasegaran et al. [14] used experimental investigation and finite element simulation to compare the heat transfer performance of a loop heat pipe with different concentrations of SiO_2–water and Al_2O_3–water nanofluids with pure water. A decrease in thermal resistance was observed with nanofluids. Wang et al. [15] suggested miniature loop heat pipe with Cu–water nanofluid having mass concentrations of 1.0, 1.5, and 2.0 wt% for cooling of electronic components after conducting both experimental and thermodynamic study. Putra et al. [16] recommended the use of biomaterial (collar) as wick material in loop heat pipe (LHP) instead of sintered copper wick and nanofluid as working fluid to achieve lower thermal resistance and operating temperature of LHP. The working fluid used was Al_2O_3–water nanofluid (average nanoparticle size = 20 nm) with volume fractions of 1%, 3% and 5%. The nanofluid gave lower thermal resistance and evaporator wall temperature at all volume fractions compared to distilled water. Wan et al. [17] used copper–water nanofluid and deionised water to compare their heat transfer performance in a specifically fabricated miniature loop heat pipe (mLHP). Cu nanoparticles (average size = 50 nm) with mass concentrations of 1.0%, 1.5%, and 2.0% and deionised water were used to prepare nanofluid along with small amount of sodium dodecyl benzene sulfonate (SDBS) surfactant. The nanofluid showed a better thermal performance and the optimum concentration was found to be 1.5 wt%.

The general trend of nanofluid is to increase the heat transfer performance of the loop heat pipe. Application of nanofluid in miniature loop heat pipe is a promising area of research which is still in its initial stage. To the best of authors' knowledge no paper has been published with graphene–water nanofluid in miniature loop heat pipes.

Thus, in the present study stable graphene–water nanofluid at three different volume fractions is used as working fluid in a miniature loop heat pipe to understand its heat transfer performance. The experiments are performed in a newly designed miniature loop heat pipe in vertical orientation. The design consists of a flat evaporator with four inside fins to increase the heat transfer, seven layers of capillary wick structure to overcome the pressure losses and a compensation chamber to act as a reservoir. The partition in CC prevents bypassing liquid to vapour line. Different diameters for vapour and liquid lines are used to prevent reverse flow of working fluid in heat pipe and to get improved flow rate of working fluid. The heat load range varied from 20 to 380 W. The heat transfer performance of nanofluid is compared with pure distilled water and increase in thermal performance with nanofluid is highlighted.

2. Experimentation

2.1. Nanofluid preparation

The working fluids used in this study are distilled water and graphene–distilled water nanofluid. The graphene nanosheets were bought from Skyspring, USA. The thickness of graphene nanosheets is in the range of 1–5 nm and density is 2200 kg/m^3. The nanofluid is prepared by two step method. No surfactant is used in the preparation of nanofluid. The used volume fractions are 0.003%, 0.006% and 0.009%.

$$\text{Volume fraction }\% = \frac{\text{Volume of nanosheets}}{\text{Volume of nanosheets} + \text{Volume of basefluid}} \times 100$$

The low volume fractions are selected for this study because higher volume fractions of nanoparticles would block the capillary wick structure. That will lead to dry out in evaporator. The accurately measured quantity of nanoparticles is added to the distilled water and the mixture is sonicated for 30 min using an ultrasonic homogenizer. The prepared nanofluid is found to have very high stability by visual observation even without surfactant.

2.2. Zeta potential and particle size analyses

To ensure stability of the graphene–water nanofluid the zeta potential analysis is conducted before experiments and after three months using zeta potential analyser (Nano ZS90 ZETASIZER