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Thermal performance of thermosyphons in series connected by thermal plugs

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ABSTRACT

Thermal performance of a novel heat exchanger setup consisting of two thermosyphons connected in series was investigated. An intermediary heat transfer element (IHTE) transported heat from a fictitious component to be cooled to the evaporator of a second thermosyphon. Cylindrical and conical shaped couplings were used as the IHTE condenser geometry. The effects of IHTE filling ratio, inclination angle, aspect ratio and coupling geometries on the system thermal performance were evaluated. While increasing filling ratios promote increasing operation temperatures, decreasing filling ratios facilitate dryout. The critical input heat flux due to dryout decreases with decreasing thermosyphon inclination angle. Higher aspect ratio values imply higher operation temperatures. Both conical and cylindrical IHTE condensers were demonstrated as possible fitting elements for thermal couplings.

1. Introduction

Recent advances in electric-powered equipment have raised the demand for novel thermal control systems in compact, lightweight and high-performance devices. Moreover, the trend of miniaturization increases the need of developing reliable thermal management systems, capable of dissipating high heat transfer rates per area. Conventional cooling mechanisms by forced convection have been widely used to cool down electronic equipment. However, size, periodical maintenance, power consumption and low cooling efficiency are significant penalties when this approach is used. These drawbacks have motivated the introduction of novel cooling systems based on heat pipe technology.

Thermosyphons are wickless gravity-assisted heat pipes vastly used in applications such as solar collectors, thermoelectric power generators and large equipment as industrial heat exchangers [1]. Due to the low overall thermal resistance, these devices allow heat transfer between a heat source and a heat sink even when they are subjected to low temperature differences. Moreover, they do not require power to work. A thermosyphon consists basically of a sealed evacuated container (tube, for instance) where of a suitable amount of working fluid is inserted. It is usually divided into three main parts: evaporator (where heat to be transferred is captured), adiabatic and condenser section (where the transferred heat is released) [2,3].

Several parameters can affect the thermosyphon thermal performance, including: working fluid properties [4], inclination angle [5], geometry [6], vacuum level [2] and filling ratio [7] ($FR = V_w/V_{evap}$, defined as the ratio between working fluid to evaporator volumes, V_w and V_{evap}, respectively [2]). A thermosyphon must be carefully designed, in order to avoid typical operating limits, such as dryout, flooding and boiling. These limits impose restrictions to the maximum heat transfer rate [1,2,8,9]. As stated by Mantelli [3] the two phase phenomena within thermosyphons are gravity driven, and so, they are expected transfer heat more efficiently when compared to other capillary driven devices, such as heat pipes.

The use of two or more thermosyphons in series can be a feasible solution when, due to geometry limitations, the application of conventional thermosyphon or heat pipe technologies would lead to the design of very complex devices. Actually, the fabrication of complex appliances demands the welding of several pieces in different locations, which can favor air infiltration. On the other hand, smaller thermosyphons can be easier to fabricate, enabling proper evacuation, and so, resulting in devices with good thermal performances. However, care should be taken to guarantee minor thermal contact resistances in the connections between the thermosyphons.

Moreover, in this kind of arrangement it is possible to have only one large evaporator which is able to collect heat from several independent sources. Fig. 1 illustrates this concept. The idea is making an analogy with electrical net, plugs and domestic appliances of a house, that the heat exchanger evaporator works as a

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Nomenclature

$\bar{v}_{C1}$	mean air velocity at the air duct, [m/s]
Δt_{ps}	interval of partial start-up, [s]
Δt_{to}	transient operation interval, [s]
$\dot{m}$	mass flow rate, [kg/s]
η	thermal efficiency
$\overline{T}_{cond}$	condenser mean temperture, [°C]
$\overline{T}_{evap}$	evaporator mean temperature, [°C]
ϕ	inclination angle from horizontal axis, [°]
A_{evap}	evaporator area, [m^2]
c_p	specific heat at constant pressure, [J/(kg·K)]
d	diameter, [m]
d_{ad-in}	adiabatic inner diameter, [m]
$d_{evap-out}$	evaporator outer diameter, [m]
l_{ad}	adiabatic lenght, [m]
l_{evap}	evaporator lenght, [m]
p_o	operating pressure, [Pa]
p_{sat}	saturation pressure, [Pa]
q_{C1}	heat transfer rate at the condenser C1, [W]
q_{C2}	heat transfer rate at the condenser C2, [W]
q_{C3}	heat transfer rate at the condenser C3, [W]
q_{in}	input power, [W]
q''_{in}	input heat transfer flux, [W/m^2]
q_{out}	output power, [W]
R	thermal resistance, [°C/W]
T	temperature, [°C]
t	time, [s]
$T_{C1,in}$	inlet temperature at condenser C1, [°C]
$T_{C1,out}$	outlet temperature at condenser C1, [°C]
$T_{C2,in}$	inlet temperature at condenser C2, [°C]
$T_{C2,out}$	outlet temperature at condenser C2, [°C]
$T_{C3,in}$	inlet temperature at condenser C3, [°C]
$T_{C3,out}$	outlet temperature at condenser C3, [°C]
T_o	operation temperature, [°C]
V_{evap}	evaporator volume, [m^3]
V_w	working fluid volume, [m^3]
AR	aspect ratio
FR	filling ratio
HES	heat exchanger system
IHTE	intermediary heat transfer element
LHS	left hand side
RHS	right hand side

