CFD investigation of turbulent Prandtl number effect in 19 fuel pin bundle with liquid sodium fluid

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1. Introduction

- In Sodium Fast Reactor, SFR, the fuel pins are composed to helical wire-wrap for making space to flow through the fuel bundle. This helical wire-wrap spacer makes better mixing of coolant among the area between fuels and duct. The effect of flow mixing generates the transverse flow and make temperature distributions of coolant in sub-channel. Due to the transverse flow It is not easy to predict the subchannel flow and temperature distribution.
- For predict the subchannel temperature in CFD simulation, turbulent prandtl number have to apply for calculate the energy equation in RANS-based CFD investigation of the 3 dimensional with turbulence model (SST). This variable entered constant value and the shape function likes Pr number. The coolant with water was recommended 0.02. The case of liquid metal was recommended higher than 1.0 [1].
- In Oak Ridge National Laboratory do experiments with a 19-rod test assembly in the fuel failure mockup sodium loop in which fuel rods were simulated by electrical cartridge heaters having the same external configuration, spacer arrangement, temperature, and heat flux as those of a typical liquid-metal fast breeder reactor (LMFBR) [2]. Temperatures were measured within the rod bundle, at the exit for widely varying conditions of flow and power density and for non-uniform radial power distribution.
- In this study, we assess the turbulent Prandtl number in RANS based CFD methodology using ORNL-19 experimental data and recommend the turbulent Prandtl number under liquid sodium properties.

2. Methods and Result

2.1 Numerical analysis methodology

- For CFD temperature analysis, CFD analysis results were compared for experimental data with geometrical similarity to ORNL-19 test assembly. A commercial CFD code, Star-CCM+, was used, and a grid was constructed using the surface, polyhedral and prism mesh provided in the code. As a numerical analysis method, 3-D, steady-state, segregated flow scheme, and all y+ wall treatment were set, and the analysis conditions are shown in Table 1 below.

Table 1. Numerical analysis conditions

Power (kW)	166
Mass flow rate (kg/s)	2.932
Coolant temperature (℃)	341.7
Density (kg/m^3)	Reference [3]
Conductivity (W/m-K)	Reference [3]
Specific heat (J/kg-K)	Reference [3]
Viscosity (Pa·s)	Reference [4]

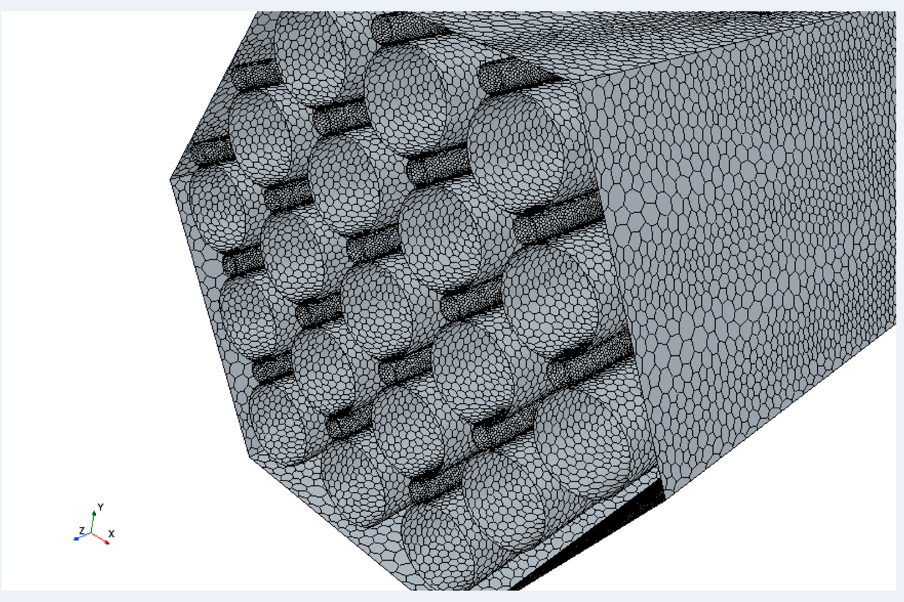

Figure 1. Polyhedral mesh for CFD simulation

- The mesh sensitivity test was performed from 16.6 million to 22.5 million, total four cases (Figure 2, 3). For estimating the convergence, pressure drop was used at inner and outer subchannels and 19.7 million mesh was selected.

