Applied Thermal Engineering 143 (2018) 275–282

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Experimental study of the liquid/vapor phase change in a porous media of two-phase heat transfer devices

Riadh Boubaker[a,*], Souad Harmand[a], Vincent Platel[b]

[a] Laboratoire d'Automatique, de Mécanique et d'Informatique industrielles et Humaines (LAMIH), Université de Valenciennes et du Hainaut-Cambrésis (UVHC) Le Mont Houy, F59313 Valenciennes CEDEX 9, France
[b] Univ Pau & Pays Adour, Laboratoire de Thermique, Energétique et Procédés-IPRA EA1932, Pau, France

HIGHLIGHTS

- A 75% reduction in the hydrostatic head decreases the casing temperature by 25%.
- A 300% increase in the hydrostatic head reduces the heat transfer coefficient by 27%.
- Vapor pocket increases with the adverse hydrostatic head.
- Effect of the wick material on heat transfer is important.

ARTICLE INFO

Keywords:
Phase change
Porous media
Capillary pumping
Heat transfer

ABSTRACT

The study presents an experimental examination of heat and mass transfer with phase change in a porous media composed of copper foam. The aim of the study involves separately examining the effect of the adverse hydrostatic head, subcooling at the wick inlet and wick properties (porosity and average pore diameter) on the heat and mass transfer inside porous media. The experimental results indicate that an increase in the adverse hydrostatic head from $\Delta h = 0.5$ cm to $\Delta h = 2$ cm increases the casing temperature of 5 °C for low heat loads and 40 °C for high heat loads owing the vapor breakthrough toward the wick inlet. The results also suggest that the heat transfer coefficient and the critical heat flux are reduced by approximately 27% (for a heat load of 106 W) and 17%, respectively for the same adverse hydrostatic head variation. The increase in the subcooling at the wick inlet reduces the thermal performance of the evaporator. With respect to wick property effects, the results indicate that the porosity and average pore diameter significantly impact the phase change phenomenon inside the porous wick and the casing temperature. There are optimal values of porosity and average pore diameter leading to the best thermal performance of the capillary evaporator.

1. Introduction

The phase change phenomenon in porous media occupies an important role in several applications, and particularly in heat transfer systems such as Capillary Pumped Loop (CPL) and Loop Heat Pipe (LHP) [1–4]. Passive two-phase heat transfer devices use fluid circulation and phase change properties in a porous medium to transfer high amounts of heat over distances of a few meters from a hot source to a cold source. As shown in Fig. 1, they are composed of an evaporator, a condenser, a reservoir (a compensation chamber) and vapor and liquid lines.

The evaporator is the key element of such devices, which absorbs the heat dissipated by the hot source (electronic components). The generated capillary pressure in the pores is responsible for the fluid circulation in the complete loop. As shown in Fig. 2, the evaporator consists of a porous structure called wick that is tightly enveloped by a metal container.

Over the last decade, several efforts focused on simulating the phase change phenomenon inside the porous wick of capillary evaporators. Kaya and Goldak [5] numerically examined heat and mass transfers in the porous structure of an LHP. The proposed mathematical model is inspired from a study by Demidov and Yatsenko [6]. They showed the existence of a vapor pocket when the fluid temperature exceeds the saturation temperature by a few degrees. Huang [7] also developed an unsteady model to study heat and mass transfers with phase change in the porous wick of an evaporator of a CPL.

---

[*] Corresponding author.
E-mail addresses: boubakker.riadh@yahoo.fr (R. Boubaker), souad.harmand@univ-valenciennes.fr (S. Harmand), vincent.platel@univ-pau.fr (V. Platel).

https://doi.org/10.1016/j.applthermaleng.2018.07.058
Received 16 February 2018; Received in revised form 27 March 2018; Accepted 11 July 2018

Nomenclature

V	voltage, V
I	current, A
C_p	specific heat, J kg^{-1} K^{-1}
h	heat transfer coefficient, W m^{-2} K^{-1}
S	cross section, m^2
L_v	latent heat, J kg^{-1}
p	pressure, Pa
t	time, s
T	temperature, K
K	permeability, m^2
r_m	meniscus curvature, m
r_p	pore radius, m
g	gravitational acceleration, ms^{-2}

Greek symbols

Δp	pressure drop, Pa
Δh	adverse hydrostatic head, cm
σ	surface tension, N m^{-1}
λ	thermal conductivity, W m^{-1} K^{-1}
μ	dynamic viscosity, kg m^{-1} s^{-1}
ρ	density, kg m^{-3}
ϕ	heat flux, W
θ	contact angle, rad
$\dot{m}$	mass flow rate, kg s^{-1}
Ω	volume, m^3

