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Wire-plate and sintered hybrid heat pipes: Model and experiments

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ABSTRACT

A new hybrid heat pipe technology that associates high liquid pumping capacity of sintered metal powder structures with the low liquid pressure drop of diffusion welded wire-plate grooves is proposed in this work. It consists of covering both internal surfaces of the heat pipe casing plates, in the evaporator region, with layers of sintered metal powder wicks, while the wick of the adiabatic and condenser sections consist of grooved structures, sandwiched between the metallic casing plates and wires welded by diffusion process. Hydrodynamic and thermal models were presented, composed of models developed in this work and others taken from the literature. These models were used to design several hybrid heat pipes that were tested in an experimental setup especially constructed for this purpose. The theoretical models, used for the prediction of the maximum heat transport limit and of the temperature distribution along the heat pipe, compared very well with data, showing their excellence. Also, several parameters that affect the thermal performance of this device were studied, and, among them, the geometry of the sintered porous media and the inventory of the working fluid showed to be the most important ones.

1. Introduction

Electronics is currently one of the areas of faster technology development in the world. New technologies provide smaller, lighter and more efficient equipment. On the other hand, problems due to electronic components overheating are one of the miniaturization trend's drawbacks, demanding for efficient thermal control technologies for compact environment applications. Heat pipe are reliable and simple heat transfer devices and have been considered as a technological solution for the dissipation of concentrated heat, allowing for the temperature control of electronics. However, the cost of heat pipes increase as their size decrease and, therefore, new technologies, which improve the heat pipes' efficiency while reduce their cost, are very welcome.

In the present paper, a new hybrid heat pipe technology, which combines two types of capillary structures: wire-plate diffusion welding (for the adiabatic section and condenser) and sintered metal powder (for the evaporator), is presented. Fig. 1 illustrates the heat pipe proposed.

Models for the determination of the maximum heat transfer capacity and of the temperature distribution of these hybrid heat pipes are presented. They are composed by the hydrodynamic model developed by Paiva et al. [1, 2 and 3] for the wire-plate wick structure and by models for the sintered metal powder wick structure, developed in this work. The predictions resulting from these models were successfully compared with experimental data of several devices developed, constructed and tested in the Heat Pipe Laboratory (Labtucal) at the Federal University of Santa Catarina (UFSC).

2. Literature review

The present heat pipes under study can be classified as mini heat pipes [2]. Two parameters control the performance of wicked heat pipes: capillarity and permeability. The capillarity is responsible for the pumping of the working fluid from the condenser to the evaporator while the permeability allows the liquid to be transported through the media. These effects conflict: small porous wicks have high pumping capacity and low permeability, which, in turn, causes high pressure drops in the fluid. Therefore, a good wick design must provide a good balance between pumping capacity and pressure drops [3]. One should note that the most commonly used wick structures in normal heat pipes are screens, grooves and sintered media [4]. According to [3], sintered porous wicks have high pumping capacity, low thermal resistance and, even partially dry, can work effectively; however,

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Nomenclature

A_{cv}	vapor channel cross section area [m^2]
A_s	wick structure cross section [m^2]
D_w	wire diameter [m]
f	friction factor
h_{lv}	latent heat [kJ/kg]
h_p	copper plate thickness [m]
h_{cv}	vapor channel thickness [m]
h_s	wick thickness [m]
K	permeability [m]
k_p	copper plate thermal conductivity [W/mK]
k	thermal conductivity [W/mK]
L_1	transition region length [m]
L_2	intrinsic thin film length [m]
P	pressure, Pa
P_d	disjoining pressure, Pa
Q	heat transfer rate [W]
q''	heat flux [W/m^2]
R	thermal resistance [°C/W]
r_h	hydraulic radius [m]
r_c	capillary radius [m]
R_w	wire radius [m]
R_g	gas constant [J/mol.K]
s	transversal meniscus coordinate [m]
T	temperature [°C]
T_i	interface temperature [°C]
T_p	wall temperature [°C]
u_l	liquid velocity [m/s]
u_v	vapor velocity [m/s]
V_l	molar volume [m^3/mol]
w	space between wires [m]
w_{cont}	plate/wire contact width [m]
W_t	heat pipe width [m]
W_{vs}	vapor channel width [m]

