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# Characterization of sodium flow over hexagonal fuel subassemblies $\stackrel{\leftrightarrow}{\sim}$

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## ABSTRACT

Steady flow of liquid sodium over a bundle of heat generating hexagonal subassemblies has been investigated. The cross flow pressure drop and heat transfer are characterized using the general purpose CFD code STAR-CD. Analysis has been carried out for both laminar and turbulent regimes of interest to liquid metal fast reactors. Turbulence has been modeled using low Reynolds number ( $\tilde{Re}$ )  $k-\varepsilon$  model. The estimated pressure drop and heat transfer coefficients are compared against that of a straight parallel plate channel. It is seen that in the low Reynolds number range, the pressure drop for the hexagonal path is nearly equal to that of the parallel plate channel for the same length. However, in the high Reynolds number range, the pressure drop of the hexagonal path is much higher than that in the parallel plate channel, the ratio being 2 at Re = 2000 while it is 3.6 at Re = 20,000. Two competing factors, viz., (i) jet impingement/flow development effect and (ii) flow separation effect are found to influence the average Nusselt number (Nu). In the laminar regime, the latter effect dominates leading to a decrease of the Nusselt number with an increase in the Reynolds number. However, in the turbulent regime, the former effect dominates leading to an increase in the Nusselt number with Reynolds number. The Nusselt number in the hexagonal path is about twice that of the parallel plate channel due to under development of velocity/temperature profiles and the recirculation associated with the hexagonal path due to the changes in flow direction. Detailed correlations for both the pressure drop and the average Nusselt number have been proposed.

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### 1. Introduction

The core of a fast breeder reactor consists of a large number of tightly packed heat generating subassemblies (SA) immersed in a sodium pool. These SA are hexagonal in cross section. Nuclear heat generated by fuel pins inside the SA is removed by both sodium flowing through and that flowing over the SA (see Fig. 1(a)). The sodium flow over the SA (i.e., between two SA) is known as 'Inter-Wrapper Flow' (IWF). When sodium flow rate through the SA is small, the heat transfer by the IWF becomes important and helps in reducing clad temperature of fuel pins.

The IWF gaps are narrow (3.4 mm) compared to length of the SA (4 m) and width of the SA (131.6 mm). A large number of SA (~1760) stacked vertically in a large pool of sodium (12 m diameter) makes the flow path complex and three dimensional in nature. Due to the inability of common experimental liquids like water to represent heat transfer features of sodium and opaque nature and high freezing point of sodium, experimental simulations of IWF heat transfer are very formidable. Furthermore, the measurement of velocities in an IWF gap

is very difficult due to small hydraulic diameters associated with them.

Consequent upon the above, heavy responsibility is placed on Computational Fluid Dynamics (CFD) based investigation in sodium cooled fast reactors. A transient analysis with a complete model for the IWF integrated with hot and cold pools of the reactor calls for a high fidelity analysis involving billions of computational grids. One of the options to circumvent this difficulty is to employ a porous body model for the core linking it with hot pool. In the porous medium formulation, a relatively coarser mesh can be used with appropriate surface permeability and volumetric porosity. In this formulation, the pressure drop encountered by the IWF is specified as additional resistance in the momentum equations and the heat exchange between SA and IWF is specified as additional heat source in the energy equation.

A detailed survey of literature [1,2] indicates that correlations for pressure drop and heat transfer are scarce for cross flow over tightly packed hexagonal SA. However, extensive research has been carried out in the area of cross flow over circular tube bundle [1–7]. Studies were carried out for both inline and staggered circular and square tube configurations. These studies are useful for improving heat exchanger designs. Wang has studied flow over inline and staggered rectangular tube bundle which simulates flow through a porous medium [8]. Kim et al. investigated flow through an S-Shaped duct to

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