Modelling and Optimisation of Metal Foam Integrated Heat Sinks for Power Electronics Cooling

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Jury :

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Abstract: Several decades ago, power electronics (PE) emerged as an important discipline in the world of electrical engineering. Thanks to regular technological advancements, namely the use of "wide band gap" materials for semiconductors, PE devices have become more compact and efficient, but this has unfortunately resulted in a less efficient thermal management. Thus, as a collaborated effort between the G2Elab, LEGI and SIMAP laboratories of Univ. Grenoble Alpes, this work has studied the use of metal foam as a novel heat sink used in a forced-convection cooling system that can be integrated into PE modules for superior cooling. Metal foams are lightweight, have low densities, high specific surface areas, an open-celled structure and good thermal properties. They are typically categorised by their porosity (ε), their pore density (PPI, pores per inch) and by the diameter of the solid fibres ( ). The advantages to heat transfer arise from the possibility of an increased specific surface area over other heat sinks, such as microchannels, and from the tortuous structure of metal foam that generates flow turbulence and improves convective transfers within the coolant. Thermal performances of metal foam based heat sinks were modelled by developing an analytical model that considered them as a network of resistances in series. This was achieved by simplifying the LTNE equations that govern energy transfer through the solid and fluid phases. The model was initially compared with numerical simulations and experimental results from the scientific literature, where it performed well. As an additional level of validation, a thermo-hydraulic test bench, as well as a test section, were designed and assembled in-house. After a validation of the experimental means on a microchannel heat sink, the characterization of thermo-hydraulic performances of a novel heat sink integrating metal foams was carried out. Analytical and experimental results agreed well with each other, with an average deviation of the thermal resistance of less than 10%. The model was then used to optimise the foams physical properties in order to produce a heat sink that maximises thermal performances whilst minimising the required hydraulic power. The results show that for a pressure drop of 50kPa, the thermal resistance of a metal foam heat sink is 0.127 K/W. Metal foams are thus a viable heat sink material and the model proposed in this work can be used as a quick and inexpensive means of optimisation.