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# POLYMER MATERIALS IN PULSATING HEAT PIPES: CHALLENGES AND OPPORTUNITIES

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## 1. ABSTRACT

This work discusses the use of polymer materials in the fabrication of two-phase passive thermal management systems such as pulsating heat pipes, with an analysis of their limitations and technical challenges. Although heat transfer systems are usually built with metals due to their excellent thermal properties, there is an increasing interest in replacing metallic materials with polymers and composites that can offer cost-effectiveness, light weight and high mechanical flexibility. However, polymer materials suffer from poor thermal conductivity, poor wettability, viscoelasticity, selective permeability to moisture and incondensable gases, as well as ageing.

## 2. INTRODUCTION

The increasing technology challenges posed by volumetric density scaling in integrated, functional, or packaged systems [1] drive the interest in high-performance, compact heat transfer devices that can efficiently manage large heat fluxes. In this context, passive two-phase thermal management systems such as pulsating heat pipes (PHPs) represent a very promising, simple and cost effective technology compared to other heat transport devices [2]. Similar to other thermal management systems, passive heat transfer devices are usually built with metallic materials, often with high thermal conductivity such as copper. However, recent advances in technology such as foldable and flexible electronic components and devices, soft robotics, as well as spacecraft components, often have additional requirements of mechanical flexibility, low-cost, and/or low weight, which sometimes are difficult to achieve using metallic materials. Thus, there is a growing interest in replacing metals in full or in part with polymer and/or composite materials, which offer cost-effectiveness, light weight, high mechanical flexibility, resistance to corrosion and ease of manufacturing, at the price of a generally much lower thermal conductivity. In the present work, the main limitations and technical challenges of polymer and composite materials relative to their use in thermal management systems are discussed, based on the results of a comprehensive experimental study of flat-plate polypropylene pulsating heat pipes.

## 3. METHDOLOGY

Several PHP prototypes with different number of turns were produced by selective transmission laser welding [3,4]. The thermal performance was fully characterised in different operating conditions for both straight and bent

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conformations by measuring the equivalent thermal resistance, $R = (T_E - T_C)/\dot{Q}$, where $T_E$ and $T_C$ are the average temperatures of the evaporator and the condenser, respectively, measured at pseudo-steady-state operation, and $\dot{Q}$ is the heat input at the evaporator [5,6]. Flow visualisation in the adiabatic region of the PHP by high-speed imaging enabled to characterise different flow patterns [7]. The effectiveness of aluminium and aluminium oxide ($Al_2O_3$) coatings in mitigating the selective permeability of polypropylene to moisture and incondensable gases was also investigated [8].

## 4. RESULTS

The equivalent thermal resistance of the polymeric PHP is four to five times smaller than the resistance of the PHP envelope without heat transfer fluid, and is only weakly dependent on the PHP conformation [3,5,6]. The viscoelastic behaviour of the polymer material was shown to affect both the hydraulic diameter and the operating pressure of the PHP [3], while the material wettability should be taken into account at the design stage to determine the appropriate value of the hydraulic diameter [5]. Metallic coatings (e.g., aluminium) provide an effective barrier to moisture and incondensable gases permeation.

## 5. CONCLUSIONS

Polymer materials are not ideal for heat transfer applications due to low conductivity, thermal inertia, low wettability, viscoelasticity, and permeability; polymer-metal composites seem to be a more viable solution. A cost-effective solution to mitigate moisture and gas permeability is provided by metallized polymer films used for food packaging. Consensus on a dynamic criterion to determine the hydraulic diameter of the PHP channel as opposed to the conventional static criterion based on the Bond number remains an open issue.

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