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Flow characteristics in HyperVapotron elements operating with Nanofluids

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Introduction

HyperVapotrons are highly robust and efficient heat exchangers able to transfer high heat fluxes of the order of 10-20MW/m^2. They employ the Vapotron effect, a complex two phase heat transfer mechanism, which is strongly linked to the hydrodynamic structures present in the coolant flow inside the devices. HyperVapotrons are currently tested in the Joined European Torus (JET) and the Mega Amp Spherical Tokamak (MAST) fusion experiments and are considered a strong candidate for the International Thermonuclear Experimental Reactor (ITER). The efficiency of heat transfer and the reliability of the components of a fusion power plant are important factors to ensure its longevity and economical sustainability. Optimisation of the heat transfer performance of these devices by the use of nanofluids is investigated in this paper. Nanofluids are advanced two phase coolants that exhibit heat transfer augmentation phenomena (up to 200% enhancement compared to traditional coolants). A cold isothermal nanofluid flow is established inside two HyperVapotron models representing the geometries used at JET and MAST (sectional view of geometries in FIGURE 1). A hybrid Particle Image Velocimetry method (PIV) is then employed to map in high spatial resolution (30μm) the flow fields inside each replica. The instantaneous and mean flow structures of a nanofluid are compared to those present during the use of a traditional coolant (water) in order to detect any departure from the hydrodynamic design operational regime of the device. It was discovered that the flow field of the JET model is considerably affected when using nanofluids, while the flow in the MAST geometry does not change significantly by the introduction of nanofluids. Evidence of an unknown viscosity change mechanism in nanofluid flows is found and it might be important to calculating the pumping power losses of a functional nuclear fusion power plant cooling system ran with nanofluids instead of water.

HyperVapotrons and PIV Experimental Rig

- HyperVapotron (HV) elements are highly durable and capable of conveying large amounts of thermal power (of the order of 10-20 MW/m^2).
- Hydrodynamic coolant flow structures established inside devices are controlling their thermal performance.
- Nanofluid use in HVs might affect the designed hydrodynamic coolant flow behaviour which might prove beneficial or detrimental to their operation.
- Particle image velocimetry (PIV), a laser-based method, has been employed to measure the velocity field and flow structures inside full-scale MAST and JET HV models (FIGURE 2) in high spatial resolution (30μm).
- Post processing of data via image recognition algorithms is used to define morphological features and provide a full characterisation of the coolant flow inside the device. (FIGURE 3)
- Quantitative data was recorded to elucidate understanding of the initial flow field inside the HV grooves (i.e., before the short phase change Vapotron bursts).

