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Improvement of thermosyphon performance by employing nanofluid

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ABSTRACT

The presented study aims to make nanofluids applicable for thermosyphons. Experiments employing a vertical thermosyphon are carried out utilising deionised water, water based titanium dioxide and gold nanofluids with different concentrations as working fluids. A maximal reduction of the thermal resistance of about 24% can be achieved when nanofluids are employed. An optimum is reached at concentrations between 0.2 vol. % and 0.3 vol. %, whereas at higher concentrations the thermal resistance remains either unchanged or increases again. A nanoparticle layer on the evaporator surface seems to cause the found changes. Experiments with the gold nanofluid indicate that no nanoparticles are transported with the vapour phase and deposited on the condenser surface. Long term experiments carried out with 0.3 vol. % indicate a massive aging of the porous layer built of nanoparticles on the evaporator surface.

Amélioration de la performance d’un thermosiphon grâce à l’utilisation d’un nanofrigorigène

Mots clés : Experiments ; Thermosiphon ; Nanofrigorigènes ; Résistance thermique ; Nombre de Nusselt

1. Introduction

Limited energy resources require innovative technologies to save, transfer, and store thermal energy. Nanofluids – suspensions with nanoparticles of size 20 nm–200 nm – might be one such technology. Choi and Eastman (1995) were the first to investigate the enhanced thermal conductivity of nanofluids and opened the gate for numerous studies analysing this specific class of fluids. More recent overview studies by Sergis and Hardalupas (2011), Thomas and Sobhan (2011), and others support the general assumption that nanofluids improve heat transfer. However, nanofluids are still controversially discussed. According to Feja and Buschmann (2012), nanofluids are complex two-phase liquids. The influence of particle size and shape, agglomeration, and the influence of chemical ingredients employed to stabilise nanofluids are often underestimated. The situation becomes even more complicated because nanofluids behave as such even in measurement devices, which makes the determination of thermophysical properties challenging.

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Nomenclature

D	non-dimensional temperature difference
d_i	inner diameter of thermosyphon
l	length of thermosyphon
Nu	Nusselt number
P_e	provided electrical power at evaporator
Pr	Prandtl number
p_v	vapour pressure
q	heat transferred
R	thermal resistance
R_T	ratio of temperatures
T_c	condenser temperature
T_e	evaporator temperature
T_{in}	inlet temperature of cooling coil
T_{out}	outlet temperature of cooling coil
T_v	vapour temperature
ΔT_{ec}	difference between condenser and evaporator temperature, K
V_c	volumetric flow rate of coolant

Greek symbols

Δ	relative error
ϕ	concentration of nanoparticles
η	dynamic viscosity
Θ	non-dimensional temperature ratio

Abbreviations

Au	gold
DI	deionised
TiO_2	titanium dioxide

Two very recent surveys of the application of nanofluids as working fluid in thermosyphons, heat pipes, and oscillating heat pipes are published by Liu and Li (2012) and Buschmann (2013). These studies elucidate that in the most cases nanofluids reduce thermal resistance and therewith enhance the amount of heat transferred. Buschmann (2013) points out that while the majority of the analysed experiments show an improvement (e.g. Senthilkumar et al., 2011; Huminic et al., 2011; Putra et al., 2012), several other studies indicate deterioration (e.g. Khandekar et al., 2008; Han and Rhi, 2011; Hajian et al., 2012). So far, the physical mechanisms responsible for the observed increases and decreases of heat transfer remain largely unclear. Many authors argue that the primary cause of the performance changes is a porous layer built from nanoparticles on the evaporator surface. Alternatively it is hypothesised that the bubble departure frequency at the evaporator might be augmented due to bubble bombardment by nanoparticles. A third explanation is based on the increased thermal conductivity of nanofluids which should improve heat conduction within the working fluid. Furthermore, several issues remain unsettled with respect to optimisation of nanoparticle concentration and long term stability of nanofluids.

This study aims to answer some of the questions raised above. Our focus is on the influence of nanofluids on the thermal performance of a vertical thermosyphon. Geometry, filling ratio, and inclination angle of the employed thermosyphon are kept unchanged during experiments to reduce the number of influencing parameters. At the centre of the experiments stands the dependency of the thermal resistance on the nanoparticle concentration and their long term stability. Moreover, the question as to if the condenser is affected by nanoparticles transported by the vapour phase is addressed. The general goal is to draw conclusions in view of the improvement of the thermal performance of thermosyphons and related gadgets.

2. Experiment

2.1. Experimental apparatus

A vertically oriented thermosyphon (Fig. 1) made of a chemical- and thermal-resistant borosilicate glass cylinder is employed to investigate the performance enhancement of nanofluids compared with deionised water (DI-water). The glass cylinder has an inner diameter d_i of 25 mm and a length l of 500 mm. The pellucidness of the glass cylinder allows inspection of the nanofluid before and after experimental investigation. During the experiments the thermosyphon is completely insulated with two ARMAFLEX insulation shells (each 20 mm) to ensure thermal decoupling from the surrounding environment.

Working principle of the thermosyphon and a schematic of the complete test rig are depicted in Fig. 2. The evaporator consists of a horizontally oriented copper cylinder of a height of 22 mm which is tight-fitted in the lower opening of the borosilicate glass cylinder. Therefore, the effective length of the glass cylinder indeed relevant for the transport of the vapour phase reduced to 482 mm. A resistance wire embedded in the evaporator is employed to heat it electrically. Despite the ability to vary the heating power infinitely, here only the discrete heating powers of 20 W, 40 W and 60 W are utilised. A Pt-100 element is positioned concentrically within the evaporator to measure its surface temperature. The Pt-100 element is countersunk in a tapped blind hole positioned on the lower side of the evaporator. The blind hole itself is 18 mm deep so

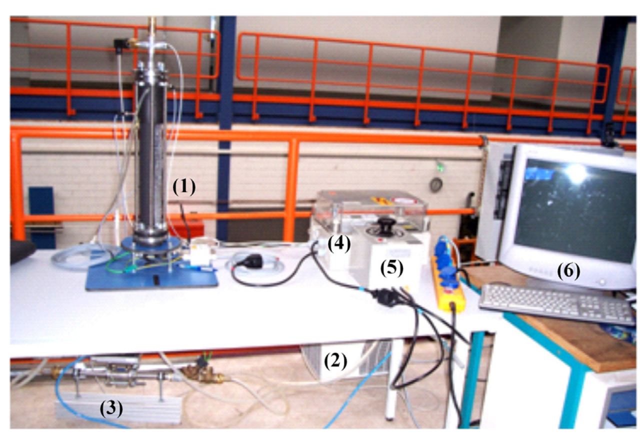

Fig. 1 – Experiment set up. Numbers denote (1) thermosyphon, (2) thermostat, (3) flowmeter, (4) data acquisition, (5) power supply for electrical heating, and (6) data processing.