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Space structures with embedded Flat Plate Pulsating Heat Pipe built by Additive Manufacturing technology: development, test and performance analysis.

Federico Belfi*[1], Filomena Iorizzo[1], Claudio Galbiati[1], Fabio Lepore[1]

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Abstract

In this paper is described the development and the experimental study of a Flat Plate Pulsating Heat Pipe (FPPHP) built by means of metal additive manufacturing. In the recent years, small/medium aerospace companies have gained interest in the development of small satellites. The small dimensions, coupled with the need of high power devices for science and communications, increase the interest in thermally functional structures. The space business is characterized by a very small production lot, and custom designs from project to project. The Additive Manufacturing (AM) exactly fits these needs and, in the past years, the use of this technology in aerospace projects has grown significantly. This paper, after a brief review of the Pulsating Heat Pipe (PHP), focuses on the development and testing of a panel with an embedded closed loop Flat Plate Pulsating Heat Pipe built by means of metal AM technique. The article presents a trade-off analysis between the metal AM technologies available on the market; by means of the trade-off analysis a design strategy is proposed by the authors. A comparison between available FPPHP results in literature and the 3D printed structure will show the differences between the common subtractive technology and the innovative AM technique.

Keywords: Additive manufacturing; Pulsating heat pipe; Flat plate pulsating heat pipe; Direct metal laser melting

1. INTRODUCTION

In the last decades, the role of two-phase passive heat transfer devices in space thermal control systems has gained more and more relevancy, mainly because of their lightweight, high performances and reliability. The small dimensions, coupled with the need of high power devices for science and communications, increased the interest for thermally functional structures applied to small satellite such as CubeSats. The development of structures with embedded heat transfer systems poses a number of challenges; for example the manufacturing, and the proper sealing of the devices.

Currently the market offers very expensive technology suitable for producing parts with internal features such as tubing, empty volumes, porous sections or reticular structures. Thanks to this particular capability, these new manufacturing techniques facilitate the integration of Passive Two Phase Heat and Mass Transfer devices in structures.

The devices that are most suitable for integration into a surface are Heat Pipes (HP) or Pulsating Heat Pipes (PHP). The latter were engineered by *Akachi* [1]-[2] in the early '90s. Recently the literature regarding the PHP presents the results of several test campaigns showing functional prototypes working both on the ground and in microgravity conditions. A particular kind of PHP is represented by the Flat Plate Pulsating Heat Pipes (FPPHP), whose channels are

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Titanium Water Heat Pipe Radiators for Space Fission System Thermal Management

Kuan-Lin Lee[1], Calin Tarau[2] and William G. Anderson[1*]

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Abstract

For future space transportation and surface power applications, NASA Glenn Research Center (GRC) is currently investigating a small fission system (Kilopower system), which has operable range of 1 to 10kW$_e$. The Kilopower system uses alkali metal heat pipes to transport heat from a nuclear reactor to the Stirling convertors to produce electricity and titanium water heat pipes to remove the waste heat from the convertors to the radiators. In a Small Business Innovation Research (SBIR) program, Advanced Cooling Technologies, Inc. (ACT) developed the titanium/water heat pipes for Kilopower waste heat rejection. These heat pipes are featured with bi-porous screen in the evaporator, and a screen-groove hybrid wick for the rest of the pipe, that allow the Kilopower system to survive and function under following four conditions: (1) space operation with zero gravity (2) ground testing with slight adverse gravity orientation (3) surface operation with gravity-aided orientation (4) and launch, with the against-gravity orientation and below freezing temperature. This paper presents the development of the titanium water heat pipes with radiator for Kilopower waste heat rejection, including the hardware design, heat pipe radiator assembly and thermal performance experimental validation.

Keywords: Bi-porous screen; Screen-groove hybrid wick; Titanium water heat pipe; Kilopower system

1. INTRODUCTION

For future space transportation and surface power applications, NASA Glenn Research Center (GRC) is leading the efforts to develop a small-scale nuclear fission power system (i.e. Kilopower system). This system is designed to provide 1 to 10 kW of electricity through Stirling conversion [1]. The conceptual design and the thermal management architecture of the Kilopower system can be seen in Fig. 1. Thermal energy of the nuclear reactor core is transferred to the Stirling convertor's hot end through a series of sodium heat pipes. After the energy conversion, the waste heat from the convertor's cold end is transferred to the radiator panels through multiple titanium water heat pipes and ultimately rejected into the space environment.

