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Effect of nitrogen-doped graphene nanofluid on the thermal performance of the grooved copper heat pipe

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ABSTRACT

Thermal performance of a grooved heat pipe using aqueous nitrogen-doped graphene (NDG) nanofluids was analysed. This study in particular focused on the effect of varying NDG nanosheets concentrations, heat pipe inclination angles and input heating powers. The results indicated that the inclination angle had a major influence on the heat transfer performance of heat pipes and the inclination angle (θ) of 90° was corresponded to the best thermal performance. The maximum thermal resistance reduction of 58.6% and 99% enhancement in the evaporator heat transfer coefficient of the heat pipe were observed for NDG nanofluid with concentration of 0.06 wt%, inclination angle of $\theta = 90°$ and a heating power of 120 W in comparison to DI-water under the exact same condition. Additionally, the surface temperature distribution was decreased by employing NDG nanosheets, which can in return increase the thermal performance of a grooved heat pipe. The present investigation indicated that the thermal performance of the grooved heat pipe can be improved significantly by using NDG nanofluids.

1. Introduction

Heat transfer and energy supply play a major role in various industries including transportation, air conditioning, power generation, nuclear plants, electronic devices etc. [1,2]. The modification of the surfaces of heat exchangers as well as use of high performance working fluids were among many techniques implemented for enhancing the overall performance of the heat exchangers. Now a days, renewable energy resources are attracting much interest [3,4]. Consequently, the current objective of many countries is to employ various renewable energy resources such as solar energy. Renewable energy sources could be employed for long-term energy options, along with the corresponding alternative energy systems [5,6].

Heat pipe is a device that employs an evaporation mode of heat transfer in the evaporator section and the condensation mode in the condenser section to convey heat. The liquid flow from the condenser to the evaporator section could be produced by the gravitational force, capillary force [7], or other external forces that directly acting on the fluid (i.e. electrostatic force). On the other hand, the vapor flow from the evaporator to the condenser section is caused by the vapor pressure difference between these two sections [8–10]. Heat pipe is a significant thermal engineering achievement due to its unique capability to transfer heat, over a large distances without considerable heat loss. Heat pipes are mainly used on various applications such as environmental protection, fuel and energy savings [11,12]. Heat pipes are efficient thermal conductor which can be used in applications requiring high input heat fluxes, in an environment with a very limited airflow over a heat source sections, a non-uniform heat generation and weight or space limitations [9,13].

As mentioned above, there are many applications for heat pipes that are well proven and may now be regarded as routine. The heat pipes are designed to be integrated into a thermal subsystem for the purpose of conveying heat from the heat source to remote areas for the heat rejection purpose [14,15]. The main advantage of the heat pipes are their ability to act as a major heat conductive path, which will allow the engineers to solve a thermal issues in applications with limitations including space constraints. Additionally, heat pipes can carry massive amount of heat away from the heat sensitive components to the heat sink (finned array) where more space for heat dissipation is available [16,17].

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Nomenclature

A	area (m^2)
c_p	specific heat at constant pressure (J/kg K)
d	diameter (m)
h	heat transfer coefficient (W/m^2 K)
I	electrical current (Amps)
k	thermal conductivity (W/m K)
$\dot{m}$	mass flow rate (kg/s)
N	number
$\dot{Q}$	heat supply rate (W)
q	heat flux (W/m^2)
R	thermal resistance (°C/W)
T	temperature (°C)
V	voltage (V)
v	mean velocity (m/s)
ΔT	temperature difference (°C)

Acronyms

NDG	Nitrogen-doped graphene

Subscripts

ad	adiabatic
avg	average
bf	base fluid
c	condenser
cap	capillary
cr	cross section
e	evaporator
en	entrainment
eff	effective
hp	heat pipe
in	inlet
nf	nanofluid
np	nanoparticle
o	outlet
s	surface
t	thermocouple
tot	total
th	thermal
vap	vapor
w	water
wt%	weight percentage

Greek symbols

η	efficiency (%)
θ	angle (°)
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
σ	surface tension (N/m)

Considering that the heat pipe is a closed-loop heat exchanger and primary mode of its operation is based on phase change of the working fluid, the selection of a suitable working fluid is one of the most important aspects of the heat pipe design for a given application [18,19]. Obviously, the selection of the appropriate working fluid for a given application is based on many considerations. One of the alternatives for a heat pipe's working fluid is a Nanofluid. Nanofluid is a homogenous suspension of nanoparticles in a base fluid which could be oil, distilled water (DI-water) etc. Nanofluids are promising heat exchanger fluids due to their enhanced heat transfer performance as a result of their higher thermal conductivity [20,21]. However, heat pipes are working based on a phase change heat transfer, hence, the relevant physical mechanisms of heat pipes are totally different from that of conventional heat exchangers that operate based on a single phase.

Numerous worldwide investigations have been carried out on the performance evaluation of nanofluids in a heat pipes [22,23]. The assessment, in these studies, was carried out based on the standard characteristic operation parameters of the heat pipes, namely, thermal resistance, thermal performance, heat transfer coefficient and axial heat pipe's wall temperature distribution. These investigations were mainly focused on the influence of the base fluid type, nanoparticles shape and size, nanoparticle concentration as well as suspension stabilization (i.e. different surfactant) [24,25]. The general trend was observed that an employment of various nanofluids in the heat pipes could result in a decrease on the wall temperature of the heat pipe, in comparison to DI-water, under various heat loads [26,27].

Asirvatham [28] studied the heat transfer performance of a thermosyphon using graphene + acetone nanofluid. They have found that the overall thermal resistance of the heat pipe was reduced by 70.3% in comparison to the acetone under the same condition. At the same time the heat transfer coefficient in the evaporator section was increased by 61.25%. Ma et al. [29], investigated the thermal resistance of an oscillating heat pipe filled with 1 vol% diamond + DI-water nanofluid. They observed that the diamond nanofluid can reduce the temperature difference between the evaporator and condenser from 40.9 to 24.3 °C, at the input power of 80 W. Goshayeshi et al. [12], worked on the Fe_2O_3 + kerosene nanofluid in a copper oscillating heat pipe and indicated 16% enhancement in the overall heat transfer performance of the heat pipe, in comparison to the kerosene as a working fluid. Ghanbarpour et al. [30], showed that an average effective thermal conductivity of the heat pipe that filled with aqueous Ag nanofluid, was increased by 11% compared to that of DI-water. Naphon et al. [31], examined the thermal performance of TiO_2 + alcohol nanofluid, in comparison to the alcohol and DI-water as a working fluids. They have concluded that the thermal efficiency of heat pipe was increased by up to 80% at a 66% filling ratio, a tilt angle of 45°, input heat flux of 7.27 kW/m^2 and a nanofluid concentration of 0.1 vol%.

It is clear that the selection of working fluid is important to promote the thermal performance of heat pipe. Nitrogen-doped graphene (NDG) nanofluid is expected to improve the overall thermal performance of a heat pipe for several reasons including high stability for a long time span and high thermal conductivity compare to other types of nanofluid, as reported earlier by Mehrali et al. [32]. Also, NDG nanofluids have not been investigated as the working fluid in heat pipes [33–35]. Therefore, the objective of this research is to find the effect of NDG nanofluids on the thermal performance of grooved heat pipe through an experimental investigation.

Given the objective of the work, thermophysical properties of various working fluids, which were used in this study, were measured under various temperatures. Temperature distribution of the heat pipe, thermal resistance, heat transfer coefficient, effective thermal conductivity and overall thermal performance of the heat pipe were also measured and compared for different working fluids, at various input heat powers and different inclination angles.