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MODELLING TURBULENT FLOW WITHIN NUCLEAR HEAT EXCHANGERS

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Cross-flow tube-bank configurations achieve high heat transfer with relatively low manufacturing complexity, making them attractive heat exchangers for fossil-fuel and nuclear power plants. Indeed, a specific design of in-line tube bank used within Advanced Gas-cooled Reactors (AGR) was found to produce particularly high levels of turbulent mixing. Experiments conducted during the AGR design stages indicated large-scale 3D secondary flows [1; 2]. However, the thermo-fluid conditions within the heat exchanger are routinely predicted using 2D lumped-parameter models, where the high turbulent mixing phenomenon is crudely approximated by an enhanced thermal diffusion coefficient. As High Performance Computing (HPC) becomes more affordable, the nuclear industry is resorting to CFD to resolve the small-scale details of integral locations within their power plants. This paper will report the outcome of applying different CFD approaches in modelling turbulent flow and heat transfer around both generic (academic) and specific (industrial) in-line tube banks.

Firstly, the suitability and accuracy of wall-resolved LES and URANS approaches are examined for generic, square, in-line tube banks, where experimental data are limited but available [3]. Within the latter approach, both eddy-viscosity and Reynolds stress-transport models have been tested. The assumption of flow periodicity in all three directions is investigated by varying the domain size. It is found that the path taken by the fluid through the tube-bank configuration differs according to the assumed flow dimensionality (pitch-to-diameter ratio, P/D) and the treatment of turbulence.

Secondly, the important effect of confining walls is shown by making direct comparison with the available experiments (see Figure 1). The correct pressure forces and heat transfer around the central tubes could only be accurately predicted when the walls in the cross-flow direction were modelled. The inclusion of walls in the span-wise direction gave rise to small flow asymmetries predicted by the Reynolds-stress-transport models, which have been reported experimentally on similarly-spaced in-line tube banks.

Finally, the 3D secondary flow patterns observed in the in-line tube bank section of the AGR heat exchanger are investigated with the aid of High Performance Computing (HPC) facilities (see Figure 2). Large 3D secondary flow structures were predicted using a wall-modelled Reynolds-stress-transport model, producing the same level of cross-flow thermal diffusion as reported experimentally. The adequacies of the assumptions inherent within the 2D lumped-parameter code are also discussed.

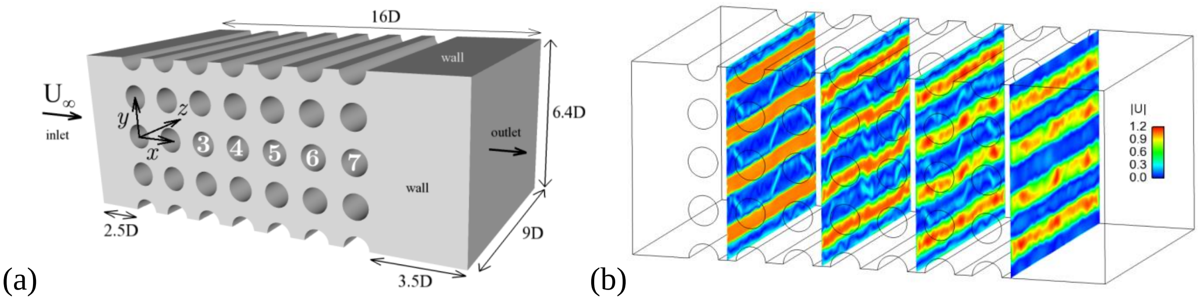

Figure 1: Generic in-line tube bank of P/D = 1.6: (a) Configuration of Aiba et al. [1] (b) mean velocity magnitude at various planes thought the domain using the EB-RSM.

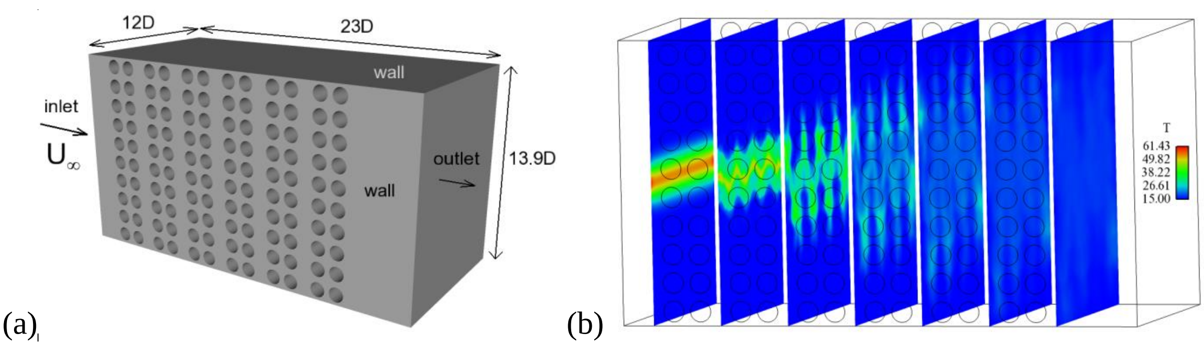

Figure 2: Specific industrial in-line tube bank: (a) Configuration of Jones at al. [4] (b) Mean temperature dispersion of Gaussian inlet spike using wall-modelled RSM.

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