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Research Paper

An experimental study of evaporation and condensation heat transfer coefficients for looped thermosyphon

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HIGHLIGHTS

- Experimental investigations are conducted on thermosyphon loop's performance.
- The new correlations for thermosyphon evaporator and condenser heat transfer coefficients are proposed.
- Evaporator heat transfer surface is enhanced with micro-porous layers.
- Evaporator thermal resistance is enhanced up to 75% using thin porous layer.

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ABSTRACT

An experimental investigation on a thermosyphon loop performance using water as a working has been carried out. A two-phase loop consisting only of a condenser and an evaporator separated by the liquid and vapor lines is developed. It uses the process of fluid phase change to transfer energy from the heat source to the condenser. The thermosyphon loop's evaporator and condenser heat transfer coefficients are compared with available predictive correlations. The new correlations for thermosyphon evaporation and condensation heat transfer coefficients are proposed. They predicted heat transfer coefficients with ±10% compared to the experimental data. A micro-porous layers are tested as a mean of evaporator heat transfer coefficient enhancement. It shown that the evaporator thermal resistance could be reduced up to 75% compared to a smooth surface evaporator, at low heat flux. In the same conditions, the system thermal resistance could be diminished up to 20%. Moreover, micro-porous layer fastened the loop's start up time.

1. Introduction

Passive cooling systems arose as an innovative solution due to their ability of withstanding high heat fluxes, highly-evolved temperature and power control, minimum energy consumption, less noise, protection of the environment, and suiting through any compact system. Among the available techniques, two-phase capillary thermal control devices such as Heat Pipes (HP), Micro Heat Pipes (MHP), Loop Heat Pipes (LHP), Capillary Pumped Loops (CPL), and loop thermosyphons are specially promising. They offer various advantages such: (i) Ability of dissipating heat from a heat source to a heat sink over a relatively long distance, (ii) no moving parts leading to a more reliable system operation, (iii) greater flexibility while choosing working fluids compatible with telecommunication equipment, (iv) reduction in the working fluid fill charge.

Thermosyphon loops is used as the appropriate cooling solution for various industrial applications: avionics [1], gas turbine blades [2], nuclear reactors [3], solar collectors [4], and electronic devices [5]. It is a passive heat transfer device consisting of an evaporator and a condenser connected by two vapor and liquid lines. Working fluid is circulating under gravity without any active control instrumentation and mechanical moving parts. Thermosyphon loop operates with working fluid phase change, that offers higher heat transfer at low fluid fill charge. It is developed as an appropriate way for energy savings by reducing greenhouse gas emissions. The phase change processes take place in the thermosyphon evaporator and condenser where it needs available correlation to predict heat transfer coefficient and to predict the loop's thermal performance. Groβ [6] found that much of the empirical data is over-predicted by Nusselt's theory [7] at low Reynolds numbers. He proposed a correlation for condensation heat transfer inside a two-phase thermosyphon loop. Hung et al. [8] analysed system thermal resistance for different filling ratio and concluded that

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Nomenclature

A	area (m^2)
C_p	specific heat capacity (J/Kg K)
D, d	diameter (m)
g	gravity (m/s^2)
h_{lv}	latent heat of vaporization (J/kg)
L	length (m)
M	molar mass (kg/Kmol)
Nu	Nusselts number
P	pressure (Pa)
P_r	Prandtl number
q	heat flux (W/m^2)
Q	heat (W)
R	thermal resistance (°C/W)
Re	Reynolds's number
RMS	root mean square
T	temperature (°C)
x	vapor quality
X_{tt}	Martinelli parameter

Greeks

α	thermal expansion (1/K)
β	contact angle (°)
λ	thermal conductivity (W/m °C)
σ	surface tension (N/m)
ρ	density (kg/m^3)
μ	dynamic density (Pa s)
ϕ	two phase pressure drop multiplier