3. Planetary surface operation with gravity-aided orientation, which is the simplest scenario.
4. Startup after being exposed to the launch condition. In such scenarios, heat pipes are orientated in an extreme against gravity and the sink temperature is lower than the freezing point of water.

This paper presents the development of titanium water heat pipes with radiator for Kilopower system waste heat rejection, including the hardware design, prototype development, deliverable heat pipes assembly and thermal performance experimental validation in a relevant environment.

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A theoretical investigation of a controlled hybrid mechanical/capillary pumped loop

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[3]*Institut PPRIME (UPR CNRS 3346), ISAE-ENSMA, 1 av. Clément Ader-BP40109, 86961 Futuroscope-Chasseneuil, France*
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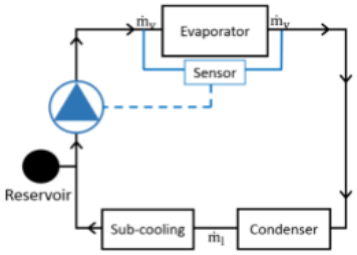
Abstract

A series hybrid mechanical/CPL system is a way to improve the performance characteristics over a plain CPL system, as demonstrated by Schweickart et al [1]. However, few hybrid loops actually operate because the control of the system remains difficult. An investigation of a controlled hybrid CPL is proposed based on a dynamic model, consisting of the coupling of a CPL model and a mechanical pump whose speed is controlled by a PID. We first theoretically determined the controller parameters versus the CPL characteristics in order to optimize the command for a given CPL. In a second part, some simulations of two different architectures were performed and analyzed. These results have confirmed that the hybrid system is very attractive to greatly improve the CPL performance.

Keywords: Hybrid Capillary Pumped Loop; Mechanical pumping; Non-linear modelling and control;

1. INTRODUCTION

Two-phase capillary pumped loops such as CPL and LHP are passive and highly efficient systems for the cooling of a large range of electronic components. The maximum heat load operation is given by the maximum pressure drop across the wick (the capillary limit) or when vaporization deeply develops in the capillary structure (thermal limit). Since the thermal limit occurs at very high heat load, failures in operating conditions are largely due to the capillary limit. This becomes more and more critical for terrestrial transportation applications in which two-phase loops experience acceleration and dynamic changes of position in the gravity field and in which demanding heat load occur. As explain by Schweickart *et al* [1], a way of overcoming this limitation is to introduce a mechanical pump which hybrid system allows to examine the use of some new working fluids with lower Global Warming Potential and toxicity even if the surface tension is low, which means a lower maximum capillary pressure. It can also permit to dimension the capillary evaporator for the loop nominal functioning point, and not for rare phenomenon.



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Theoretical and experimental analyses of the thermal resistance of a loop thermosyphon for passive solar heating of buildings

Pedro Bellani[1*], Fernando Milanez[2], Marcia Mantelli[1], Sauro Filippeschi[3], Mauro Mameli[3], Fabio Fantozzi[3]

[1]*Department of Mechanical Engineering, Federal University of Santa Catarina, Florianopolis 88040-900, Brazil*
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[3]*Department of Energy, Systems, Land and Construction Engineering, University of Pisa, Italy*

Abstract

This study presents experimental and theoretical analyses of the thermal performance of a two-phase copper-R141b loop-thermosyphon, which was developed for solar heating of buildings. A prototype of the so-called wall-thermosyphon was built and tested at the Heat Pipe Laboratory of the Federal University of Santa Catarina (Labtucal-UFSC). During the tests, three parameters were varied: purge method, power input levels and inside wall evaporator roughness. The results show that recent boiling heat transfer coefficient literature correlations is in good agreement with the experimental data for the thermal resistance of the device under study. However, the condensation thermal resistance calculated with the literature correlations do not represent the same trend found in the experiments. The total thermal resistance of the wall-thermosyphon varies between 0.22 and 0.011 °C/W.

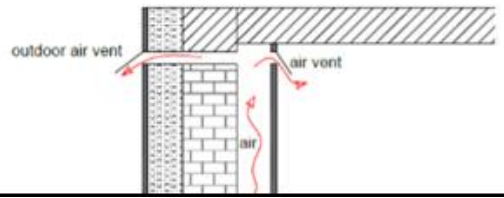
Keywords: Two-phase loop-thermosyphon; thermal resistance; Wall-thermosyphon.

