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MODELLING AND OPTIMISATION OF HIGH TEMPERATURES HEAT PIPE RADIATORS FOR NUCLEAR ELECTRICAL PROPULSION (NEP) APPLICATIONS

Abstract

Nuclear propulsion is increasingly recognised as a key technology for humanity's aspirations to become a multiplanetary species. Based on an EPFL Master's thesis carried out at ESA under the supervision of Valère Girardin and Volker Gass, this paper provides some insights into the choice of working fluids for NEP radiators. In fact, the existing literature shows a lack of detailed information on radiators for Nuclear Electric Propulsion (NEP). There is little knowledge on the optimal design and fluid choices required for NEP applications for radiators operating at high temperatures. To address this gap, the thesis presents a physics-based model that simulates the steady-state operation of heat pipe radiators using a two-phase mechanical pump loop. The model uses a macro approach to simulate heat pipes. It calculates four heat transfer limits of heat pipes: capillary, boiling, entrainment and sonic, and selects the lowest of the four as the maximum heat transfer. The thermal conductance is also calculated to verify the physical reality of the design. The model is verified by comparing the results of heat pipe experiments with those predicted by the model. In addition, the mass estimate given by the model is compared with the open source NASA COMPASS case.

The model simulates two types of heat pipes using different wicks: axial grooves and sintered mesh screens. Subsequently, this model is utilized systematically to identify the most efficient combination of operating fluids for these radiators and which heat pipe wick is the most promising. Six different fluids are analyzed: Water, Sodium, Potassium, NaK, Cesium, and Lithium with their respective compatible solids. The initial findings of this optimization are further scrutinized in the third phase of the study, where the impact of manufacturing constraints on the proposed radiator designs is assessed. Results show that sodium and lithium are the most interesting heat pipe working fluids.

However, lithium needs a higher temperature, which complicates the material selection and manufacturing and increases the cost. Therefore, the radiators equipped with sodium heat pipes, with an axial grooved wick, in Stainless Steel, manufactured by extrusion, seem the most promising in cost and weight. In addition, the 3D-printing technology is of limited interest to manufacture axial grooved heat pipes but seems the only viable option to manufacture in large quantities sintered wick heat pipes.