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Heat pipe efficiency enhancement with refrigerant–nanoparticles mixtures

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A B S T R A C T

In the present study, the enhancement of heat pipe efficiency with refrigerant–nanoparticles mixtures is presented. The heat pipe is fabricated from the straight copper tube with the outer diameter and length of 15, 600 mm, respectively. The refrigerant (R11) is used as a base working fluid while the nanoparticles used in the present study are the titanium nanoparticles with diameter of 21 nm. The mixtures of refrigerant and nanoparticles are prepared using an ultrasonic homogenizer. Effects of the charge amount of working fluid, heat pipe tilt angle on the efficiency of heat pipe are considered. For the used pure refrigerant as working fluid, the heat pipe at the tilt angle of 60°, working fluid charge amount of 50% gives the highest efficiency. At the optimum condition for the pure refrigerant, the heat pipe with 0.1% nanoparticles concentration gives efficiency 1.40 times higher than that with pure refrigerant.

1. Introduction

An advanced electronic devices employing high speed and high level of heat generation have to be small in size, light-weight. However, the level and reliability of heat rejection efficiency largely require for these devices. Heat pipe technology has been used in a wide variety of applications in the heat transfer devices. Lin et al. [1] experimentally investigated a study of two-phase flow and heat transfer of R141b in a small tube. Lin et al. [2] developed the high performance miniature heat pipes for cooling of high heat flux electronics. Esen [3] experimentally studied a solar cooking system using vacuum-tube collectors with heat pipes using a refrigerant as working fluid. Song et al. [4] studied the heat transfer performance of axial rotating heat pipes under steady state. Effects of rotational speed, working fluid loading, and heat pipe geometry on the heat transfer performance were considered. Xuan et al. [5] measured the performance of a flat plate heat pipe under different heat fluxes, orientations and amount of the working fluid. Effects of charge amount of the working fluid, thickness of the sintered layer, and orientation of the heat pipe on the performance were discussed. Vasiliev [6,7] applied the micro and miniature heat pipes in modern heat exchangers for cooling electronic components. Huang et al. [8,9] used a heat pipe in the solar-assisted heat pump water heater system. Lin et al. [10] presented a design method by using CFD simulation of the dehumidification process with heat pipe heat exchangers. Liu et al. [11] developed a looped separate heat pipe as waste heat recovery facility for the air-conditioning exhaust system. Effects of the length of the evaporator, vapor temperature, and power throughout on the critical values of the upper and lower boundaries were considered. Vlassov et al. [12] investigated the optimal mass characteristics for a heat pipe radiator assembly for space application. Recently, Dussadee et al. [13] developed an aeration–thermosyphon heat pipe for controlling paddy temperature in a paddy bulk silo.

The most frequently used coolants in the heat transfer devices study are air, water, and fluoro-chemicals. However, the heat transfer capability is limited by the working fluid transport properties. One of the methods for the heat transfer enhancement is the application of additives to the working fluids to change the fluid transport properties and flow features. Therefore, in order to further enhance thermal performance of heat pipe, the use of nanofluids is proposed. Xuan and Li [14] presented a procedure for preparing a nanofluid. Xue [15,16] considered the interface effect between the solid particles and the base fluid in nanofluids. The theoretical results on the effective thermal conductivity of nanotube/oil nanofluid and Al_2O_3/water nanofluid were in good agreement with the experimental data. Roy et al. [17] numerically investigated on the laminar flow and heat transfer of nanofluid in a radial flow cooling system. Tsai et al. [18] considered effect of structural character of gold nanoparticles in nanofluid on heat pipe thermal performance Maiga et al. [19] experimentally studied the heat transfer behaviours of water–γAl_2O_3 and ethylene glycol–γAl_2O_3 nanofluids in a uniformly heated tube. Wen and Ding [20] experimentally studied on the convective heat transfer of nanofluids in a copper tube. Zhou [21] experimentally investigated on the heat transfer characteristics of copper nanofluids with and without acoustic cavitation. Bang and Chang [22] studied the boiling heat transfer characteristics of water with nanoparticles suspended. Effects of different volume concentrations of alumina