1. INTRODUCTION

Energy savings in buildings, allied to the necessity of heating, need to be improved in many countries, especially in those with cold weather. Many resources can be used to increase the global efficiency of the heating system in those buildings. Among them, some are based on passive methods, e.g. the Trombe wall, solar collectors, green walls, wall-thermosyphons, heat pipes, etc. [1]-[7].

The use of heat pipes for passive solar heating began in 1979 with a study of Corliss. In this study, a detailed analysis about the use of heat pipes as a passive heating system was made, were different configurations of heat pipes, working fluids and case materials as well as collector configurations were tested [6]. Although the use of heat pipes as passive

This device provides a thermal bridge between the exterior and the interior of the building, allowing the heat enter the house. The great advantage of using a two-phase loop-thermosyphon instead of other methods for heating is that a thermosyphon act as a thermal diode, i.e., the heat flux is unidirectional, from the outside irradiated wall to the house interior.



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Thermo-fluid dynamics in a wettability-enhanced evaporator based on microscale infrared/visible observations

Kimihide Odagiri[1*], Chiemi Oka[2], Chieko Kondou[3] and Hosei Nagano[2]

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[2]*Department of Mechanical System Engineering, Nagoya University, Furo, Chikusa, Nagoya, Aichi, 464-8603, Japan*
[3]*Graduate School of Engineering, Nagasaki University, 1-14 Bunkyomachi, Nagasaki, Nagasaki 852-8521, Japan*

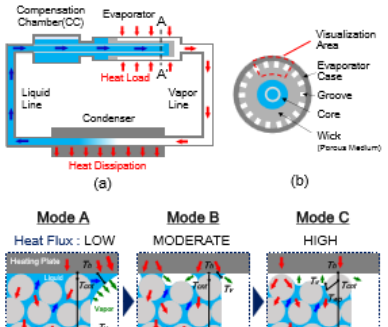
Abstract

In this paper, an effect of wettability improvement on a thermo-fluid behavior in an evaporator of a loop heat pipe (LHP) is studied experimentally and theoretically. Based on the numerical model developed in our previous study, it is known that an improvement of wettability between the evaporator case and working fluid enhances the heat transfer performance of the evaporator. In order to verify this trend, the experiments are conducted. In the experiment part, three kinds of heating plate, that have the different morphology of the surface: normal flat plate, a sandblasting plate and a short-pulse laser irradiation plate are used. The contact angles between ethanol and them are 8.2 ± 1.3 °, 0 °, and 0 ° respectively. The porous sample is made of stainless steel whose pore radius is 4.5 μm. The measurement of the heat transfer performance and liquid-vapor interface behavior is conducted with a microscopic infrared camera and a microscope. As results, the sandblasting plate and the short-pulse laser irradiation plate show higher heat transfer performance than the normal flat plate. In addition, it is found that there are different liquid-vapor interface behaviors between them. In the modeling part, the predicted heat transfer coefficient is calculated for each case. The calculation results are in good agreement with the experimental results. The mechanisms of the enhancement of heat transfer performance are discussed. Based on the experimental and numerical study, this paper represents a new approach for enhancement of heat transfer coefficient of a capillary evaporator.

Keywords: Loop heat pipe; Evaporator; Wettability improvement; Thermo-fluid behavior

1. INTRODUCTION

A heat transport device that can remove the dissipated heat with a high flux is required due to performance improvement and downsizing of an electronic device. A loop heat pipe (LHP) is a promising heat transport device which satisfies this requirement. To date, LHP is applied to a thermal control device in space [1] and terrestrial systems [2, 3]. The heat transfer performance of an LHP strongly depends on heat and mass transfer within a capillary evaporator (Fig. 1(a), (b)). Therefore, the



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Copper-Water and Hybrid Alumi

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Joint 19th IHPC and 13th

A theoretical inve

Marie Levêque[12*], S

[3]Institut PPRIME (U

Abstract

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Keywords: Hybrid Capilla

1. INTRODUCTIO

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Thermo-fluid dynamics in a wettability-enhanced evaporator based on microscale infrared/visible observations

Kimihide Odagiri[1*], Chiemi Oka[2], Chieko Kondou[3] and Hosei Nagano[2]

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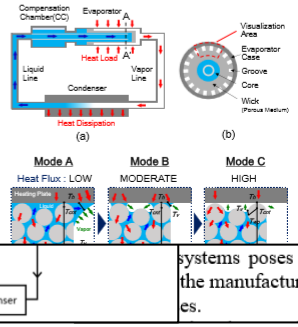

