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Thermal performance of an internally finned two phase closed thermosyphon with refrigerant R134a: A combined experimental and numerical study

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ABSTRACT

In this work, the heat transfer performance of a two phase closed internally finned thermosyphon has been studied by both experimental and numerical investigations. The working fluid considered for the experiments is R134a, which is compatible with copper material and is environment friendly. The thermosyphon comprises an evaporator of length 200 mm, adiabatic length 100 mm and a condenser section 200 mm long. Rectangular cross section fins are placed internally along the length of the condenser. These are of constant area and are 5 mm wide and 1 mm thick. The fill ratios considered in this study are 20, 35, 50, 65 and 80%. Experiments are carried out for different cooling water mass flow rates of 10, 30, and 40 LPH. A lumped parameter model is developed to validate the experimental results, wherein the heat transfer equations are coupled with the mass transfer equations and the resulting equations are discretized explicitly. A boiling heat transfer coefficient correlation is developed with the experimental data to calculate the thermal resistance at the evaporator wall. The thermosyphon is tested between power levels of 25 and 150 W. The heat transfer performance of the R134a charged internally finned thermosyphon is found to be superior to that of a water charged thermosyphon.

1. Introduction

A thermosyphon is a heat exchanger which transfers heat from the hot side to the cold side using boiling and condensation inside the shell. A wickless heat pipe is a sealed container containing a certain amount of working fluid, which undergoes phase change process and transfers high heat fluxes with minimum temperature difference from the hot (source) to the cold side (sink). In the case of a heat pipe/thermosyphon, the condensate returns to the evaporator pool with the aid of gravity. This is different from a wicked heat pipe, where the condensate returns to the pool with the help of capillary forces [1]. The heat transfer processes in a heat pipe include pool boiling, solid conduction, convection, and film condensation [2]. Fig. 1 shows a schematic of a two phase closed thermosyphon and the above mentioned processes can be clearly seen in the figure.

As compactness of electronic devices continues to increase, heat dissipation too increases exponentially. Several cooling technologies are available like jet impingement, forced convection, free convection, falling film, and heat pipe to handle high heat fluxes. A heat pipe exploits the phase change and transfers high heat fluxes without the use of moving parts, is simple in structure, is highly flexible, compact, and provides very high effective thermal conductivities [3,4]. As the heat is supplied to the evaporator wall, the pool gets heated by taking up latent heat of evaporation, followed by a change of phase from the liquid to the vapor. The high pressure and temperature vapor travels to the condenser section, loses its latent heat absorbed from the evaporator wall and gets condensed. The condensed film falls back to the evaporator pool along the inner wall of the thermosyphon. Heat pipes are widely used in applications like permafrost cooling, waste heat recovery, data center cooling, solar water heating, and cooling of electronic components [5–7].

During the past few decades, many researchers have studied the effect of filling ratio, orientation, and the choice of working fluid on the thermal performance of two phase closed heat pipes [8–13].

The most desirable characteristics of the working fluid are, (i) wettability and compatibility with the heat pipe material, (ii) high latent heat of evaporation, (iii) high thermal conductivity, (iv) low viscosity in both phases. For a thermosyphon with a diameter of 20 mm, by considering different working fluids, namely, water and acetone, at low power levels (e.g 50 W), the response to heat input was seen to be slow [9]. This leads to thermal oscillations, resulting in a high thermal resistance. Refrigerant R134a is non toxic, non flammable and non

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Nomenclature

A	area, (m^2)
C	thermal capacitance (J/K)
c	specific heat (kJ/kgK)
h	heat transfer coefficient (W/m^2K)
h_{fg}	latent heat of vaporization (kJ/kg)
I	current (A)
k	thermal conductivity (W/mK)
$\dot{M}_a$	adiabatic mass (kg/s)
$\dot{M}_c$	condensed mass (kg/s)
$\dot{M}_e$	evaporation mass (kg/s)
$\dot{M}_p$	pool mass (kg/s)
M_a	adiabatic mass (kg)
M_c	condensed mass (kg)
M_e	evaporation mass (kg)
M_p	pool mass (kg)
P	power (W)
P_v	saturated vapor pressure (Pa)
q	heat flux (W/m^2)
R	thermal resistance (°C/W)
R_v	vapor gas constant (J/kgK)
T	temperature (K)
V	voltage (V)

Greek Letters

γ	heat capacity ratio
μ	dynamic viscosity (Ns/m^2)
ν	kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
σ	surface tension (N/m)
ϕ	fill ratio

Subscripts

a	adiabatic
c	condenser
e	evaporator
f	fin
p	pool
v	vapor

Abbreviations

CFD	computational fluid dynamics
Expt	experimental
Num	numerical
sat	saturation condition

corrosive. Hence, R134a, a low saturation temperature working fluid is considered in this study.