Greek symbols

α	contact angle [°,rad]
σ	surface tension [N/m]
η	axis normal to the solid liquid interface [−]
ρ_l	liquid density [kg/m^3]
ρ_v	vapor density [kg/m^3]
δ	thin film thickness [m]
μ_v	vapor viscosity [kg/ms]
μ_l	liquid viscosity [kg/ms]
ω	opening angle [°,rad]

Subscripts

a	adiabatic section;
c	condenser;
cap	capillary;
e	evaporator;
ex	experimental;
h	hydraulic;
i	interface;
l	liquid;
m	meniscus;
max	maximum;
ope	operation;
v	vapor;
w	wire;

present low permeability (high pressure drops) and the fabrication costs are relatively high. Screen wicks have a moderate pumping capacity, present low permeability, high effective thermal resistance, their fabrication costs are low, but they have limitations regarding to the device geometry. On the other hand, grooved wicks have high permeability (low pressure drops), but moderate pumping capacity.

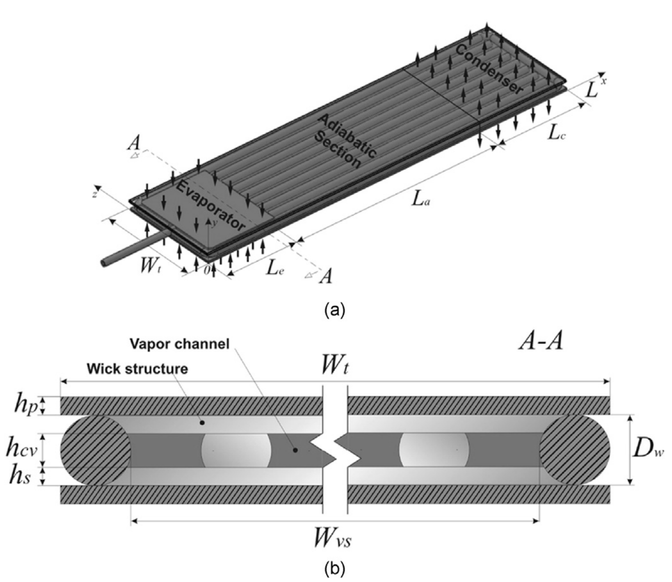

Fig. 1. (a) Hybrid heat pipe schematic representation and (b) evaporator cross section view.

As already mentioned, the hybrid heat pipe technology under study in this work is composed by grooved wicks fabricated from wire-plate diffusion welding, for the condenser and adiabatic sections and sintered powder porous media, for the evaporator section. A literature review specifically concentrated on grooved wicks for the hybrid technology under study was performed by Paiva et al. in Ref. [3] and will not be repeated here. In the present paper, a literature review, for sintered porous media and for hybrid technology heat pipes, is presented.

2.1. Sintered heat pipes

The application of sintered materials as porous wicks in heat pipes is dated from the 1970 decade, aiming satellite applications. Most of the models found in the literature concern the design of the porous material for capillary pumping of loop heat pipes (LHP) or capillary pumped loops (CPLs). The application of porous media in conventional heat pipes is not so usual because of two main reasons: fabrication problems for long structures and lousy performance for lengthy devices (more than 1 m long), due to its large working fluid pressure drops. Nowadays, owing to the reduction of fabrication costs and some modern sintering process, specialized companies have produced sintered heat pipes (usually, not larger them 200 mm) for portable computers.

In 1987, a model was developed to study the influence of the porosity of nickel and copper sintered wicks in the thermal