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Theoretical and experimental analyses of the thermal resistance of a loop thermosyphon for passive solar heating of buildings

, Marcia Mantelli[1], Sauro Filippeschi[3], Mauro Mameli[3], Fabio Fantozzi[3]

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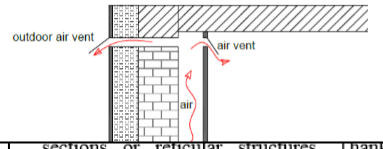

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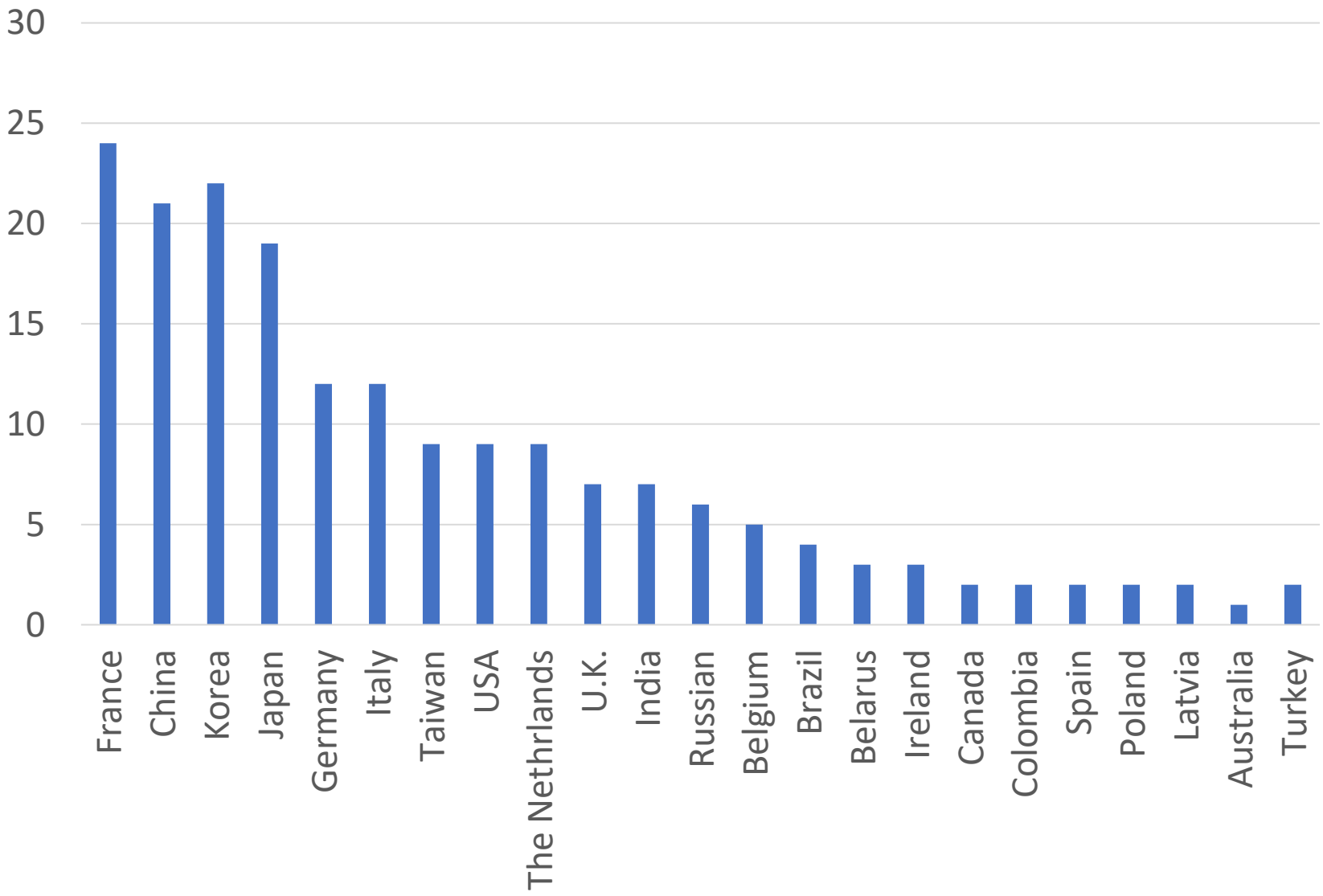
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