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Isothermal analysis of Nanofluid Flow inside HyperVapotrons using Particle Image Velocimetry

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INTRODUCTION: The focus of this work is to understand if and how the geometry of heat exchangers might be potentially affecting the nanofluid coolant flow boundary conditions established and how this might be hence further affecting their thermal characteristics.

This work contains a cold isothermal high spatial resolution particle image velocimetry (PIV) study of the instantaneous and mean flow structures of a nanofluid flowing inside two HyperVapotron (HV) models and compares them to those present when using water [1]. HVs are two phase High Heat Flux exchangers popular with the nuclear fusion industry. The properties of nanofluids alone might have the potential of improving the overall HV device performance. However, the operation of the device is strongly linked to the flow field of the coolant. The study attempts to quantify possible changes in the flow and hence examines whether the replacement of the traditional coolant with a nanofluid in a HV might disrupt the designed flow field of the device during operation in single phase heat transfer mode.

METHODS: Two variations of the HV models from the Joint European Torus (JET) and Mega Amp Spherical Tokamak (MAST) experiments were used. The basic difference between the two models is the free stream channel height which is expected to affect the size of the momentum boundary layers formed inside the devices when operated with the same free stream velocities (this is a boundary condition). The models are shortened to include five grooves and are manufactured from high optical quality transparent Perspex. The choice of the number of grooves used was based at this stage on a qualitative computational fluid dynamics (CFD) investigation performed on the models at the design process that reproduced the irregular signature vortices expected in HV for the mean flow. A closed circuit isothermal coolant flow was established through these models.

A laser-based Particle Image Velocimetry (PIV) technique [2] was used to measure with high spatial resolution (30µm) the flow velocity field inside the models. An Nd-Yag pulsed laser (a Litron Nano T PIV) was used at a beam wavelength of 532nm [1]. The pulse width of the laser was 7-9ns, while the delay between the two pulses was adjusted from 5-40ms, according to the expected velocities. A non-intensified LaVision Imager Intense CCD camera with a resolution of 1376x1040 pixels was used to capture the images. The camera was coupled to a Nikkor 50mm F/2.8 lens with manual focus. A band pass optical filter with 10nm bandwidth around the 532nm wavelength was used to reduce optical noise on the recordings. The beam was steered and manipulated into an almost 2D laser sheet before entering and illuminating tracing particles dispersed in the flow. Cross correlation algorithms and an image recognition vortex detection algorithms were used to process the tracked flow fields. A total of 1000 image



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pairs were collected which led to maximum statistical uncertainties of the order of $\pm 3.8\%$ and $\pm 3.5\%$ for the mean of JET and MAST respectively within a 95% confidence level. The maximum uncertainty of the measurements considering the PIV and flow meter uncertainty is hence estimated to be around 6% of the given quantities. The uncertainty of the image recognition analysis for the characterisation of the vortex location was below $\pm 500\mu\text{m}$.

Water based 50nm diameter Al_2O_3 nanoparticles were prepared using the two step preparation method from a dry powder. The final nanofluid used had a volumetric particle loading of 0.0001%.

RESULTS AND CONCLUSIONS: It is apparent from this work that small nanoparticle volumetric concentration nanofluids can significantly modify the hydrodynamic flow fields inside HVs. The changes were geometry dependent and cannot be explained using classical relationships (e.g. Einstein viscosity equation). The changes can be traced down to the momentum boundary layers of the flow. It is speculated that shear thinning occurs inside the momentum boundary layers due to dynamic nanoparticle migration effects when Nanofluids are used [2] . The flow changes are expected in their turn to be affecting significantly the temperature boundary layers in the presence of a heat flux either favourably or adversely.

It is clear from this work that more studies of the hydrodynamic effects of nanofluids inside given geometries is required – this is a novel finding with severe implications when nanofluids are used as a retrofitted solution to already existing heat exchangers. Caution also must be followed upon using shear inducing viscometers as these are expected to suffer from particle migration effects as well. An overall rethinking of the viscosity definition for nanofluids should be carried out to better describe and model them analytically.

The effects of heat flux on the performance of devices operated with nanofluids is under way that will be able to provide more answers regarding the complex physical phenomena observed.

This abstract is part of a larger study on HV devices published by the authors [3]–[7] with ongoing investigations under the EUROfusion fellowship of the lead author.

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