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Computational Analysis of Distorted Velocity and Temperature Profiles of Sodium Flow in the Vicinity of Local Velocity Probe

Uiju Jeong, Yoon Ho Kim, Sung Joong Kim [*]
Department of Nuclear Engineering, Hanyang University
17 Haengdang-dong, Seongdong-gu, Seoul, 133-791, Republic of Korea
[*]Corresponding author: sungjkim@hanyang.ac.kr

1. Introduction

Korea Atomic Energy Institute (KAERI) has invested a lot of efforts to develop a Korean Liquid Metal cooled Fast Breeder Reactor (LMFBR). Specifically, it is planned that a proto-type Sodium cooled Fast Reactor (SFR) with a pool type Primary Heat Transport System (PHTS) will be constructed by 2028. Currently, construction of a large-size sodium experimental facility named STELLA is underway [1]. Using the STELLA, a Passive Decay heat Removal Circuit (PDRC) system of the SFR will be tested. Since the PDRC system plays a vital role in removing heat by natural circulation of sodium in the pool during the course of transient scenario, a local velocity measurement technique has been required to properly test its performance under various conditions.

A proto-type permanent magnet local velocity probe was manufactured by KAERI [2]. The probe is planned to be tested and calibrated through the Instrument Test Sodium Loop (ITSL) in KAERI. It is considered that the relationship between flow velocity and the velocity-induced potentials should be verified by a proper calibration in an isothermal and uniform velocity field of sodium flow. This is because Seebeck-potential, which is often referred to a thermal-induced potential, is produced when temperature gradient exists in the velocity field [1, 2]. In order to take into account the Seebeck-potential effect, a preliminary computational simulation is performed with the probe test section in the ITSL. The objective is to predict both temperature and velocity distributions. This simulation will help us minimize a possible error induced by the thermal electric effect during the experiments.

A Computation Fluid Dynamics (CFD) code, FLUENT was introduced with turning on the Reynolds Averaged Navier Stokes (RANS) model to perform an analysis of liquid metal flow. The RANS model was validated by Chandra et al. [5].

2. CFD Analysis

2.1 Description of Experimental Facility

The experimental calibration of the probe using the ITSL mainly aims to measure the velocity of the liquid sodium flow. The velocity probe is fixed at the center of the pipe in the test section as shown in Fig 1. Also the experimental conditions for numerical simulation are presented in Table 1. The material of the test section pipe and the local velocity probe is simulated as stainless steel and the fluid continuum is simulated as liquid sodium.

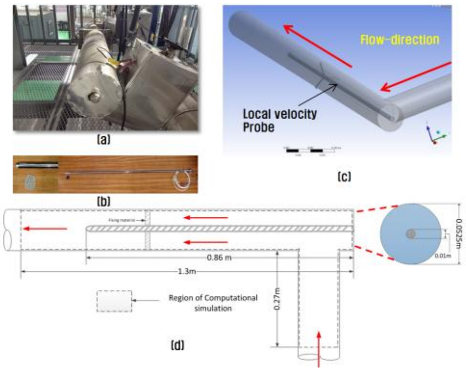

Fig. 1. Pictures and computational geometries of the test section (a) the probe insertion hole, (b) the probe (length: 1040 mm), (c) computational geometry of the pipe and the probe, (d) cross sectional diagram of the test section pipe.

Table 1. Experimental condition for the simulation

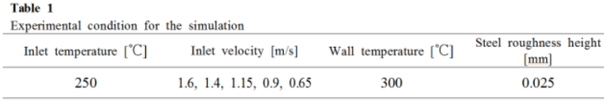

Table 1
Experimental condition for the simulation

Inlet temperature [℃]	Inlet velocity [m/s]	Wall temperature [℃]	Steel roughness height [mm]
250	1.6, 1.4, 1.15, 0.9, 0.65	300	0.025

2.2 CFD model

Detailed information about meshes adopted in this analysis is summarized in Table 2. First, a sensitivity analysis with different mesh schemes was performed. For the more detail analysis, Case 3 was selected for the analysis of velocity profile and temperature distribution according to velocity at the inlet boundary as a reference mesh. Also the mesh scheme used in Case 1 was used for the sensitivity analysis of k-epsilon model as a reference mesh. All the simulations continued until all the residuals fall below the order of 10^{-4}~10^{-6} and until the convergences are clearly shown up.