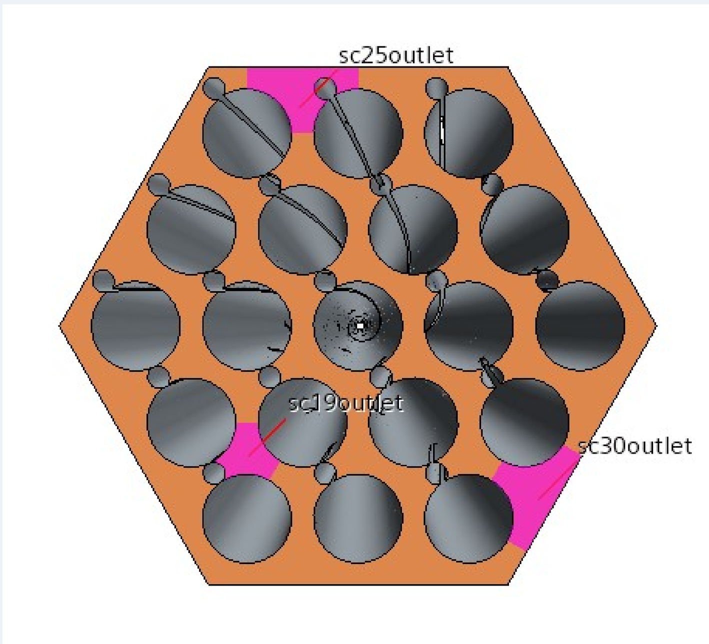

Figure 2. Subchannel information for the mesh sensitivity

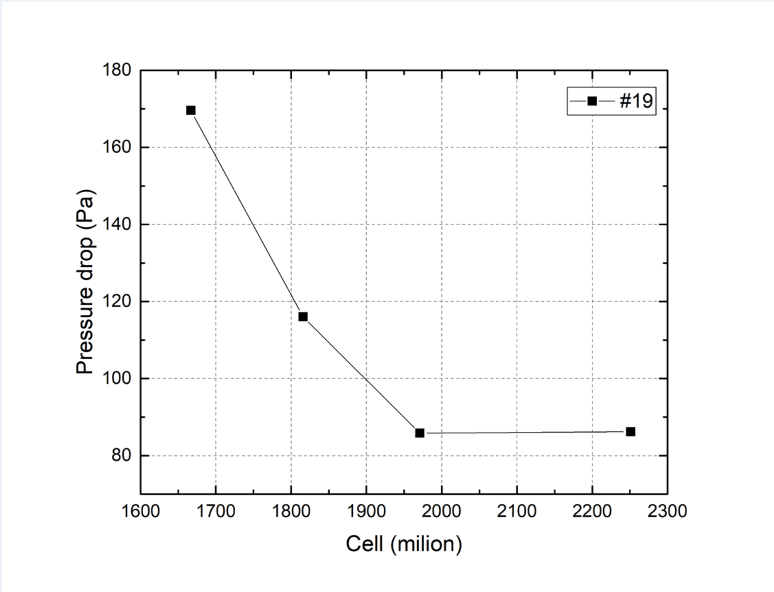

Figure 3. Pressure drop change in #19

- The axial power was uniformed by electrical cartridge heaters. The test series 2.test 14, run 101 was simulated. The radial power imposed 3/1 skew in bundle to exaggerate temperature differences across the bundle and across the hexagonal flats.

2.2 Description of experimental facility

- The ORNL-19 pin test bundles simulate fuel assemblies by using electric heater s having the same linear power density and external configuration as LMFBR fuel rods. The rods were 5.84 mm in diameter and were placed 7.26 mm pitch. The bundle had a 530.1 mm, heated length, with 1016 mm, total bundle length. The detail geometry information as below Table 2.

Table 2. Geometry data of ORNL 19 test section

Number of pins	19 EA
Pin diameter	5.84 mm
Wire diameter	1.42 mm
Wire lead pitch	304.8 mm
Pin pitch	7.26 mm
Heated length	530.1 mm
Total duct length	1016 mm
Duct inside flat to flat distance	33.85 mm
Working fluid	Sodium

2.3 Numerical analysis results

- The CFD investigation performed five turbulent Prandtl number cases, 0.01, 0.1, 1.5, 5 and 10. As shown the Figure 4, the outlet subchannel temperature differences are smaller as the bigger turbulent Prandtl condition under 0.1.
- When the turbulent Pr number was 0.1, the temperature distribution is close to the experimental data with the SST turbulence model and the temperature differences remain almost the same. The biggest difference is made at subchannel #38 (Figure 5).