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Nomenclatures

A	surface area, m^2
$C_{p,w}$	specific heat of water, kJ/kg °C
e	heat pipe efficiency
I	current, ampere
m_w	mass flow rate of water, kg/s
T	temperature, °C
V	voltage, volts

nanoparticles were considered. Ding and Wen [23,24] studied on the particle migration in pressure-driven laminar pipe flows of nanofluids. Koo and Kleinstreuer [25] considered the steady laminar liquid nanofluid flow in microchannels. Liu et al. [26] investigated the thermal conductivity enhancements of ethylene glycol and synthetic engine oil in the multiwalled carbon nanotubes. Yang et al. [27] investigated the convective heat transfer coefficients of nanofluids under laminar flow in a horizontal tube heat exchanger. Gao and Zhou [28] considered effects of the physical and geometrical anisotropy of the highly conducting nanoparticle on the thermal conductivity of nanofluids. Heris et al. [29] investigated the laminar flow convective heat transfer of nanofluid in the circular tube with constant wall temperature boundary condition. Jang and Choi [30] numerically investigated on the cooling performance of a microchannel heat sink with nanofluid. Li et al. [31] studied on the heat and mass transfer process of HFC134a gas hydrate in nano-copper suspension. Palm et al. [32] numerically investigated on the heat transfer enhancement capabilities of coolants with suspended metallic nanoparticles inside typical radial flow cooling systems. Hwang et al. [33,34] measured the thermophysical properties of nanofluids, thermal conductivity and kinematic viscosity. Stability estimation of nanofluid was conducted with UV–vis spectrophotometer. Kang et al. [35] experimentally investigated on the thermal performance of heat pipe with silver nanofluid. He et al. [36] studied on the heat transfer and flow behaviour of nanofluids flowing upward through a vertical pipe. Nguyen et al. [37] experimentally investigated on the behaviour and heat transfer enhancement of a particular nanofluid flowing inside a closed system for a cooling of the electronic components. For a particular nanofluid with 6.8% particle volume concentration, heat transfer coefficient increased as much as 40% compared to that of the base fluid. Trisaksri and Wongwises [38] reviewed the researches in heat transfer over the previous several decades. Chein and Chuang [39] studied the microchannel heat sink performance using nanofluids as coolants. The theoretical predicting results were validated by comparing with the measured data. Mansour et al. [40] considered effect of uncertainties in physical properties on forced convection heat transfer with nanofluids. Wang and Mujumdar [41] reviewed summarizes recent research on fluid flow and heat transfer characteristics of nanofluids in forced and free convection flows.

To the best of author' knowledge, the papers presented the study on the heat transfer and flow characteristics of the heat pipe with nanofluids have rarely been reported. Only one work [35] reported on the thermal performance of the heat pipe with nanofluid. The objective of this paper is to study the efficiency enhancement of heat pipe with refrigerant–nanoparticles mixture. Effects of nanoparticles concentration and heat pipe tilt angle on the efficiency of heat pipe are considered.

2. Experimental apparatus and method

2.1. Test loop

A schematic diagram of the experimental apparatus is shown in Fig. 1. The test loop consists of a test section, refrigerant loop, cold water loop and data acquisition system. The test section and the connections of the piping system are designed such that parts can be changed or repaired easily. The close-loop of cold water consists of a 0.3 m^3 storage tank, an electric heater controlled by adjusting the voltage, and a cooling coil immerged inside a storage tank. The cold water is chilled by the refrigeration system. The cold water is adjusted to the desired level and controlled by temperature controller. After the temperatures of the water are adjusted to achieve the desired level, the cold water is pumped out of the storage tank, and is passed through a flow meter, test section (Condenser section), and returned to the storage tank. The flow rates of the cold water are controlled by adjusting the valve and measured by the flow meter with the accuracy of ±0.2% of full scale. The test section is fabricated from the straight copper tube with the outer

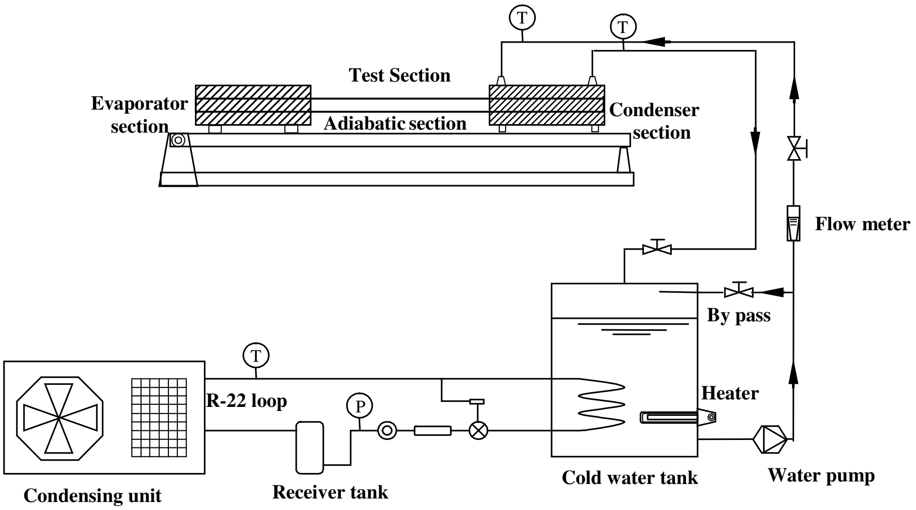

Fig. 1. Schematic diagram of experimental apparatus.