A Study on the Behavior of Humid Air in Sampling System for Leak Detection

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1. Introduction

Because steam leakage accidents at nuclear power plants could cause various problems such as radiation leakage into the environment and nuclear plants shutdown, it is very important to monitor steam leakage from the safety point of view. The steam leakage sampling system consists of the collection, transfer, and analysis processes for the humid air. The collected humid air was diffused by diffusion and convection in the collection and transport process in the sampling system. Therefore, it is necessary to understand the flow characteristics of the humid air in the sampling system for measuring and analyzing the collected humid air accurately. In this study, we established a numerical methodology for simulating the mixing, diffusion of gas mixture during collection and transportation process. Then diffusion characteristics of humid air were predicted using numerical analysis based on the established methodology, also the behavior of humid air during the transportation process was predicted.

2. Numerical Analysis Method

Two-dimensional transient CFD(Computational Fluid Dynamics) analysis under laminar flow conditions were conducted using ANSYS Fluent(Ver.18) based on the finite volume method for compressible fluid flow.

The laminar flow model was adopted, because the calculated Reynolds number in the transportation tube used in this study were in the range of 375 ~ 1498. We considered the acceleration of gravity for the more realistic CFD analysis for a horizontal tube, because it might affect the flow behaviors. A momentum equation, a continuity equation, and an energy equation were used to analyze the thermal fluid flow in the sampling system, and the multiple species transport equations were adopted to evaluate a variation of humid air concentration.

In this study, the sampling system considered in CFD analysis consists of 49 sensors and straight tubes, with a total length of 100 m. In the sampling system, one sensor had 14 mm of inner diameter and length of 15 mm. A porous medium with a thickness of 2 mm was connected to the outside of the sensor. Straight tubes had 6 mm of inner diameter. In addition, structured grids with about 900,000 grids were employed in the model of CFD analysis.

The boundary conditions adopted in the CFD analysis are shown in Fig. 1. CFD analysis was divided into two sequences depending on the operation mode of the sampling system. The first sequence was a diffusion mode, which humid air flow into through the porous medium of the sensor, the second sequence was a transportation mode, which transports the humid air through a tube. In this CFD analysis, the diffusion mode condition was analyzed for 0 ~ 9.5 s, and then, the transportation mode condition was applied to analyze.

In the diffusion mode condition, wall conditions were applied to the inlet and outlet of the sampling system.

As an initial condition, all regions were filled with the humid air which has 20% relative humidity at 48.89℃(120 ℉). A pressure boundary condition was applied to the inlet of the sensor, and static pressure of

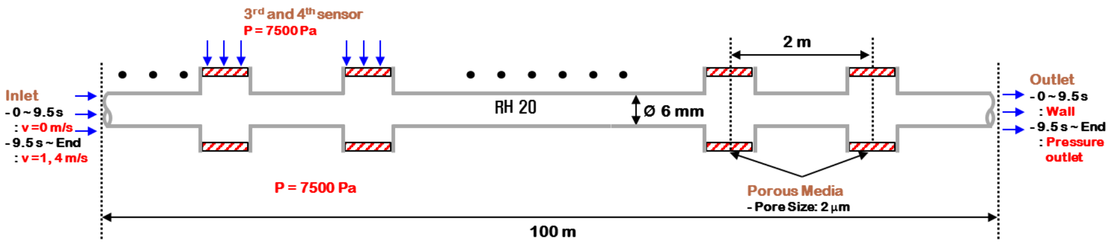

Fig. 1. Analysis domain and boundary conditions for numerical analysis.

Table I: Analysis cases

Case #	Velocity [m/s]		Temperature [C]	Pressure [Pa]		Pore Size [μm]	Turbulence Model	dt [s]	Total Time [s]
	0 ~ 9.5 s	9.5 s ~ End		3rd Sensor	4th Sensor				
V1-02-L-S1	0	1	48.89	7500	0	2	Laminar	0.001	140
V1-02-L-S2	0	1	48.89	7500	7500	2	Laminar	0.001	140
V4-02-L-S1	0	4	48.89	7500	0	2	Laminar	0.001	40
V4-02-L-S2	0	4	48.89	7500	7500	2	Laminar	0.001	40

7500 Pa was applied to the third sensor (or the third and fourth sensors), and static pressure of 0 Pa was applied to the remaining sensors. At this time, the relative humidity of the humid air entering through the sensor was set to be 90% at 48.89 ℃ (120 °F). The pressure applied to the 3rd and 4th sensors was calculated by performing a CFD analysis on the external geometry of the sampling system.