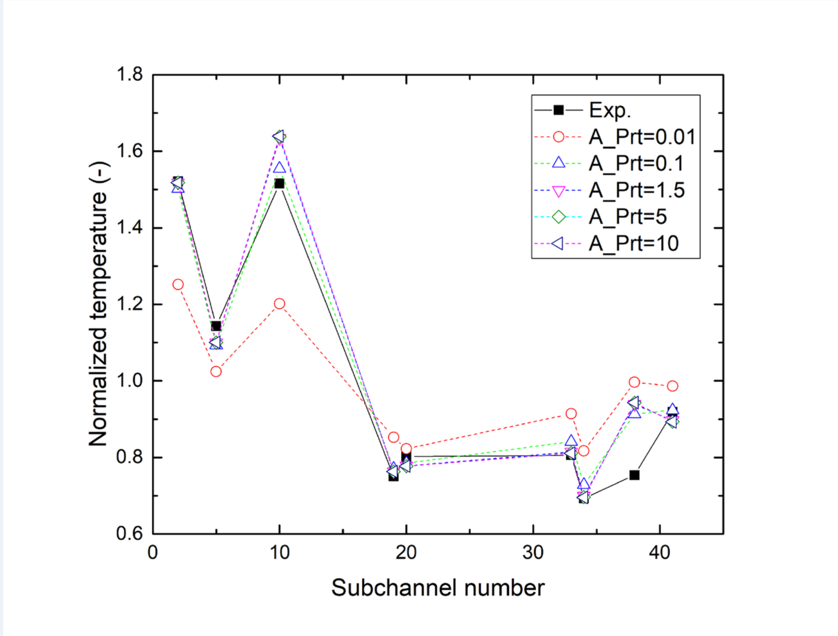

Figure 4. Normalized temperature at target subchannel

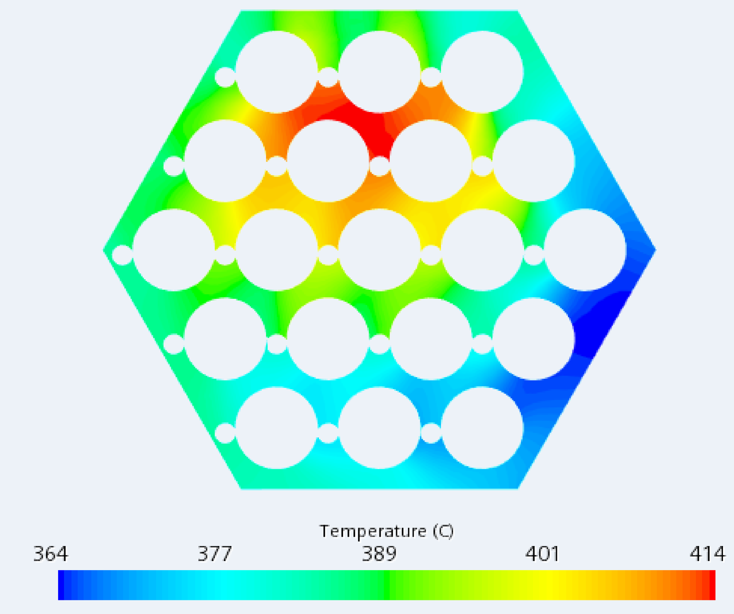

Figure 6. temperature distribution at Pr_t=0.1

Table 3. The difference between Exp. and CFD

channel #	$Pr_{turbulent}$				
	0.01	0.1	1.5	5	10
2	18%	1%	0%	0%	0%
5	10%	4%	4%	4%	4%
10	21%	-3%	-8%	-8%	-8%
19	14%	-3%	-2%	-2%	-2%
20	-3%	2%	3%	3%	3%
33	-13%	-4%	-1%	-1%	-1%
34	-18%	-5%	-1%	0%	0%
38	-32%	-21%	-25%	-25%	-25%
41	-7%	-1%	2%	3%	3%
Diff.*	136%	44%	45%	46%	46%

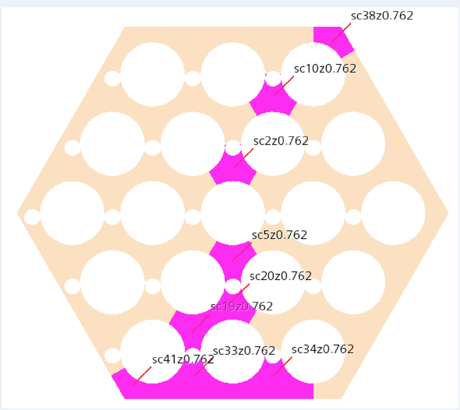

Figure 5. Subchannel information

3. Conclusion

- The turbulent Pr was evaluated using the RANS based CFD model (SST) with ORNL-19 pin experimental data. At Prturbulent = 0.1 (Figure 6), the CFD result seens most similar. We know the turbulent Pr have to be smaller than 0.1 in liquid sodium properties.

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