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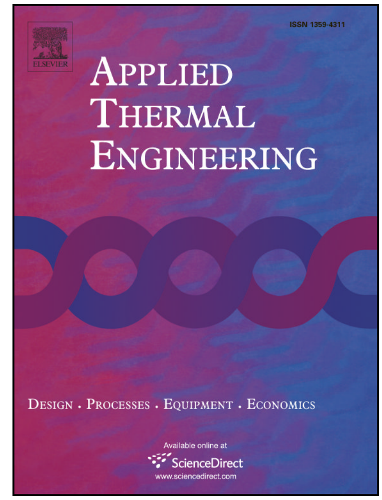

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Pool Boiling of Resin-Impregnated Motor Windings Geometry

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Abstract— **More effective cooling strategies enable lighter and more power dense electrical machines to be developed. Pool boiling using the fluorocarbon Novec 7000 was generated on copper surfaces, both flat and modified to reflect the geometry of resin-impregnated windings of an electrical machine. Four experimental surfaces were exposed to the fluorocarbon in the nucleate pool boiling regime. The motor windings geometry (MWG) surfaces displayed an improved heat transfer coefficient compared to the flat surfaces due to a longer contact line between the heated surface and the vapour during bubble development. An MWG surface was also tested at orientations from 0° (horizontally-upward) to 90°, which did not significantly affect heat transfer; while the 128° orientation gave higher heat transfer coefficients at low heat fluxes, and lower heat transfer coefficients at high heat fluxes. The 180° orientation produced an immediate boiling crisis. The flat plate experimental data was evaluated and compared with the predictions of the Borishanskii and Mostinski, Gorenflo-Kenning, Kruzhilin, Kutateladze, Labuntsov, Leiner, Rohsenow, and Stephan-Abdelsalam nucleate boiling correlations, with the Rohsenow and Labuntsov models showing best agreement with data.**

Keywords—**nucleate boiling; immersion cooling; electrical motors; orientation**

1. INTRODUCTION

The power densities of modern electrical and electronic machines are increasing as technology becomes more compact and requirements for higher power densities emerge. These trends result in the need for heat removal technologies that can maintain temperatures within acceptable operating conditions to ensure reliable operation. The heat flux density of a modern microchip is several orders-of-magnitude larger than that of an equivalent wired circuit. In most scenarios, the heat produced by a component must be dissipated to another location, which can be complicated by restrictive geometries [1–3].

Nucleate pool boiling provides amongst the highest heat transfer coefficients of any cooling mechanism. Accordingly, alongside the significant body of nucleate boiling literature on cooling individual electronic components [4], multi-chip printed circuit boards (PCBs) [5], and computing hardware in server rooms [6]; nucleate pool boiling is also relevant to nuclear reactor cooling [7], hot- pressing of paper [8], and even the manufacture of dairy confectionary [9]. Understanding and predicting nucleate boiling heat transfer characteristics is therefore important across a range of industrial sectors.

The present research investigates the use of nucleate boiling heat transfer to cool electrical motors, which consist of a magnetic rotor outside of which is a stator, consisting of windings. These windings are made from a material with good properties of electrical and thermal conduction, typically copper or steel, with resin impregnated through the windings to provide electrical insulation between each windings turn, mechanical fastening, and a thermal conduction path to the winding surface. In a high power density electrical motor, forced convection is typically used to cool the outer surface of windings [10]. The effective cooling of windings is believed to contribute significantly to the reliability of the machine, where increased winding temperature has a significant adverse effect on the longevity of an electrical motor. Montsinger's law suggests that a 10°C increase in winding temperature causes a halving of the lifespan of the stator winding insulation [11], which in-turn may cause a short-circuit and machine failure [12]. Therefore, more effective cooling of windings may result in longer lifespan for a specified power, or increased power output for a given lifespan, leading to a more compact machine; all of which provide key competitive advantages to the manufacturer. A more compact machine is especially important where power density is critical, such as in aircraft applications.

When implementing boiling as a thermal management strategy in applications where the coolant makes contact with an electrically-charged surface, a dielectric is required. The materials company 3M produce a range of dielectric fluorocarbon based coolants with varying engineering properties, many of which offer low values on the global warming potential (GWP) scale. The GWP scale rates fluids on the quantity of heat a particular gas traps in the atmosphere, relative to CO_2. Also, 3M fluorocarbons have been the subject of widespread research and use in the electronics industry and hence are the fluids investigated in this paper for potential cooling of motor windings.

This paper investigated nucleate pool boiling on flat and motor windings geometry (MWG) surfaces of varying sizes and at different orientations. Section 2 outlines the development of nucleate boiling theory and discusses competing heat transfer correlations; work on

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