Xu et al. [14], studied, both experimentally and numerically, the effect of wettability and fill ratio on heat transfer performance of a two phase closed thermosyphon. The authors concluded that, at a low fill ratio (12%), the system underwent dryout, and at high fill ratios bubbles are prevented from reaching the top of the pool. Hence the thermal resistance are high at low and high fill ratios. Fadhl et al. [15] conducted both numerical and experimental studies on two phase closed thermosyphon charged with R134a and R404a. A numerical model was developed to simulate the phase change. Pool boiling in the evaporator and condensation on the inner walls of condenser section were observed and steady state results were reported. The authors concluded that the numerical model can reproduce the complex phenomena inside the system quite well, and good agreement was seen between the simulations and the experiments. Further, smaller diameter bubbles were observed in the pool, which help to reduce the response time to heat input. Xu et al. [16], developed a model, to simulate the heat transfer characteristics of a two phase closed thermosyphon. Model results were compared with experimental results in literature and were found to be in good agreement. Authors concluded that, this model can be used to predict the heat transfer characteristics of different thermosyphons. Naphon et al. [17], experimentally, investigated, the effect of refrigerant nanoparticle mixtures on heat pipe efficiency. The base working fluid considered for the mixture was R11. Titanium nanoparticles with diameter of 20 nm were mixed with R11 to obtain the nanofluid. The heat pipe was tested with different filling conditions and fill ratios. The orientations considered were 0, 15, 30, 45, 60, 75 and 90°. The heat pipe performance was best at 50% fill ratio, 60° orientation and 0.1 wt% concentration. The effect of vapor flow resistance on the thermal characteristics of a two phase closed thermosyphon was numerically investigated by Ziapour and Shaker [18]. A comprehensive FORTRAN code was combined with the EES software to obtain the vapor resistance. The refrigerants considered in their study were water, ammonia, R-134a, R-11, and R-22. The evaporator heat transfer coefficient was calculated by using the Imura correlation [18], whereas the film condensation heat transfer coefficient was predicted by using the Nusselt correlation for a vertical plate. The numerical results from the code developed agreed well with the experimental results of Farsi et al. [19].

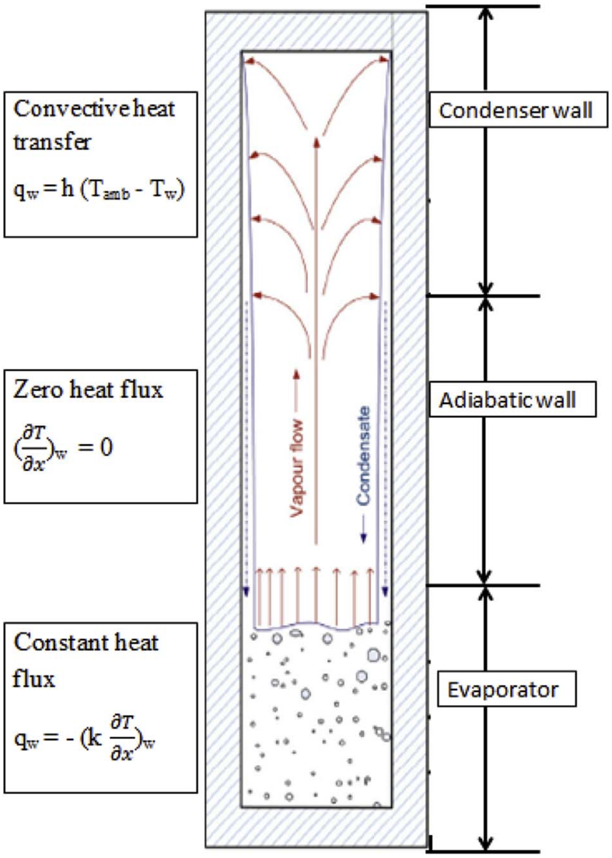

Fig. 1. Schematic of the two phase closed thermosyphon.

The effect of R134 on the thermal performance of two phase closed wick less heat pipe was experimentally investigated by Ong and Haider [20]. R134a refrigerant is an environmentally friendly refrigerant, and is generally accepted as a substitute for R22 and R12. The thermosyphon was tested for different coolant mass flow rates and bath