In the transportation mode condition, a velocity boundary condition was applied to the inlet of the sampling system and a pressure boundary condition was applied to the outlet. The applied inlet velocity at this condition was 1 m/s or 4 m/s, and the relative humidity of the supplied humid air was set to be 20% at 48.89℃(120°F).

CFD analysis cases are shown in Table 1. The CFD analysis was performed according to the number of sensors entering the high humidity air and the supplied inlet velocity of the sampling system. Air and steam were assumed to be ideal gas properties. The viscous and inertial resistances of porous medium were set to be 7.575758E+13, and 2.410468E+07 respectively.

3. Results

Fig. 2 shows the average mass fraction of H2O in the vertical sections by axial locations. The third and fourth sensors were installed at 6 m and 8 m respectively in the axial location.

In the cases of inlet velocity 1 m/s, as the number of sensors in which humid air entered increased, the maximum value of the mass fraction evaluated at the outlet of the sampling system was increased. This is because of the humid air entering the two sensors were mixed during the transportation process (Fig. 2 (a), (b). A similar trend was observed in the cases of the inlet velocity of 4 m/s (Fig. 2 (c), (d)).

In addition, as the inlet velocity increases, humid air flow into through the two sensors tended to merge faster than low inlet velocity conditions (Fig. 2 (b), (d)). Because the velocity profile in laminar flow is formed longer as the average flow velocity increases, and convection, compared to diffusion, more contributes to the flow when the inlet velocity increases.

4. Discussion and Conclusion

In this study, the diffusion characteristics of humid air during the diffusion process and the behavior of humid air during the transportation process were investigated by using numerical analysis. The results of this study show that diffusion and convection behavior of the humid air varied according to the inlet velocity, and accordingly the mass fraction of h2o measured at the outlet of the sampling system varied. Therefore, it is important to evaluate the diffusion and convection characteristics of the humid air in the design process of the sampling system. The results of this study may be useful for understanding flow characteristics in the sampling system and designing the sampling system as the basis.

ACKNOWLEDGMENTS

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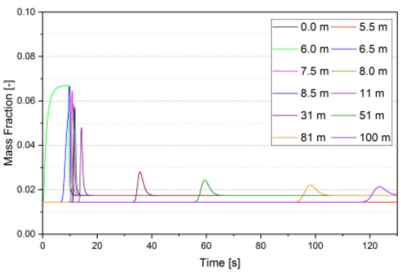
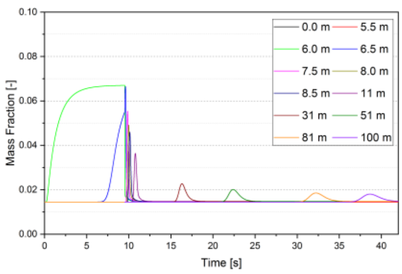
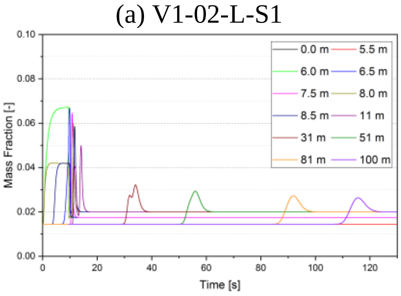


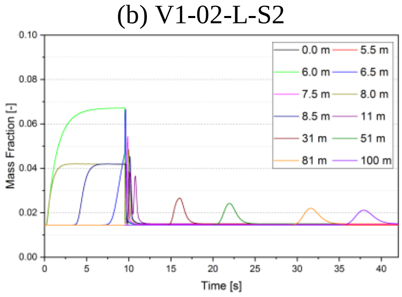
(a) V1-02-L-S1



(b) V1-02-L-S2



(c) V4-02-L-S1



(d) V4-02-L-S2

Fig. 2. Relative humidity change on the centerline of a transportation pipe in cases with high velocity conditions.