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A Study on Flow Characteristics by Air Ingression for Downward Flow Research Reactor

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1. Introduction

We have conducted the experimental and numerical studies on air-water two fluid behaviors in cooling system of RR (research reactor). Previous study showed the flow characteristics and air flow rate according to the pipe rupture size [1]. At the pipe rupture accident, air entrainment phenomena were observed by the differential pressure between pipe and atmosphere. From the results, as the rupture size increases, the pressure difference between pipe inside and atmosphere decreases and air entrainment amount increases. It was also found that the increase of air entrainment has been reduced for the largest rupture size because the pressure is substantially recovered at the medium rupture size in a given pressure difference.

There are other major parameters affecting the phenomena, such as differential pressure, rupture direction, coolant velocity, and so on. In the present study, air-water two fluid behaviors in cooling system were simulated by the pressure difference. And, the flow characteristics and air entrainment amount were analyzed for the pipe rupture size in a given pressure difference.

2. Geometric configuration and numerical methods

The geometric configuration is almost identical to the previous one, as shown in Fig. 1. The height of air inlet boundary is 4 meters and the pipe diameter is 8 inches. Only hexahedral meshes are adopted and total 3.4 – 5.0 million meshes are utilized by the rupture size.

A commercial computational fluid dynamics (CFD) software, ANSYS Fluent, is utilized for the calculation [2]. The fluid motion is modeled by incompressible Reynolds-averaged Navier-Stokes equations. Detailed explanation for the numerical methods was given in the previous study [1].

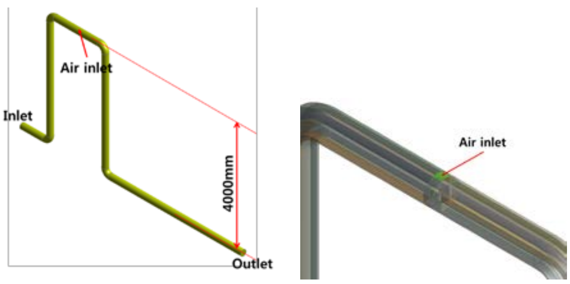


Fig. 1 Geometric configuration of downward flow pipe for air entrainment flow simulation

3. Result and Discussion

Major flow parameters are described in Table 1. Inlet coolant velocity is 2.5m/s and three different rupture size and three differential pressure conditions were assumed to analyze the flow characteristics and observe the air entrainment phenomena. Differential pressure was imposed by controlling the pressure magnitude for outlet boundary.

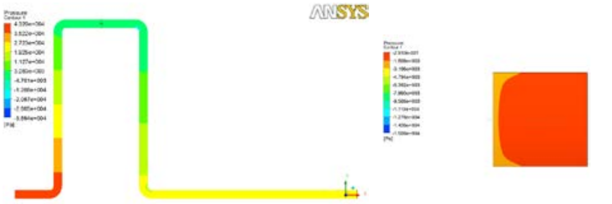
Table 1. Flow parameters for air entrainment simulations

Condition	Coolant velocity	Rupture size (hydraulic diameter)	Differential pressure
Value	2.5m/s	0.02m 0.04m 0.06m	17 kPa 37 kPa 57 kPa

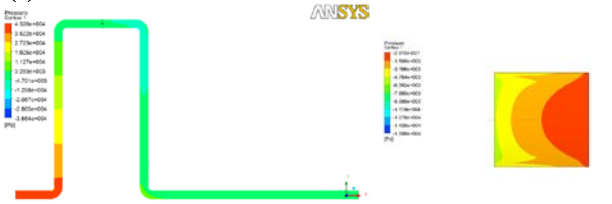
Transient simulations are required to analyze the flow characteristics by air ingression. Prior to the transient calculation, the steady state simulations were conducted until the residuals are lower than 10^{-6}. With the steady state solution, the transient simulations are conducted to advance the flow variables with 0.001 seconds time step and 20 times sub-iterations.

Figure 2 compares the gauge pressure contours according to the pressure difference at the center plane and air inlet boundary with 0.04m rupture size. It can be shown that pressure distributions are similar in all cases. For 17kPa pressure difference case, static pressure near the rupture area is almost recovered to atmosphere pressure by air ingression. However, static pressure is still lower than atmosphere pressure for 57kPa DP case. It means that 0.04 rupture size is sufficient to increase the pressure inside pipe to atmospheric pressure for 17 kPa DP case, but not enough for 57 kPa DP case. In other words, air entrainment amount can be increased by the extension of rupture area.

