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Prediction of ThAI TH-13 Experiment Using CFX User Defined Function

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1. Introduction

Steam with high energy and non-condensable gas induce very complex behaviors of the atmosphere inside the containment which include condensation and evaporation phenomena when an accident happens such as LOCA (Loss-Of-Coolant-Accident). Prediction of these complicated behaviors of the atmosphere inside the containment is highly important when designing a device to prevent rapid pressure increase like a passive heat exchanger in the containment. In this paper, ThAI-TH13 experiment was simulated using the ANSYS-CFX15.0[1]. The wall condensation was modeled using Uchida correlation[2] in a single-phase calculation by User-Defined Functions included in the CFX. A similar study was performed using CFX as described in Ref. 3.

The purpose of this study is to obtain detail methods and analytical technology of the previous study throughout reproduction of the simulation. Also this study is a preliminary calculation to simulate behaviors of atmosphere in the containment based on the recreation of the previous study.

2. TH-13 experiment

2.1 THAI facility

The THAI facility is a cylindrical vessel of 3.2 m diameter and 9.2m height. The total volume is 60m^3. The inner cylinder vessel with an internal diameter of 1.38 m is located between elevations 2.16m and 6.25m relative to the bottom of vessel. The condensation collectors are located at elevation 4.00m from the vessel bottom. Vessel walls and internal structures are all made of steel of thickness between 5 and 130 mm. The outer wall of the vessel is thermally insulated by a layer of heating/cooling jackets which consist of 12mm rock wool and 1mm thick aluminum.

2.2 Specific features of TH-13 experiment

The initial inside of vessel was filled temperature of 22 ℃ and relative humidity of 70% air, in atmospheric pressure. TH13 experiment consists of three phases with gas injection at three different locations and a last phase without gas injection. The gas was injected toward the upper side of the vessel for the first two phases and during the third phase the gas was injected in a horizontal direction. During the first phase, steam at 111℃ and helium at 20℃ were injected from the nozzle located at the top, a height of 5.8m at a mass flow rate of 0.59g/s and 0.16g/s, respectively. The first phase is up to 2700sec. In the second phase, steam at 111℃ was injected at a mass flow rate of 35g/s from 2700sec to 4700sec at the nozzle located on the opposite side of the first nozzle. The second nozzle was located at a height of 5.0m. During the third phase, steam at 111℃ was injected for 1000sec from the nozzle of a height of 1.8m at the bottom of the inner cylinder in horizontal direction. The last phase from 5700sec to 7700sec was observed for the internal flow features of THAI vessel without gas injection.

3. Simulation of TH13 experiment

3.1 Wall condensation model

The wall condensation has been modeled in a single-phase simulation using the Uchida correlation by user-defined function in the CFX code. The condensation near the walls was assumed to occur within only one grid layer adjacent to the walls and the mass and energy sink due to the condensation were implemented within the layer. The mass and energy of condensed water were not treated and a condensed film is not considered. A gaseous mixture which consists of air, helium and steam was modeled in a single-phase to simulate atmosphere including non-condensable gas in the vessel. Steam condensation rate on the walls was calculated from the following Eq. (1) and the enthalpy sink due to the wall condensation was calculated from the Eq.(2).

$$\dot{m}_{sink} = C_u \left(\frac{\rho_{steam}}{\rho_{nc}}\right)^{0.8} A(T - T_{wall})/h_{fg} \tag{1}$$

$$\dot{H}_{sink} = \dot{m}_{sink}(C_{p,steam}T - C_{p,air}T_{ref}) \tag{2}$$

where T means temperature of gas in a cell near the wall. An adjustable coefficient, Cu, was applied and the wall condensation was limited to occur when the steam partial pressure exceeds the steam saturation pressure at the temperature of walls contiguous to the walls. In order to simulate the wall condensation physically, the quantity of mass sink was limited to the same quantity of difference between the steam density in the condensation cell and the saturated steam density at temperature of the condensation surface.

3.2 Input Model

The temperature at the outer wall of the vessel is 22℃ initially with a heat transfer coefficient of 0.0001 W/m^{2}K. In this study, first two phases in TH-13 were simulated and steam and helium were injected as mixed gas phase at 30℃ with a mass flow rate of 0.59g/s and 0.16g/s during the first phase(0-2700sec), respectively. The injection of steam is lasted for 2000 sec during the second phase with a mass flow rate of 35g/s from the nozzle located at a height of 5m.

The turbulence was modeled by k-ε model and buoyancy effect was considered. Cells contiguous to the wall where wall condensation occurs were 2cm wide and the adjustable coefficient Cu of 540 W/m^{2}K. In this simulation, only wall condensation was modeled whereas homogeneous condensation and evaporation in atmosphere will occur, which is believed less important in overall pressure trend. Depending on the quantity of steam, the Uchida correlation has some errors. It might be affected from the effect of homogeneous condensation and evaporation. Therefore, the adjustable coefficient was enlarged by 1.5 times of value when the condensation layer's wide is 2cm to obtain a good agreement between the calculation and the experiment[3].

