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Numerical Analysis on Internal Flow of Westinghouse Moisture Separator for the Development of Similarity Method

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1. Introduction

A moisture separator is an essential component in PWR steam generator. The performance of separator is the most important to assure acceptable steam quality for the operation efficiency in nuclear power plant. The major parameter related to the performance of moisture separation system (MSS) are the moisture carryover (MCO) rate and pressure loss through the MSS. KAERI (Korea Atomic Energy Research Institute) has developed the experimental method to evaluate the performance of Westinghouse (WH) type separator using a scaling law with the reduced models in low pressure air-water test facility. However, a considerable investigation is required to simulate the complex fluid flow of a mixture of two-phase. Besides, there is no verified experimental method based on a scaling law, even though a large number of studies have been carried out. As a preliminary study, in this paper, a numerical analysis is carried out to validate the similarity for the internal flow under a single-phase flow, since the flow field can be assumed as a stokes flow if the only small droplets have low relative velocity to the gas flow, and the single-phase flow field in the internal region is of great importance to better understand the momentum and steam-water separating mechanism.

2. Numerical Implementation

The numerical method solving the continuous phase is with the help of commercial CFD software-FLUENT 18.0.

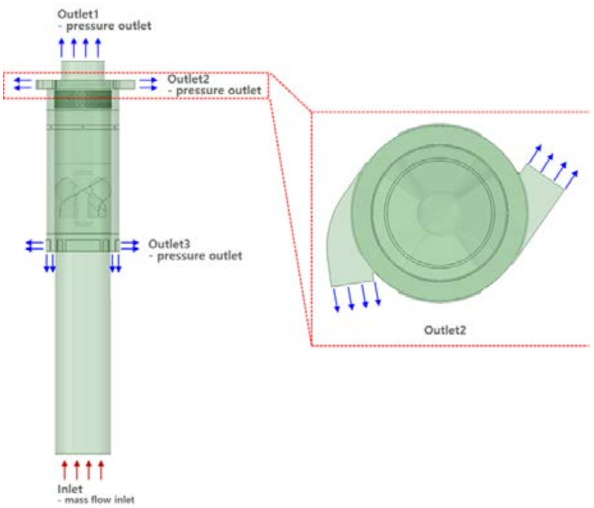

Fig. 2. Boundary conditions for the WH separator

The pressure-based coupled module was applied to solve the steam or air flow-low field in 3D steady state according to the test conditions. The standard $k-\epsilon$ model was adapted for the turbulent flow in the moisture separator. In addition, the gravity effect was considered here. The inlet and outlet boundary conditions are specified as velocity inlet and pressure outlet, respectively, for the geometric model of the separator as shown in Fig. 2. For the whole computational domain, 9,100,000 and 4,080,000 the hexahedral mesh are applied for the full and half scale model, respectively.

3. Analysis of Similarity

Test conditions were determined from the two methods [1, 2] preserving the hydraulic characteristics of separator. There exist several hydraulics representing the fluid flow inside the moisture separator, Among them, following two factors were chosen to simulate the flow under operation condition of prototype to that of test facility.

- Superficial velocity
- Quality and centrifugal forces

It is noted that the detailed explanation was omitted for the three methods to save the space. Table 1 shows the test matrix in this research.

The velocity ratio along the flow path between the model and prototype should be maintained to preserve the kinematic similarity. Besides, the dynamic similarity could be confirmed by comparing the Euler Number from the dimensional analysis. Therefore, in this study, the velocity profile and the Euler Number were compared with each test conditions.

Table I: Test conditions for WE separator

Test ID	Working Fluid	Scale	Flow Rates [kg/s]	Remarks
M-1	Steam	Full	22.680	Prototype
M-2	Air	Full	0.790	Velocity
M-3	Air	Full	4.804	Quality/Fc
M-4	Air	Half	0.197	Velocity
M-5	Air	Half	0.849	Quality/Fc

Figure 3 and 4 shows the pressure and velocity distributions for the whole test cases, respectively. The absolute values are different since the test conditions were obtained from the scaling law considering the difference of density of working fluid. As shown in the

Fig.5 and 6, the averaged velocity ratio along the designated position shows almost constant value. In addition, the value was similar for the same scale model.

