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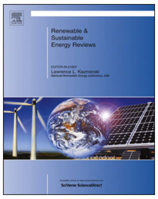

Thermoeconomic analysis of thermosyphon heat pipes

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ABSTRACT

Thermoeconomic analysis combines economic and thermodynamic analysis by applying the concept of cost, originally an economic property, to exergy. In this study, effects of different three working fluids as methanol, petroleum ether and distilled water on thermoeconomic analysis in the thermosyphon heat pipes which it heats the air is investigated. Under different air velocities, the energy and exergy efficiencies of the thermosyphon heat pipes are determined and compared in terms of thermoeconomic experimentally. Under all air velocities, while the highest energy and exergy performance are calculated for methanol, the lowest energy and exergy performance are calculated for petroleum ether. However, the thermoeconomic results of this study show that distilled water is more cost-effective than that of methanol and petroleum ether.

Contents

1. Introduction

Thermosyphon Heat Pipe (THP), a gravity-assisted wickless heat pipe, uses the evaporation and condensation of the working fluid inside to transfer heat and is also called as two-phase close thermosyphon (TPCT). As opposed to the conventional heat pipe using capillary force to make the liquid return to evaporator, in THP, gravitation is used to return the condensate.

It has a lot of supremacy including simpler structure, smaller thermal resistance, higher efficiency and lower production cost. Also, it contains no mechanical moving parts and typically requires no maintenance. All these advantages enable the THP to be widely used in a number of fields, including industrial heat recovery, electronic component and turbine blade cooling, solar energy systems, climatization processes, preservation of permafrost, deicing of roadways, and so on.

Thermo physical properties of working fluid, filling ratio, inclination angle, structure and geometry influence considerably the performance of THP. There are many studies on the heat transfer analyses of the THP system in the literature. In order to improve performance of THP systems, investigators have focused on working fluids, filling ratio, inclination angle and components of the THP systems.

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Nomenclature

A	area (m^2)
AC	annual capital cost (\$ $year^{-1}$)
c	unit exergy cost rate (\$ $W^{-1}h^{-1}$)
$\dot{C}$	exergetic cost rate (\$ h^{-1})
C_p	specific heat (kJ kg^{-1} K^{-1})
CRF	capital recovery factor
$\dot{E}x$	exergy rate (W)
h	enthalpy (kJ kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
P	pressure (bar)
PW	present factor
PWF	present worth factor
PVC	poly vinyl chloride
$PPRC$	polypropylene random copolymer
$\dot{Q}$	heat transfer rate (kW)

Subscripts

a	air
atm	atmosphere
c	cross sectional
CI	capital investment
cond	condenser
dest	destroyed
e	environment
evap	evaporator
elec	electricity
R	ideal gas constant (kJ kg^{-1} K^{-1})
s	entropy (kJ kg^{-1} K^{-1})
SV	salvage value (\$)
T	temperature (K)
TCI	total capital of investment (\$)
THP	thermosyphon heat pipe
V	velocity (m s^{-1})
W	electrical consumption (kW)
$\dot{Z}$	capital cost rate (\$ h^{-1})
η	efficiency
μ	salvage value percentage
τ	working hour in a year (h $year^{-1}$)
ρ	density (kg m^{-3})
Ø	diameter (mm)
Ψ	flow exergy (availability) (W)
heater	electrical heater
in	inlet
m	mean
o	restricted dead state
out	outlet
OM	operating and maintenance
I	first law (energy)
II	second law (exergy)

Terdtoon et al. investigated experimentally the effect of aspect ratio and Bond number on heat transfer properties of two-phase closed thermosyphon using R-22, ethanol, and water as working fluids at normal operating condition [1]. Also, Terdtoon et al. studied experimentally internal flow patterns of thermosyphon and the effect of aspect ratio and Bond number on it at different angles, and shifted the filling ratio from 80% to 150% with R123 as a working fluid [2]. Ong and Haider-E-Alahi scrutinized the impacts of temperature variation between bath and condenser section, fill ratio and coolant mass flow rates on the performance of the thermosyphon filled with R-134a [3]. Hussein et al. studied filling ratio identified as the volume ratio of charged liquid to the evaporator or the whole THP, using distilled water as working fluid in their systems [4]. Jiao et al. presented an extensive model to search the effect of filling ratio on the steady-state heat transfer performance of a vertical TPCT. In the TPCT, they studied the gaseous nitrogen as working fluid [5]. Khandekar et al. investigated the overall thermal resistance of TPCT in which pure water and various water based nanofluids (of Al_2O_3, CuO and laponite clay) are determined as working fluids. Based on this investigation they concluded that pure water turns out to be superior than all these nanofluids [6]. Noie et al. studied increasing efficiency of TPCT, using Al_2O_3/water nanofluid as the working fluid. After experimentally examining distinct volume concentrations of nanoparticles (1–3%) in suspension within the TPCT, they make comparison of the results with pure water [7]. Huminic et al. focused on the thermal improvement of the THP performance, choosing iron oxide – nanofluid as the working fluid. They experimentally examined the deionized water containing inside diluted iron oxide nanoparticles in THP. In this process, the two 45° and 90° inclination angles of the THP were investigated [8]. Huminic and Huminic studied largely the effects of volume concentrations of nanoparticles and the operating temperature on the heat transfer performance of the THP using the nanofluids. They carried out the analysis for water and γ-Fe_2O_3 nanoparticles, three volume concentrations of nanoparticles (0 vol%, 2 vol% and 5.3 vol%) and four operating temperatures (60, 70, 80 and 90 °C) [9]. Kamyar et al. intensified their efforts on the thermal performance of TPCT filled with two nanofluids using water as the base fluid mixed with Al_2O_3 and $TiSiO_4$ nanoparticles. Nanofluids made up of different volumetric concentrations (0.01%, 0.02%, 0.05% and 0.075%) were created and different heat loads (40, 70, 120, 180 and 210 W) were applied to the evaporator section [10]. Buschmann and Franzke carried out experiments in which a vertical thermosyphon with deionized water and water based titanium dioxide and gold nanofluids with different concentrations as working fluids was tested [11]. Heris et al. studied effects of different electric field intensity on the thermal performance and thermal resistance of the system, which used Al_2O_3/water and CuO/water nanofluid as working fluids. They examined various working fluids at different conditions. They found that the electric field intensity positively affected the thermal performance and decreased the thermal resistance of two-phase closed thermosyphon [12]. Long and Zhang studied the heat transfer properties of a cryogenic thermosyphon with N_2–Ar binary mixture as the working fluid in different rates. Focusing the mass transfer of the components, they theoretically make discussion on the heat transfer of the binary mixture in the thermosyphon. [13]. Baojin et al. conducted experimental investigations to examine heat transfer properties of titanium (commercially pure titanium, TA2)/water two-phase closed thermosyphon (Ti/H_2O TPCT). They also tested the performance of copper/water (Cu/H_2O) TPCT which has the same dimension and production operation [14]. Sarafraz and Hormozi presented experimental study on the thermal performance and efficiency of a copper made thermosyphon heat pipe charged with alumina–glycol based nanofluids. They experimentally investigated influence of different operating parameters such as applied heat flux to the evaporator section, % charged value of working fluid, tilt angle of the heat pipe and volumetric concentration of nanoparticle on the thermal performance and efficiency of the heat pipe. Results demonstrated that heat transfer coefficient of the heat pipe significantly increases, when nanofluids are used as