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USING CFD TO IMPROVE THE HEAT TRANSFER PERFORMANCE OF AN OIL SPRAY COOLING SYSTEM FOR AN ELECTRIC MOTOR BY VARYING THE INCLINATION ANGLE

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1. ABSTRACT

This paper develops a validated Computational Fluid Dynamics (CFD) model for the oil spray cooling of an electric motor with hairpin windings, and investigates the effect of nozzle inclination angle on heat transfer performance. The results show that the optimum inclination angle for nozzles in the bottom half of the motor housing is 22.5°, and this can be attributed to a higher local Reynolds number on the lower part of the windings. The results also show that the optimum inclination angle could depend on the position of the nozzle with respect to the circumference of the motor housing.

2. INTRODUCTION

The European Green Deal Road Map has put pressure on the automotive industry by stating that new vehicles can have a maximum of 95 g of CO2 emissions per km, and this has led to significant development of Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) [1]. Integral to the powertrain of these vehicles is the electric motor which requires sufficient cooling to avoid demagnetisation and a reduced lifespan for the motor. Existing cooling systems for electric motors are bulky, inefficient and don't effectively target the high temperature endwindings. Therefore, direct cooling to these windings has to be employed and spray cooling is one approach, using a nozzle to atomise the coolant and provide better wall film coverage, and more effective heat transfer for a reduced working volume. Oil spray cooling has been used in the new Toyota Prius with results indicating a cooling efficiency improvement of 58% compared to the previous design [2]. Optimising the spray nozzle arrangement to maximise the heat transfer performance of the coolant is therefore critical to provide the best cooling efficiency. This paper aims to improve the heat transfer performance of an existing oil spray cooling system by developing a validated CFD model and varying the nozzle inclination angle, γ.

3. METHDOLOGY

The CFD model developed is based on the experimental setup from Liu et al. [3] where oil is used as a coolant and is pumped through an axial nozzle forming a spray which then directly cools the endwindings. Nozzles are numbered using a clock system shown in **Fig 1 (A).** A half bagel simplification was made for the geometry of the endwindings which can be seen in **Fig 1 (B**) and **(C)**, and this simplification is consistent with [4]. In **Fig 1 (B)** the upper winding is defined to be the curved part of the winding, and the lower winding is the straight edged part. The inclination angle of the nozzle, γ, was varied to improve the spray coverage of the lower windings for nozzles 5 and 6. The effect of nozzle positioning around the housing was also tested by evaluating the performance of $\gamma = 45°$ at the 3 different nozzle positions. The solver used was pressure based and transient, the models used were DPM, Energy and k-epsilon realizable, the phases are air (continuous) and oil (discrete). The timestep chosen was 1e-4 s, the coolant inlet temperature is 293 K, and the windings temperature is a constant boundary condition of 360 K.

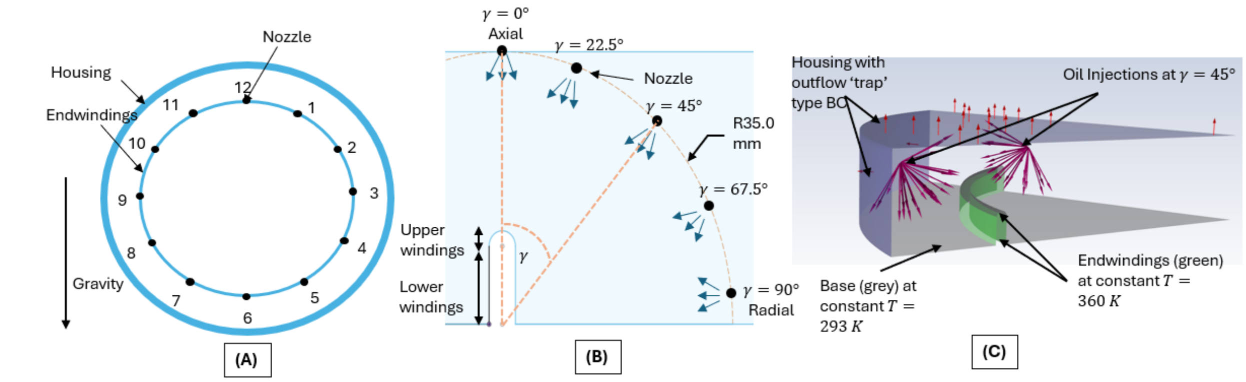


Figure 1 – (A) Top view of the clock nozzle numbering system, (B) Cross section view of the windings showing how inclination angle is defined, (C) Model geometry and BCs for $\boldsymbol{\gamma = 45°}$

4. RESULTS

The model validation is shown in **Fig 2** which shows a good match between experimental and simulation results, and a maximum percentage error of 16% at a flow rate of 3.5 l/min, which is comparable with similar simulations run by Zhao et al [4]. The reason for the higher error at high flow rate could be due to the near wall turbulence modelling underestimating the thickness of the boundary layer. Therefore, the inclination angle experiments were run at a lower flow rate of 2.28 l/min. It can be seen from **Fig 3 (A)** that the HTC for endwindings below nozzle 6 are higher than the HTC under nozzle 5, and this could be because of the wall-film dripping effect. From **Fig 3 (C)**, $\gamma = 22.5°$ had the best heat transfer performance, improving the average HTC by 8.67% compared to the original design. This can be attributed to an improved local velocity and an improved the local Reynolds number and consequently the calculated HTC. It can be seen from **Fig 3 (D)** that $\gamma = 45°$ is most effective at the for nozzles 2 and 3, as the average HTC is 15.3% higher than on nozzles 5 and 6. This could be because the gravity effect on the wall film is dripping along the winding surface at this position, and this is causing an improved cooling effect. The results indicate that the optimal inclination angle could be varied for each nozzle to enhance the wall film dripping effect.