Subscripts

b	bubble
cap	capillary
cond	condenser
evap	evaporator, evaporation
exp	experimental
gr	gravity
i	inlet
insol	insolation
l	liquid
o	outlet
p	process
sys	system
tp	two phase
v	vapor
VL	vapor line
w	wall

more the system thermal resistance is low, more the cooling device is reliable. Tsoi et al. [9] conducted experimental study to examine the thermal performance of a plate-type two-phase loop thermosyphon with cooling applications to electronic boards of telecommunication systems under free and forced convective cooling conditions. It was found that at free convective cooling conditions, the increase of boiling heat flux intensifies the multi-channel boiling instabilities and hence the vapor–liquid circulation. Khodabandeh and Furberg [10] tested a copper nano and microporous structure in a thermosyphon loop's evaporator. They found that the enhanced structure surface decreased the oscillations at the entire range of heat fluxes. Kang et al. [11] found that sintered copper wicks structures in a loop thermosyphon's evaporator reduces the heater surface temperature. Evaporator temperature with 1 mm wick was reduced by 10% in comparison with that without wick. Chang and Lin [12] investigated thermosyphon loop thermal performance using the smooth and roughened surfaces. They found that nucleation sites are increased and bubbles departure is improved with a roughened surface. Moreover, segmentation of Taylor bubbles by scale imprints considerably suppressed evaporator temperatures oscillatory amplitudes and enhanced loop's thermal stabilities.

Based on the previous works, this paper treated thermal performance of thermosyphon loop using water as working fluid is reported. Experiments are conducted under various heat flux. Numerous correlations for predicting the heat transfer in the evaporator and condenser sections are compared with experimental measurements. Moreover, the effect of a micro-porous layer in the loop's evaporator is investigated.

2. Experimental setup

Fig. 1 shows the experimental set up used to conduct measurements for the heat transfer in the thermosyphon loop. Evaporator test assembly used in this work is presented in Fig. 2. The condenser consists of two coaxial cooper tubes. It is cooled by water forced convection using a 6 l water Fisher scientific thermostatic bath. It has a built-in pump and an automatic thermostatic system. The cooling water flow rate is adjusted using a valve and a calibrated flow meter. During tests, condenser cooling water temperature and flow rate are always controlled under the desired values. After passing the condenser, cooling water is automatically adjusted to an initial desired temperature. K type thermocouples are located on the entire system for temperature measurements. Four thermocouples are installed for direct measurement of the working fluid temperature at the inlet and outlet of the evaporator and the condenser. Two thermocouples are installed at the inlet and outlet of the condenser cooling jacket.

As shown in Fig. 2, the evaporator consists of liquid and vapor chambers and a minichannels layer. While heating, vapor flows from the liquid chamber to vapor chamber crossing the parallel minichannels. The vapor and liquid lines are stainless steel tubes. Additionally to their low thermal conductivity, they are insulated unlike the evaporator and condenser that have high thermal conductivity. A heating copper block is in direct contact with the loop's evaporator. A 500 W cartridge heater is inserted inside the copper block as shown in Fig. 2. The power supply is adjusted through a voltage autotransformer having 0–220 V output voltage. Also, the power measurements and recordings are done using Hameg wattmeter. Moreover, Teflon cover adiabatic plates assembly with very low thermal conductivity is placed on all the faces of the evaporator and the heating block in order to minimize heat losses. Besides, they are used to make a good thermal contact between evaporator bottom and heating block top surfaces.

As shown in Fig. 2, ten thermocouples are installed in the heating block in axial direction. Five thermocouples are placed at 3 mm below the top surface of the heating block and at axial distances; 7, 27, 47, 67, and 87 mm from the left edge. The other five thermocouples are placed at the same axial locations but at 10 mm from the top surface of the heating block. Besides, a thermocouple situated separately beside the loop is used for the ambient temperature measurement. Two 7 bar absolute omega pressure sensors are used for the absolute pressure measurement at the condenser inlet and evaporator outlet. Moreover, 8 bar absolute HBM pressure sensor is installed at the condenser outlet for the