Subscripts

ℓ	liquid
v	vapor
s	solid
eff	effective
cap	capillary
sat	saturation
C	casing
R	reservoir
in	inlet
o	outlet
W	wick
p	parasitic
sens	sensible

In the study, the porous wick was divided into the following three regions: a liquid zone, vapor zone and two-phase zone where the phase change occurs. The results showed that the thickness of the liquid/vapor interface is non-zero. Xuan et al. [8] simulated the coupled heat and mass transfer with phase change in a global CPL evaporator by using a two-dimensional (2D) transient model based on the lattice Boltzmann method. Masahito Nishikawara and Hosei Nagano [9] investigated the effect of adding a microgap between the casing and porous wick on capillary evaporator performance. The results indicated that an optimal gap distance exists leading to a high thermal coefficient. Mottet and Prat [10] investigated heat and mass transfer with phase change in a bidispersed capillary structure characterized by a bimodal pore size distribution using a mixed pore network model. The simulations demonstrated that the bidispersed wick exhibits better thermal performance than a monodispersed wick for high heat loads. Boubaker et al. [11] presented an unsteady mathematical model of a flat CPL evaporator. The developed model describes heat and mass transfers as well as phase change phenomenon within the porous wick. Subsequently, the evaporator model was coupled with a complete loop model [12,13]. The effects of applied power, working fluid and porous wick properties on the thermal performance of a capillary pumped loop and vapor pocket behavior inside the porous wick were analyzed. Z.M. Wan et al. [14] presented a 2D model to analyze heat and mass transfer in a miniature flat capillary pumped loop evaporator with a fully saturated wick. Wu et al. [15] investigated the impact of the bayonet tube on the phase change in the porous wick of a capillary evaporator. The results indicate that the bayonet tube decreases the temperature inside the porous wick and reduces the risk of evaporator failure. Le et al. [16] developed a 2D pore network model to describe heat and mass transfer in an unsaturated porous wick and to examine the impact of microstructural properties on the vapor pocket pattern. Three dimensional (3D) models were also developed to study the liquid/vapor phase change in capillary evaporators with a fully saturated wick [17–20] and unsaturated wick [21].

Although numerical studies focused on analyzing the phase change inside a porous wick, there is a paucity of experimental studies that examine heat and mass transfers inside a capillary evaporator in the case where it is decoupled from the rest of the CPL/LHP components owing to the complexity of the coupled physical phenomenon that occurs inside the wick. Liao and Zhao [22,23] performed an experiment to investigate mass and heat transfer processes in a rectangular porous structure in a stationary regime. Experimental results indicated the existence of a vapor pocket that develops inside the porous wick. The authors also demonstrated that the temperature field in the porous medium depends on gravity losses, subcooling at the wick inlet and pore radius. Cao et al. [24] investigated heat and mass processes in bidispersed wick structures of a capillary evaporator. The results indicated that the use of bidispersed wicks significantly improves the thermal performance of capillary evaporators. An experimental study

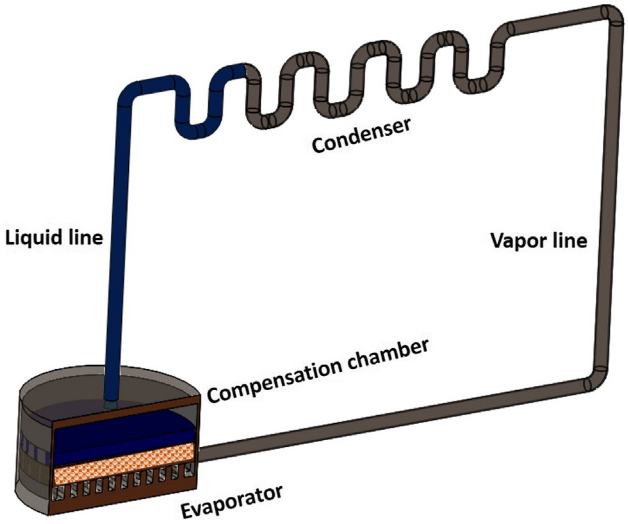

Fig. 1. LHP design.

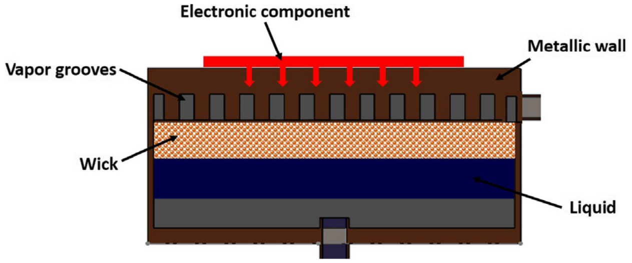

Fig. 2. Capillary evaporator.