The Euler number was compared to evaluate the dynamic similarity and defined as follows;

$$\mathrm{Eu} = \frac{2gA^2\Delta P}{\dot{m}^2}$$

where, the A is the cross section area at the inlet, ΔP is the differential pressure between the inlet and the outlet, and $\dot{m}$ is the mass flow rates at the inlet. The relative error for the full and half scale test conditions are about 1.4-4.4%, 13.2-16.3%, respectively. In the case of half scale, the swirl intensity depends on the diameter, and thus, there was an inherent limitation to simulate the internal flow.

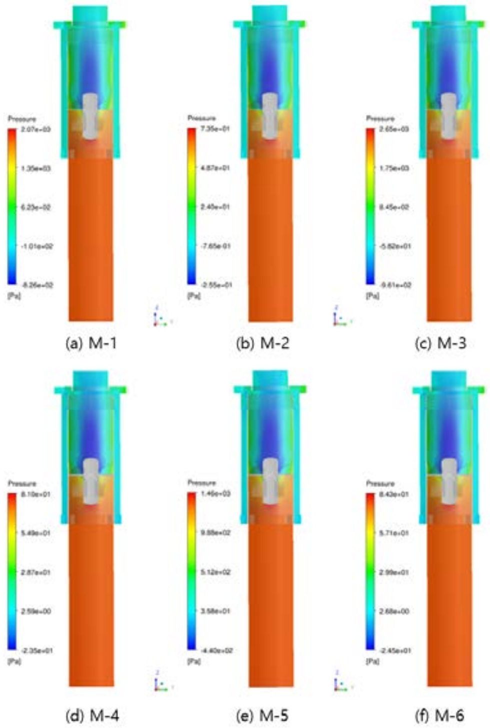

Fig. 3. Pressure distribution in the WH separator

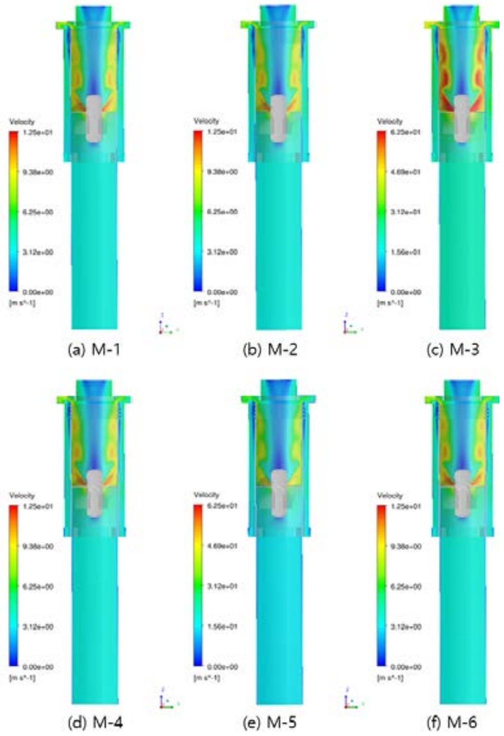

Fig. 4. Velocity distribution in the WH separator

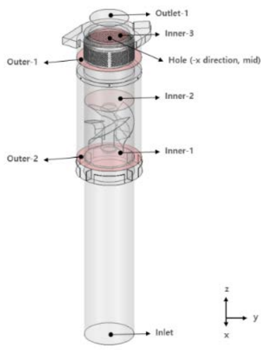

Fig. 5. Schematic of the cross section for comparison of velocity profile

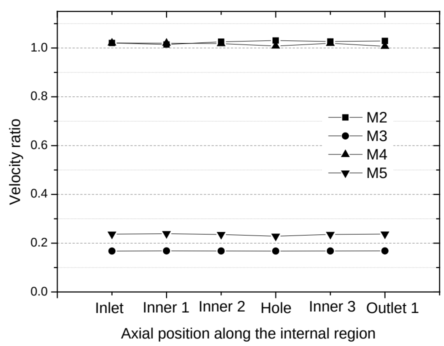

Fig. 6. Velocity ratio along the internal flow path

4. Conclusions

The numerical analysis was conducted assuming a stokes flow in the internal region of separator. Namely, except for the droplet behavior, numerical study was carried out for the model and prototype conditions. The kinematic and dynamic similarities were evaluated for the various test conditions under the single phase flow. The kinematic similarity shows good agreement, and the dynamic similarity is fairly good. The obtained results of this study will be applied practically to the development experimental method to be done in the future at KAERI.

ACKNOWLEDGEMENT

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