FIGURE 1

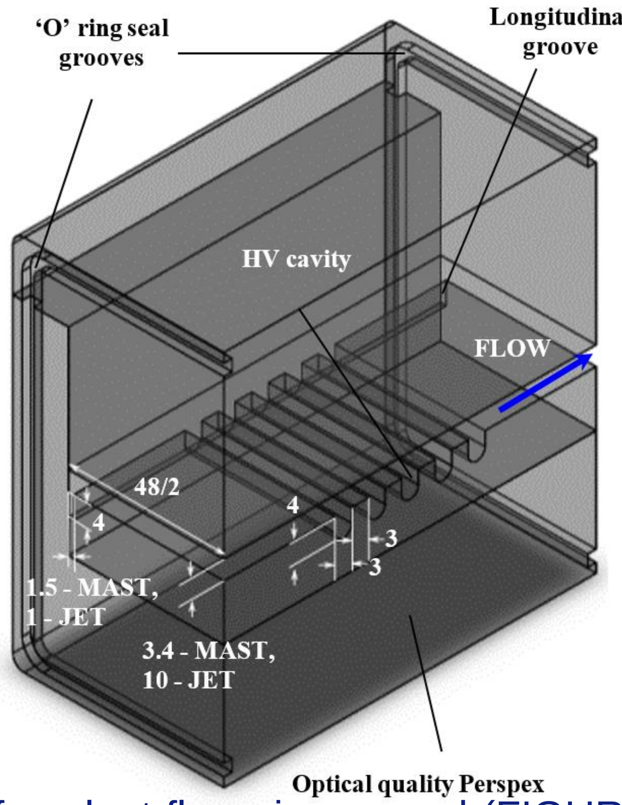
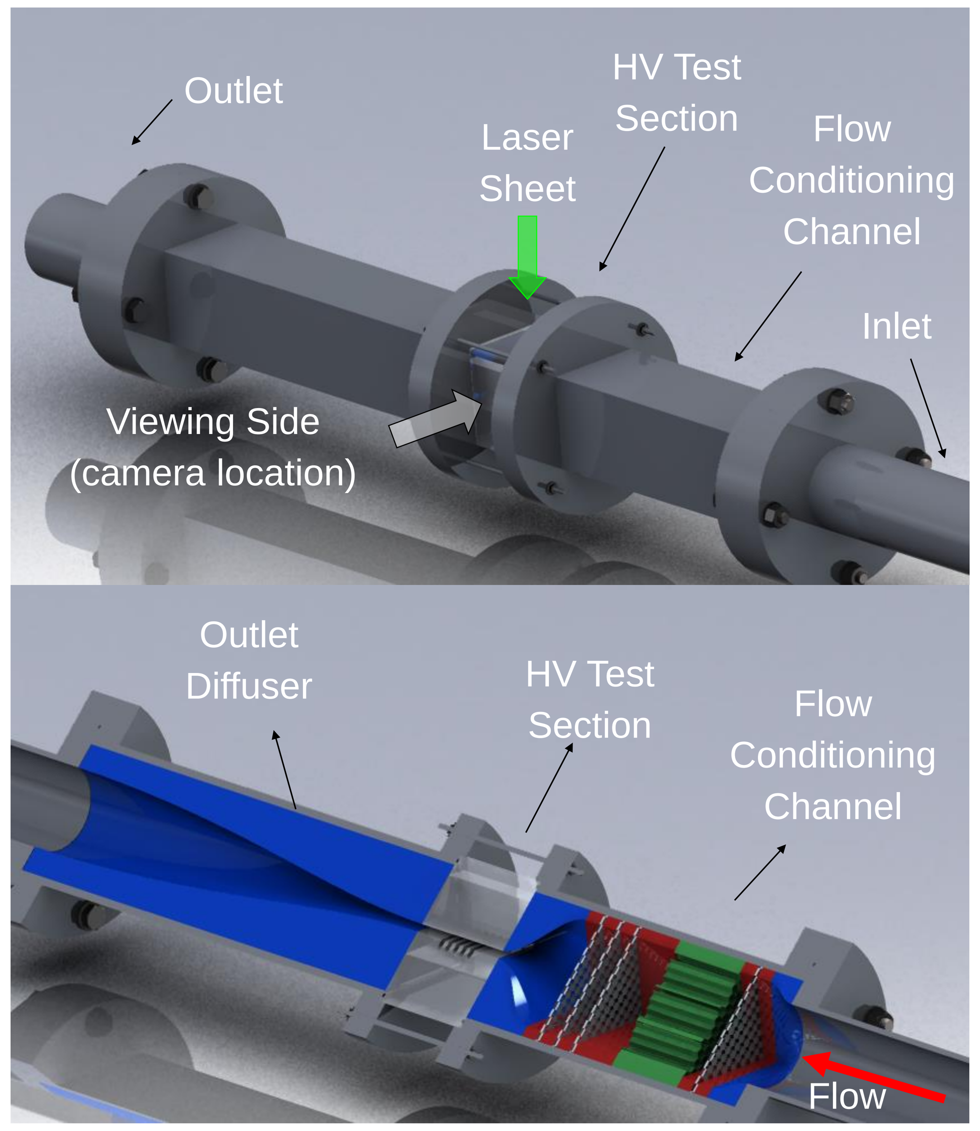


FIGURE 2



- Mean and instantaneous behaviour of coolant flows is mapped (FIGURE 4).
- Measurements are taken for water from previous work and compared to current ones with a dilute 50nm Al_2O_3-water-based nanofluid (0.0001% vol.) as the flow medium, revealing the effect of nanofluids on the HV hydrodynamic properties.

