LDA measurements of coherent flow structures and cross-flow across the gap of a compound channel with two half-rods

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A B S T R A C T

The enhancement of heat transfer from fuel rods to coolant of a Liquid Metal Fast Reactor (LMFR) decreases the fuel temperature and, thus, improves the safety margin of the reactor. One of the mechanisms that increases heat transfer consists of large coherent structures that can occur across the gap between adjacent rods. This work investigates the flow between two curved surfaces, the gap between two adjacent fuel rods. The aim is to investigate the presence of the aforementioned structures and to provide, as partners in the EU SESAME project, an experimental benchmark for numerical validation to reproduce the thermal hydraulics of Gen-IV LMFRs. The work investigates also the applicability of Fluorinated Ethylene Propylene (FEP) as Refractive Index Matching (RIM) material for optical measurements.

The experiments are conducted on two half-rods of 15 mm diameter opposing each other inside a Perspex box with Laser Doppler Anemometry (LDA). Different channel Reynolds numbers between Re = 600 and Re = 30,000 are considered for each P/D (pitch-to-diameter ratio).

For high Re, the stream-wise velocity root mean square \( v_{rms} \) between the two half rods is higher near the walls, similar to common channel flow. As Re decreases, however, an additional central peak in \( v_{rms} \) appears at the gap centre, away from the walls. The peak becomes clearer at lower P/D ratios and it also occurs at higher flow rates. Periodical behaviour of the span-wise velocity across the gap is revealed by the frequency spectrum and the frequency varies with P/D and decreases with Re. The study of the stream-wise velocity component reveals that the structures become longer with decreasing Re. As Re increases, these structures are carried along the flow closer to the gap centre, whereas at low flow rates they are spread over a wider region. This becomes even clearer with smaller gaps.

Moreover, a transversal flow of coherent structures across the gap between two rods can also occur. In a nuclear reactor cross-flow is important as it enhances the heat exchange between the nuclear fuel and the coolant. As a result, the fuel temperature decreases improving the safety performance of the reactor.

Much research has been done in studying periodic coherent structures and gap instability phenomena in rod bundles resembling the core of LMFRs, PWRs, BWRs and CANDUs. Rowe et al. (1974) measured coherent flow structures moving across a gap characterised by a P/D of 1.125 and 1.25. A static pressure instability mechanism was proposed by Rehme to explain the formation of coherent structures (Rehme, 1987). Möller measured the air flow in a rectangular channel with 4 rods (Möller, 1991). The rate at which the flow structures were passing increased with the gap size. The instantaneous differences in velocity and vorticity near the gap, responsible of the cross-flow, were associated with a state of metastable equilibrium. Recently, Choueiri gave an analogous explanation for the onset of the gap vortex streets (Choueiri.

1. Introduction

The rod bundle geometry characterises the core of LMFBR, PWR, BWR or CANDU reactors, as well as the steam generators employed in the nuclear industry. In the presence of an axial flow of a coolant, this geometry leads to velocity differences between the low-speed region of the gap between two rods and the high-speed region of the main sub-channels. The shear between these two regions can cause streaks of vortices carried by the stream. Generally those vortices (or structures) develop on either sides of the gap between two rods, forming the so-called gap vortex streets (Tavoularis, 2011). The vortices forming these streets are stable along the flow, contrary to free mixing layer conditions where they decay in time. Hence the adjective coherent. The formation mechanism of the gap vortex streets is analogous to the Kelvin-Helmholtz instability between two parallel layers of fluid with distinct velocities (Meyer, 2010). The stream-wise velocity profile must have an inflection point for these structures to occur, as stated in the Rayleigh’s stability criterion (Rayleigh, 1879).

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