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Numerical Study for Turbulent Heat Transfer in Helical Wired Sub-channel Flow Regime of Duct-less Assembly in SFR

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1. Introduction

In development prototype gen-IV SFR, duct-less fuel assembly was suggested for long-term fuel cycle operation. Concept of duct-less fuel assembly is designed by elimination of duct structure to make influenced fuel assembly with neighbor assemblies. Grid spacer was also designed to substitution of duct for supporting the duct-less fuel assembly. A fuel assembly had hexagonal structure adjacent to 6 fuel assemblies, which influence to the target fuel assembly due to elimination of duct. For calculating the influence, 6 additional channels were generated between the adjacent fuel assemblies and cross flow model was applied to the channels. The adjacent fuel assemblies were analyzed and the results were used in the additional channel as boundary condition of the target fuel assembly. To design the specifications of duct-less assembly, modified or brand-new thermal-hydraulic methodology is needed which is using MATRA-LMR [1] and CFD codes in this study.

The MATRA-LMR is a sub-channel analysis code for LMR that has been developed in Korea Atomic Energy Research Institute. It is designed to analyze a fuel assembly with wire-wrap and duct structure. However, the duct-less core is not able to be analyzed by the MATRA-LMR which doesn't consider cross flow between the fuel assemblies and effect of grid spacer. The code need improvement by editing source code to eliminate effect of duct and analyze pressure drop and mixing between the sub-channels caused by grid spacer and cross flow between the fuel assemblies.

To validate reformed pressure drop model and cross flow model in MATRA-LMR, CFD analysis is performed. For verifying the results of CFD, LMR sub-channel experimental data is benchmarked which is done by ORNL [2]. The verified CFD for thermal-hydraulic analysis calculated pressure drop and mixing caused by grid spacer and cross flow between fuel assemblies. The CFD results were compared with the pressure drop model and cross flow model used in MATRA-LMR and the models were modified by the CFD results. In this study, CFD analysis validation is performed for ORNL Test series 2, Test 2, Run 109 case for the further system design calculation with MATRA-LMR

2. Methods and Results

In this section, reference experiment and numerical study specifics are represented that experimental apparatus, purpose of selected experimental cases and flow-regime, initial and boundary conditions, mesh studies and used turbulent model respectively.

2.1 Reference Experiment

To validate numerical simulation results, ORNL LMFBR experiments are selected. There are several cases for each purposes for configuration and power level of the Fast Test Reactor fuel. Bundle consisted of 19 electric cartridge heaters with outside diameters of 0.230 in. spaced by 0.056 in. wire-wraps on a 12-in. pitch all enclosed in a hexagonal can. This experiment purpose of the test series was to obtain thermal-hydraulic data for use in design of the Fast Test Reactor core. In this study, Test series 2, Test 2, Run 109 case was selected which to provide base-line data on the temperature profiles that exist in a simulated segment of an FTR core subassembly at typical operating conditions. The average heat flux through heater section is around 5 kW/ft and it performed 9 times for estimate deviations of measured data. Total 101 thermocouples are installed in ungrounded flow junctions, duct wall, heaters and wire-wraps. Liquid sodium properties from ANL report [3] are used in this calculation.

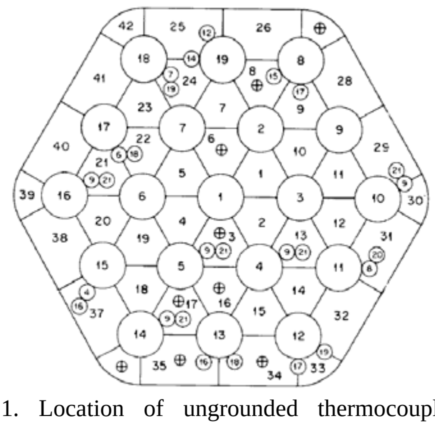

Fig. 1. Location of ungrounded thermocouples. (⊕ Symbols)

2.2 Mesh Generation Study

In this study, numerical simulation is done by STAR-CCM+ 8.06.007. To optimize the node cell generation with proper wall function, various cases are calculated. About 21 million-cell represents the optimized normal directional velocity profile for the test case. Base cell shape is polyhedral and layered option is adopted for 40 of y+ value.

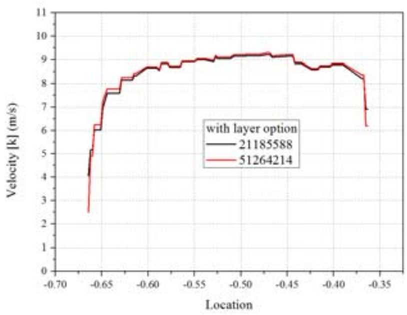

Fig. 2. Z-directional fluid velocity in flow junction 17 to 35 with various cell numbers.

2.3 Initial and Boundary Conditions

Test series 2, Test 2, Run 109 case performed with all rods heated uniformly which is shown in Table I. Volume flow rate from inlet section is 54.72 gpm with 325.9℃ of liquid sodium. All wall boundaries except heater section are configured adiabatic condition as described in ORNL experimental report.

Table I: Experimental conditions for ORNL LMFBR Test series 2, test 2, Run 109 case

Description	Value
Heater 1 (kW)	8.93
Heater 8, 18, 19 (kW)	8.82
Heater 12, 13, 14 (kW)	8.62
Heater 2, 7, 9, 17 (kW)	8.79
Heater 4, 5, 11, 15 (kW)	8.83
Heater 3, 6, 10, 16 (kW)	8.61
T_{inlet} (℃)	325.9
m_{inlet} (gpm)	54.63

2.4 Results

Table II: Temperature distribution results at the outlet surface of sub-channel

Junction No.	Experiment (℃)	CFD (℃)
#3	370.9	370.6
#6	370.8	370.0
#8	362.4	366.6
#16	366.5	367.1
#17	356.2	361.8
#27	351.6	343.7
#34	352.1	344.2
#35	353.4	344.7
#36	354.6	343.8

Calculation results for temperature distributions are represented in Table II. This calculation using k-epsilon turbulent model with 1% intensity factor and 10 of viscosity ratio. It shows similar tendency of experimental data but under predicted temperatures are calculated in outer junctions. For other calculations from Test series 2, test 2, Run 109 cases with range of turbulent intensity 1% to 10% have also same results with this case.

3. Conclusions

Numerical simulation for sub-channel analysis of duct-less assembly in SFR is done by commercial CFD code (STAR-CCM+ 8.06.007) comparing with ORNL LMFBR experiment results. The tendency of temperature distribution is similar with Test series 2, Test 2 Run 109 case in ORNL reports, however under predicted temperature results are calculated near the duct wall junctions with various turbulence model studies. Further turbulent model study is planned with DNS calculation result in swept flow over a wire in a channel for SFR core assembly [4].

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