3.3 Results of the Simulation

Fig.1. shows the pressure change in the ThAI vessel during 4700 sec. For the first phase, pressure increased linearly according to the injection of helium. Helium accumulated around the top of the vessel. Pressure increased rapidly with start of the second injection of steam but it was shown that the pressure changed to increase gradually during the second phase. According to the injection of the steam which has a higher temperature than the saturation temperature at the vessel pressure, the injected steam condensed on the cold walls.

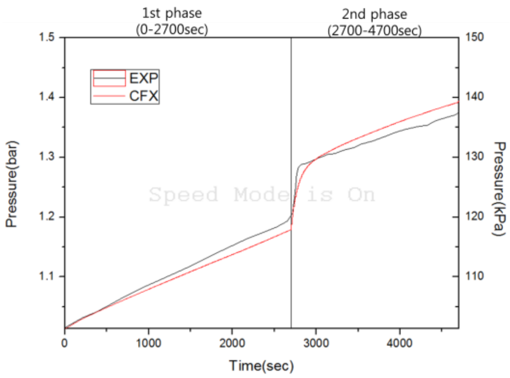

Fig. 1. Pressure distribution in THAI vessel

The molar fraction of helium in the vessel at 2000sec and 2800sec is shown in the Fig.2. As shown in this figure, helium accumulated in the top of the vessel. The molar fraction of helium increases according to the elevation as shown in the Fig.3. During the second phase, the quantity of steam increases gradually similar with the pressure curve. However the results of calculation show that the quantity of condensation is lower than that of experiment. The molar fraction of steam is shown in Fig.4. In the real phenomena, not only the wall condensation but also more complicated behaviors such as homogeneous condensation or evaporation might occur in the vessel.

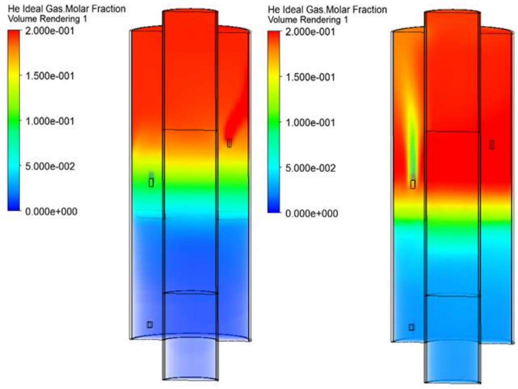

Fig. 2. Molar fraction of helium at 2000sec(Left) and 2800sec(Right)

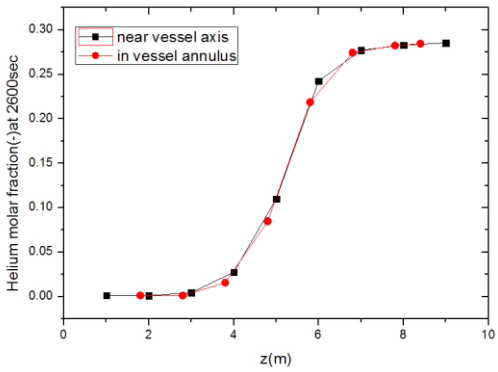

Fig. 3. Molar fraction of helium in elevation at 2600sec

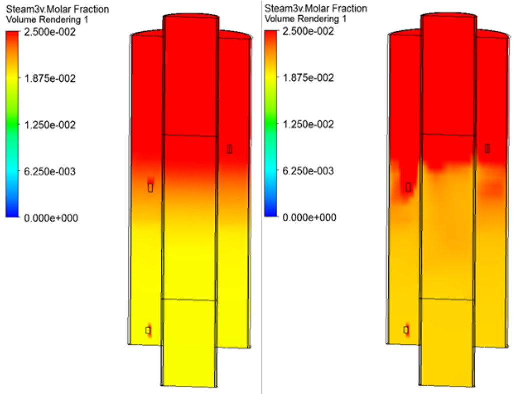

Fig. 4. Molar fraction of steam at 2000sec(Left) and 2800sec(Right)

3. Conclusions

ThAI-TH13 experiment was simulated using CFX based on the previous study. The wall condensation has been modeled in the single-phase simulation using Uchida correlation by user-fortran routines in CFX code. The results of this simulation predicted TH-13 experiment properly and physically in pressure distribution of the atmosphere in a THAI vessel. The results of this study could be useful for a simulation of atmosphere which is the most important factor in evaluation of cooling performance on SMART-PCCS.

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