PIV Results

- Average velocity and RMS of velocity PIV results focused on middle groove of HV model can be found in FIGURE 4.
- Analysis additionally extended into the freestream flow and qualitatively into the rest of the HV grooves (FIGURE 3).
- Small nanoparticle concentration nanofluids can modify the hydrodynamic flow fields of HVs significantly.
- The JET operational design is greatly affected when exchanging the traditional working fluid (water) with a nanofluid.
  i. In-groove flow structures become slower and more unstable.
  ii. Nanofluid expected to alter the thermal performance of the JET device based on hydrodynamic patterns alone.
- MAST geometry more resilient to working fluid changes with the device exhibiting similar flow structure characteristics as water – hydrodynamic operational regime of the device remains at the same locus as the original design making this a good candidate for nanofluid HHF tests.

- Possible presence of a viscosity change mechanism inside nanofluids discovered:
  i. Use of a nanofluid seems to be affecting severely the hydrodynamic flow inside the JET geometry.
  ii. The coolant circulation pumping power could be potentially affected.
  iii. Mechanism can not be explained via classical thermodynamic relationships – implications also on validity of CFD nanofluid studies.

FIGURE 3

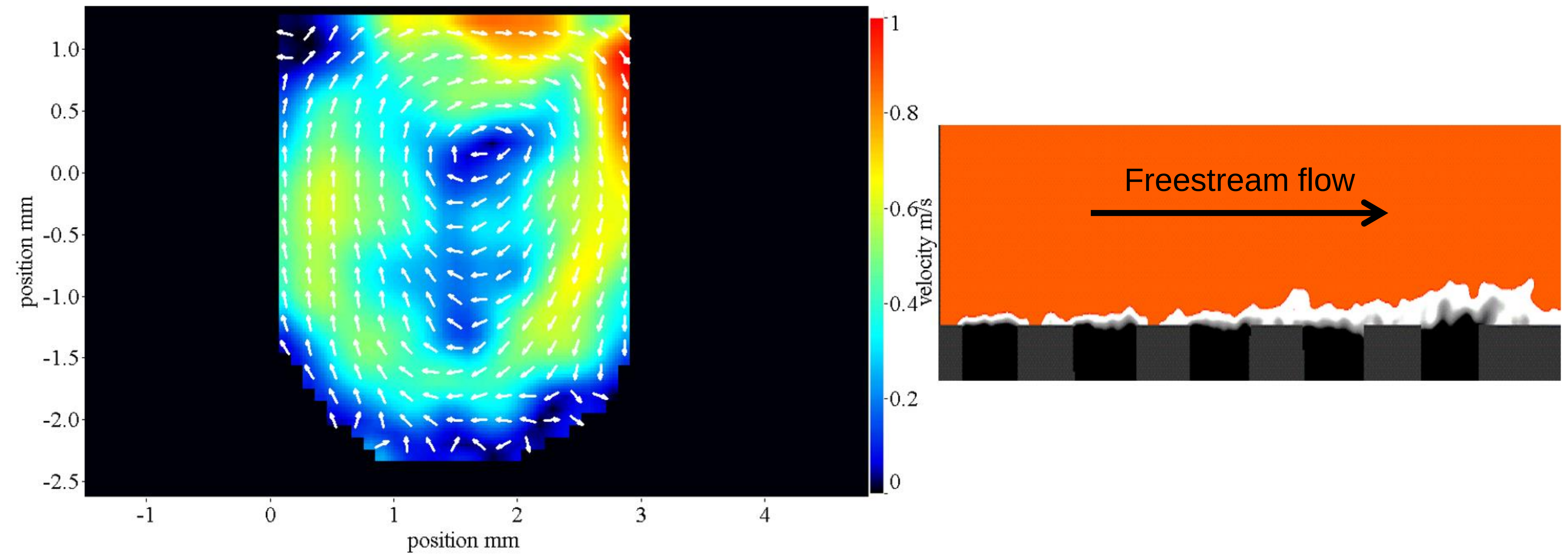
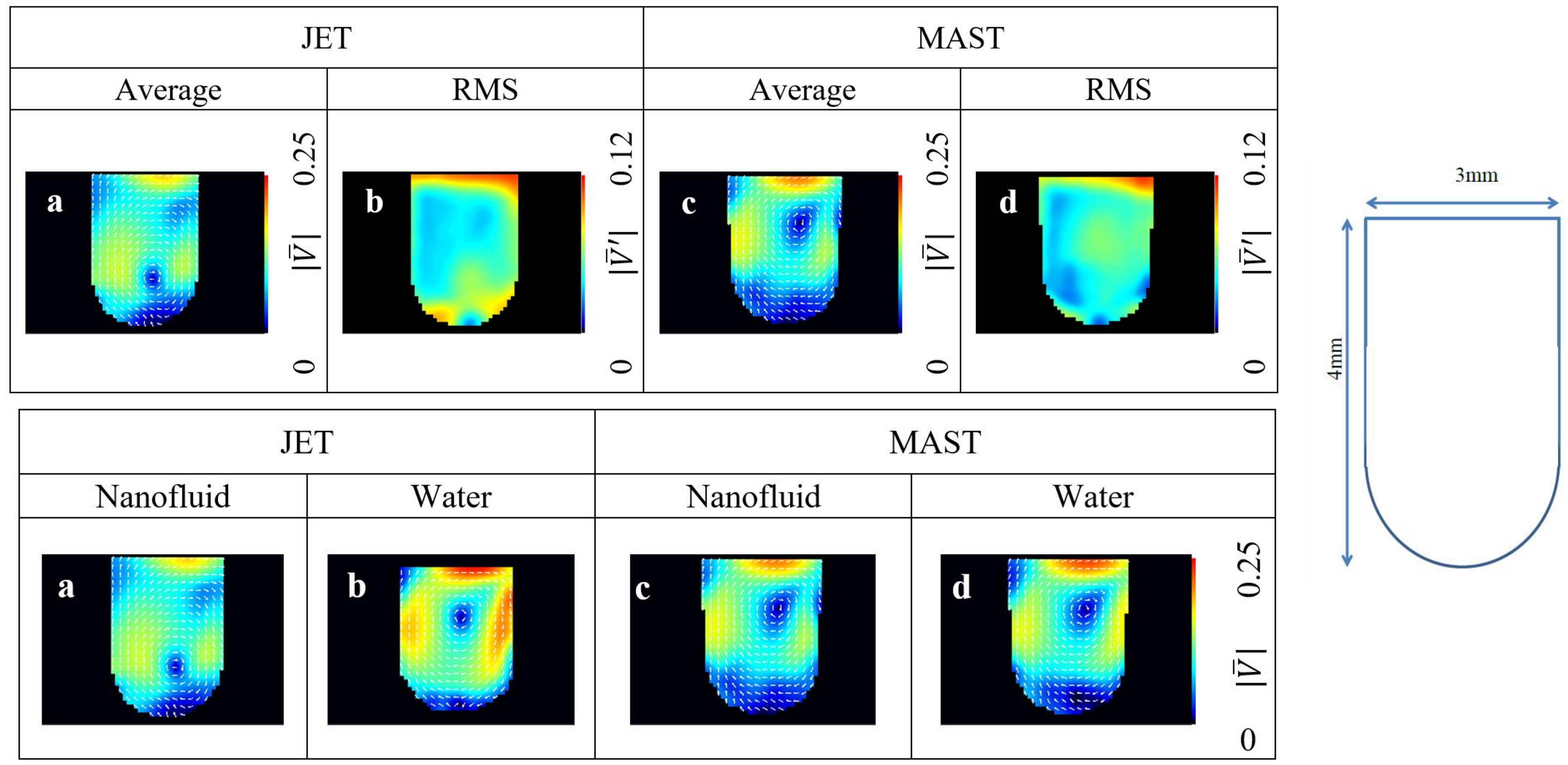


FIGURE 4



Conclusions

The heat transfer performance of HVs can be potentially enhanced by using a nanofluid coolant, both by a mechanism of nanoscale thermal diffusion as well as by modification of large scale the coolant flow structures. The MAST geometry seems to be a good candidate to test operation with nanofluids as the increased free stream shear observed forces the nanofluid to retain the same designed coolant flows as water. Evidence of a possible effective viscosity change mechanism are encountered with the use of a dilute nanofluid which cannot be predicted or explained via classical thermodynamics. This might prove of major importance in the coolant pumping power requirements for a large scale cooling circuit.

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