"heat sink net", that "energizes" the several "heat sink thermal plugs". Intermediary heat transfer elements (IHTEs) consisting of thermosyphons or heat pipes can work as the "thermal wires" transporting the heat (electrical current) from the source (domestic appliance) to the sink (electrical system net); see Fig. 1. As shown by Tecchio et al. [6], in applications such as avionics cooling the aircraft cabin-external air stream could work as the heat sink. One large thermosyphon can serve as heat exchanger between the aircraft external environment (condenser) and the fuselage internal ambient (evaporator with several thermal plugs installed). Heat from several independent sources could be captured by the evaporators of smaller IHTEs (thermosyphons or heat pipes) and released in the large thermosyphon evaporator through thermal plugs, which are installed in its wall.

In this work, devices able to collect heat from several heat sources (which mimic electronic components to be cooled) and to dissipate to a single heat sink are tested. In one of the experiments, two devices are associated in series: a thermosyphon condenser and a loop thermosyphon evaporator. These two thermosyphons are thermally coupled using thermal plugs with different geometries: cylindrical or conical; Fig. 1 illustrates these couplings. The thermosyphon which connects the heat source to evaporator of the loop thermosyphon is referred as intermediate heat transfer elements (IHTEs). The loop thermosyphon which receives heat from the IHTEs and releases it to the heat sink, is referred as heat exchanger system (HES).

In another test one calorimeter, in which wall several thermal plugs are installed, was used to simulate a multiple plug loop thermosyphon evaporator. Tests are performed to evaluate the effects on IHTEs performance of: the thermosyphon design, the shape of the coupling plug between thermosyphons (conical or cylindrical), the filling ratio, the operating inclination angle and the input power.

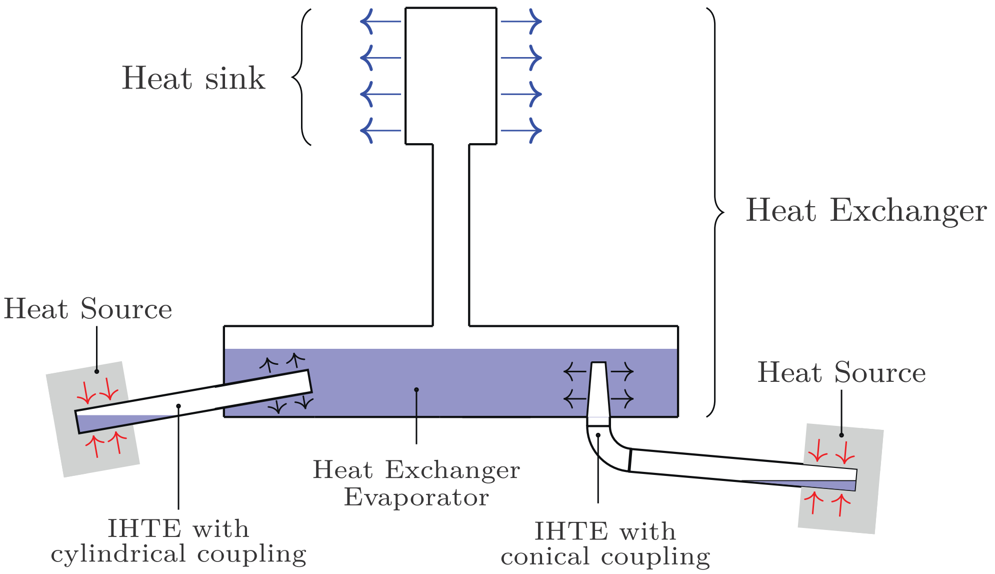

Fig. 1. Intermediary heat transfer elements (IHTEs) connected in series with a common heat exchanger. Heat is transported from independent heat sources to the heat sink through conical and cylindrical couplings.