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Review

A review on loop heat pipe for use in solar water heating

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ABSTRACT

In this paper, a comprehensive review on the loop heat pipe (LHP) for use in solar water heating (SWH) will be carried out. LHP is an efficient heat transfer device that could transport thermal energy over long distances, up to several tens of meters. It has some unique features over conventional heat pipe, e.g., gravity-unaffected and flexibility in its design and installation, which makes LHP particularly suitable for applications in SWHs. A significant literature review of the LHP technology will be illustrated, and the review results will be analyzed in terms of the performance characteristics and research methodology. For the performance characteristics, the steady-state and transient behavior of the LHP device will be examined. The research methods, i.e., theoretical analyses and computer simulations, and experimental investigations, will be analyzed. Although substantial work has been done in LHP studies, the opportunities for further work will be identified. This review will help recognize the problems remaining in the existing SWHs, remove the barriers to solar applications, identify new research subjects to improve the performance of the SWHs, expand solar thermal market potential throughout the world and broaden the application of LHP in solar water heating.

Contents

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Nomenclature

A	area (m^2)
C	constant
C_p	specific heat capacity at a constant pressure (J/(kg K))
C_v	specific heat capacity at a constant volume (J/(kg K))
D	diameter (m)
f	friction factor
g	gravitational acceleration (9.81 m/s^2)
h	convective heat transfer coefficient (W/(m^2 K))
h_{fg}	latent heat of evaporation (J/kg)
K	permeability (m^2)
L	length (m)
m	mass or mass flow rate (kg or kg/s)
M	Mach number
N	number/quantity
P	pressure (Pa)
ΔP	pressure drop (Pa)
Q	energy flux (W)
r_b	critical radius of bubble generation (m)
R	thermal resistance (K/W)
Re	Reynolds number
R_v	vapor constant (J/(kg K))
t	time (s)
T	temperature (°C)
v	velocity (m/s)
x	factor relating to the filled liquid mass, 0.8 for evaporation and condensation sections and 1 for adiabatic section
z	shape factor, 1 for circular and 0.833 for rectangular shapes
γ	specific heat ratio
δ	thickness (m)
ε	emissivity
θ	contact angle (°)
λ	thermal conductivity (W/(m K))
μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
σ	surface tension or Stefan Boltzmann constant (N/m or 5.67×10^{-8} W/(m^2 K^4))
φ	porosity
Φ	absorber tilt angle (°)

Subscripts

amb	ambient
BL	boiling limit
c	condenser
cc	compensation chamber
CL	capillary limit
e	evaporator
EL	entrainment limit
FL	filled liquid mass limit
g	gravity
i	inner surface or heat input
l	liquid
lf	liquid film
ll	liquid line
loss	heat dispersed to the ambient
max	maximum values
min	minimum values
ms	mesh-screen wick
o	outer surface or heat output
s	wick in the solid form
sp	sintered-powder wick
SL	sonic limit
v	vapor
vl	vapor line
VL	viscous limit
w	wick

1. Introduction

Solar thermal designates all technologies that collect solar rays and convert the solar energy to usable heat for use in water, space heating and cooling, electricity, fuels and agricultural and industrial processes. Solar water heating (SWH) is one of the most popular solar thermal systems and accounts for 80% of the solar thermal market worldwide [1,2]. Over the past four decades, SWHs have gained wide applications in the building sector globally [3]. In the meantime, the systems have been identified with a number of technical problems that have become the barriers to their promotions, e.g., low existing efficiency, high heat loss and poor solar energy harvesting capability. Some challenges also relate to their installations to the buildings and capital costs.

Most solar water heaters (SWH) for buildings are flat-plate types or conventional heat pipes array installed on roofs for layout convenience [4–6]. This installation requires long runs of pipelines delivering water from the roof heaters to the outlet points and receiving water from the water mains. Thus, the cost of the system is high; most importantly, the installation detracts from the esthetics of the building, particularly those multi-storey buildings containing a large number of end users.

In recent years, several façade-based solar heaters have been developed and used in practical projects [7–9]. These devices are simply positioned on the walls or balconies [10], which prevent the occupation of roof space and shorten the distance of piping runs, and thereby improve the building's esthetic view. However, this layout still requires the transportation of water from the inside of the building to the outside, which may cause the hazard of pipes freezing during winter operation.

Further development has been undertaken to introduce the loop heat pipe concept into the solar collectors. Loop heat pipe [11–13] is a two-phase (liquid/vapor) heat transfer device allowing a high thermal flux to be transported over a distance of up to several tens of meters in a horizontal or vertical position owing to its capillary or gravitational structure. However, the starting-up problem of the loop heat pipe still exists influencing the operating stability of the solar collector, as well as the high initial cost of the system. Still, the loop-heat-pipe-based solar collectors are in the laboratory experimental stage that the structure of the system needs to be optimized.

Based on the research background, this paper will focus on the comprehensive review of LHP in working principle, classification, theoretical analysis and recent application of LHP in solar water heating. The opportunities for further work will also be addressed in this paper. This study will help understand the current status of the technical developments of LHP, identify the barriers remaining to the existing SWHs, develop the potential research areas to improve the performance of the SWHs, establish the associated strategic plans related to the design and installation of the system and promote the solar thermal global market. The study will therefore contribute to achieving the targets for energy saving, renewable energy utilization, as well as carbon emission reduction in building sector.