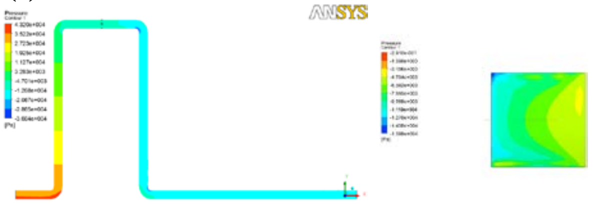
Air volume fractions are compared for three differential pressures between inside and outside at the rupture boundary in Fig. 3. It can be shown that overall air volume fraction contours are similar except for local air volume fraction magnitude near the rupture area. It is also seen that the higher differential pressure causes more air to inflow. In particular, for 57kPa DP case, air volume distribution is different from other cases near the rupture area due to increased air velocity by high differential pressure.



(a) dP = 17 kPa

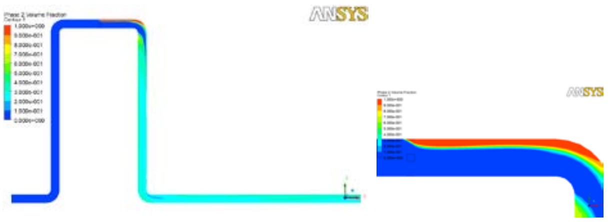


(b) dP = 37 kPa

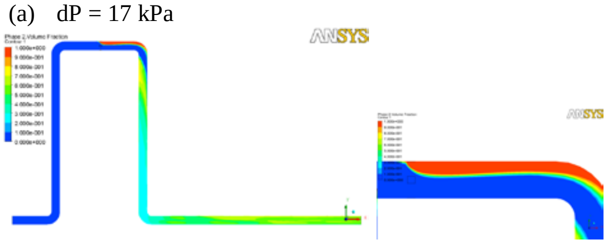


(c) dP = 57 kPa

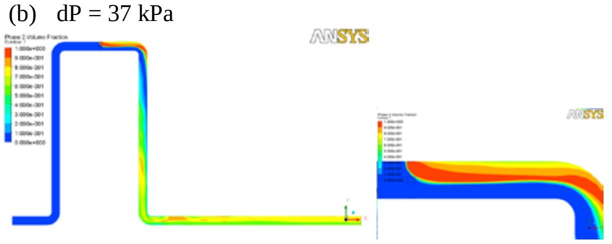
Fig. 2 Pressure contours at center plane and rupture area of the pipe for three differential pressure; a) 17kPa, b) 37kPa, c) 57kPa



(a) dP = 17 kPa



(b) dP = 37 kPa



(c) dP = 57 kPa

Fig. 3 Air volume fraction contours at center plane and rupture area of the pipe for three differential pressure; a) 17kPa, b) 37kPa, c) 57kPa

Air mass flow rate according to the rupture size is compared to each differential pressure in Fig. 4. In all cases, air entrainment amount is increased for larger rupture area and higher differential pressure. It is also shown that changes in air ingression flow to rupture area are reduced as the rupture area increases. However, in a higher differential pressure case, the increase of air inflows is reduced by a relatively small amount. It can be inferred that the pressure inside the pipe is recovered to atmospheric pressure level with small rupture area for lower differential pressure.

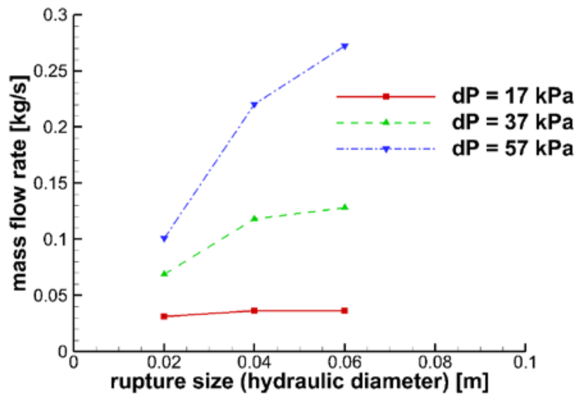


Fig. 4 Mass flow rate variation according to the rupture size for three differential pressure cases

4. Conclusions and Future works

In the present study, air-water two fluid behaviors were simulated to analyze the flow phenomena on the air entrainment and the air ingression rate according to differential pressure and rupture size were calculated. The simulations were conducted on the pipe near the rupture area. As the initial pressure difference is lower, the pressure inside the pipe is increased to the atmospheric pressure level for a given rupture area. On the other hand, initially higher a pressure difference case, large amount of air mass flow rate and high air velocity were predicted. It is also found that the air entrainment increment decreases for the largest rupture area, because the pressure at the highest pipe is substantially recovered at the medium rupture size, especially small differential pressure case.

ACKNOWLEDMENT

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REFERENCES

[1] M.K. Jung, K.J. Park, K.W. Seo, and S.H. Kim, A Numerical Study of Air Entrainment by the Pipe Rupture Size for Downward Flow Research Reactor, Proceedings of the Korean Nuclear Society Spring Meeting, May 17-18, 2018.
[2] ANSYS FLUENT theory guide, ANSYS Inc., 2017.