Table 2. Description of mesh

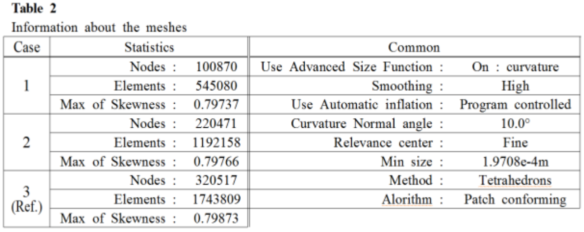

Table 2
Information about the meshes

Case	Statistics		Common	
1	Nodes :	100870	Use Advanced Size Function :	On : curvature
	Elements :	545080	Smoothing :	High
	Max of Skewness :	0.79737	Use Automatic inflation :	Program controlled
2	Nodes :	220471	Curvature Normal angle :	10.0°
	Elements :	1192158	Relevance center :	Fine
	Max of Skewness :	0.79766	Min size :	1.9708e-4m
3 (Ref.)	Nodes :	320517	Method :	Tetrahedrons
	Elements :	1743809	Alorithm :	Patch conforming
	Max of Skewness :	0.79873		

2.3 Results

2.3.1 Mesh sensitivity analysis

Using the k-ε model (Realizable-Enhanced Wall Treatment) as a reference viscous model, temperature and velocity distributions were obtained and corresponding result is given in Fig. 2. It is observed that there is no significant change in the distribution of temperature and velocity depending on the size of mesh.

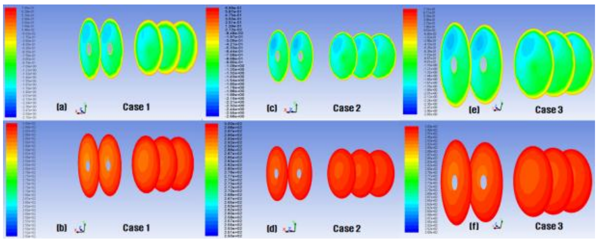

Fig. 2. Temperature and velocity distribution in the pipe cross sectional surface in the vicinity of magnet in the probe with respect to the different mesh sizes. X-direction velocity distribution (a, c, e) and temperature distribution (b, d, f).

2.3.2 Analysis according to inlet velocity

Fig. 3 shows resulting velocity profiles with respect to the various inlet velocity conditions. Velocity profiles in the cross sectional surface with respect to the inlet velocity shows similar shapes. But the magnitude of the maximum velocities differs with the inlet velocities. The cross sectional temperature distribution of the fluid becomes uniform quickly along the pipe, while the velocity distribution was concentrated locally. Thus the errors which might occur from Seebeck-potential due to temperature gradient are expected to be small. However, the errors occurring from non-uniformity of velocity distribution should be considered carefully in the calibration experiments.

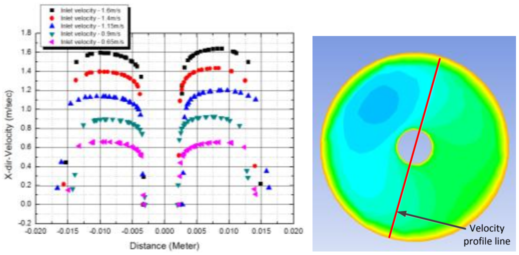

Fig. 3. The velocity profiles along the above red line with respect to inlet velocity. X-direction velocity vs. distance from the center of the probe (Left), cross sectional surface in the vicinity of magnet of the probe (right).

2.3.3 Viscous model sensitivity analysis

Simulations were performed to compare the effectiveness of Standard and Realizable options implemented in the k-ε model. Resulting temperature and velocity distributions are given in Fig. 4.

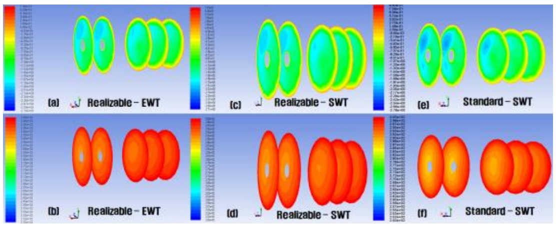

Fig 4. Temperature and velocity distribution in the cross sectional surface with respect to k-epsilon model. X-dir. velocity distribution (a, c, e), temp. distribution (b, d, f)

Unlike the mesh sensitivity analysis, there exist significant differences between Realizable and Standard models. Local non-uniformity of velocity distribution is pronounced in the Standard model compared to the Realizable model.

3. Summary and Conclusions

According to the analysis of mesh sensitivity, no significant differences in distribution of velocity and temperature were found. However, a contrary result was observed during the comparison of Realizable and Standard models. Validation of these models needs to be performed in the future work. Finally, since the distortion of velocity profile is likely to generate potential errors in the measurement, a proper calibration method will be sought for using the upcoming ITSL experiment.

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