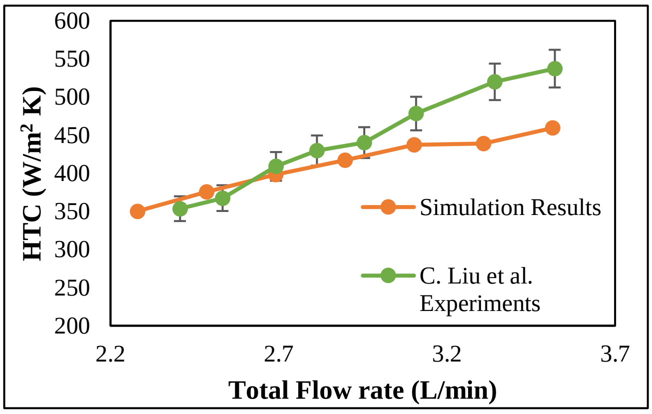
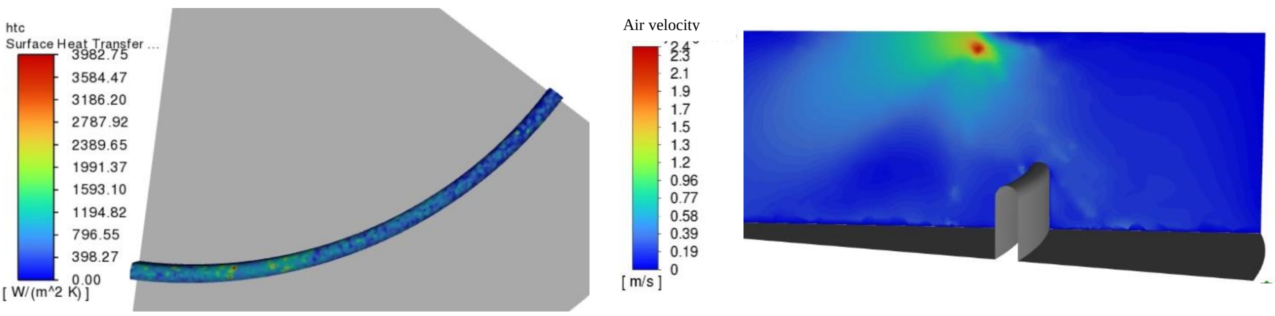
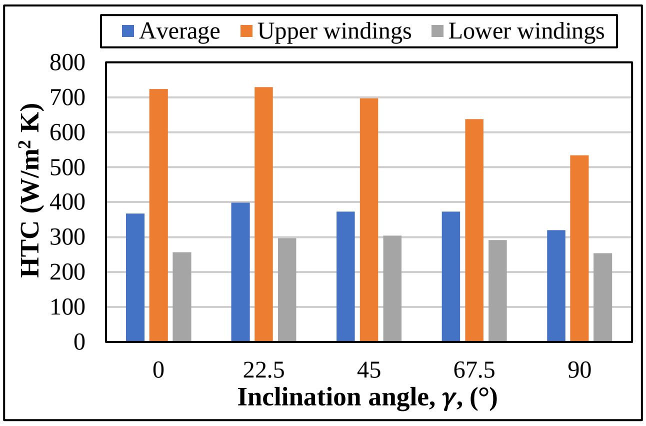


Figure 2 – Nozzle 6 axial spray simulation validation compared to results from [5]

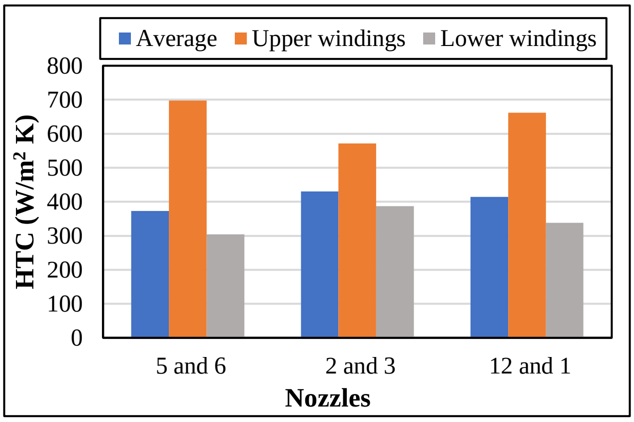


(A)

(B)



(C)



(D)

Figure 3 – (A) Surface HTC plotted on the endwindings, (B) Air velocity contour through nozzle 6, (C) HTCs for varying γ on nozzles 5 and 6, (D) HTCs for $\gamma = 45°$ at different nozzle positions

CONCLUSIONS

In this paper, a CFD model for the oil spray cooling of the endwindings of an electric motor was developed and validated against experimental values. The inclination angle was varied for the nozzles, and it was found that the best heat transfer performance for nozzles 5 and 6 was at an inclination angle of 22.5°. This is because of an improved local Reynolds number on the lower part of the windings. It was also found that the position of the nozzle with respect to the circumference of the enclosure has an impact on heat transfer performance due to the gravity effect on the wall film. This improvement in heat transfer performance at this low flow rate could result in reduced pumping pressures required for the oil spray cooling system and improve the cooling efficiency. Further work would involve testing different inclination angles at different positions to find the optimal nozzle arrangement for this geometry.

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