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Parameter analysis of siphon break in research reactor using computational fluid dynamics

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1. Introduction

In open pool type research reactor, reactor core is cooled by natural circulation after the primary cooling pump is turned off and the pool water is used as the ultimate heat sink. The reactor pool water also behaves as a shielding barrier for many kinds of radio-nuclides from the reactor core. So pool water is essential for nuclear safety. Guaranteeing the pool water inventory to be higher than the required minimum level is one of the most important tasks of a research reactor design. The lowest pool penetration of cooling pipes should be located above the reactor core against a cooling pipe break. However, system components outside the pool can be installed below the core level due to the component purpose such as the acceptance of a net positive suction head of a pump for downward core flow research reactor. So the pool water can be drained below the core through siphon effect and the core can't be cooled through natural circulation when a postulated pipe break occurs below the reactor core position. Therefore siphon breaker should be installed to limit the pool water drain.

Siphon break is very complex two phase phenomena because water and air move fast and mix with fast speed. It is difficult to simulate, so it is needed to understand the siphon break phenomena for siphon break design in a research reactor. For siphon break design, there are several parameters to consider, like depth from highest pipe and lowest pipe, siphon break line size and pool area. In this study, 3 dimensional numerical simulations are performed for siphon breaker design of a research reactor. ANSYS CFD is used to solve the Navier-Stokes equation with turbulent model and two phase model. Various cases of depth of main pipe and siphon break line size are simulated to understand siphon break phenomena.

2. Methods and Results

Numerical simulation using the commercially available CFD code, ANSYS CFD, which solved the Navier-Stokes equation, turbulent model, and two-phase model for various fluid dynamics was used to aid in the understanding of the basic mechanism of siphon break phenomena in a large pipe installed at an actual research reactor.

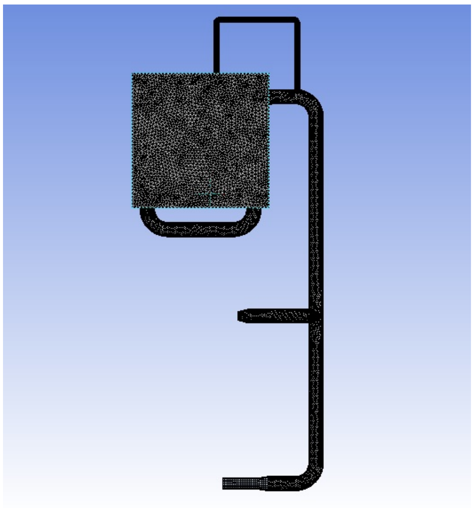

Fig. 1. Mesh of siphon break simulation

2.1 Numerical Model

In order to simulate two-phase phenomena, two-phase model is used. The ANSYS CFX employs homogeneous model and inhomogeneous model. The homogeneous model assumes that both phases are moving with same velocity and inhomogeneous model solves the equation with different velocity between phases.

For siphon break, each fluid can have own flow field and fluids interact through interphase transfer terms. The inhomogeneous model gives solution for each separate phase.

$$\frac{\partial}{\partial t}(r_\alpha \rho_\alpha) + \nabla \cdot (r_\alpha \rho_\alpha U_\alpha) = S_{MS\alpha} + \sum_{\beta=1}^{N_p} \Gamma_{\alpha\beta}$$

$$\frac{\partial}{\partial t}(r_\alpha \rho_\alpha U_\alpha) + \nabla \cdot (r_\alpha(\rho_\alpha U_\alpha \otimes U_\alpha))$$
$$= -r_\alpha \nabla p_\alpha + \nabla \cdot (r_\alpha \mu_\alpha(\nabla U_\alpha + (\nabla U_\alpha)^T)) + S_{M\alpha} + \sum_{\beta=1}^{N_p} (\Gamma^+_{\alpha\beta} U_\beta$$
$$- \Gamma^+_{\beta\alpha} U_\alpha) + M_\alpha$$

$$\sum_{\alpha=1}^{N_p} r_\alpha = 1$$

Where r, S_{MS} and S_M describe the void fraction, mass and momentum sources of phase.

2.2 Mesh and boundary condition

Fig. 1 is the mesh of the siphon break. 150millions of tetrahedral mesh is used after mesh independence test. In top of the pool, air can move freely and atmosphere pressure outlet is at the end of the lowest pipe. Water is full in entire geometry with initial condition.

3. Results

3.1 Results about height of pipe

Cases with various height between highest pipe and lowest pipe are selected. Cases are selected along the middle power research reactor primary cooling system design. Height of the lowest pipe in the primary cooling system is normalized to 1 and the heights of other components of primary cooling system are employed to cases. Table 1 shows the pool level after siphon break with various heights of the pipe. Undershooting height is the height between final pool level and bottom of the highest pipe of the primary cooling system. Undershooting height is the important factor of the siphon break design because the core in reactor pool shall be in the water of the minimum pool level for cooling the core with natural circulation. In table 1, the height of the pipe is contrast to the final pool level, and undershooting height has the same trend with height of the pipe. Table 2 shows the reason of the different undershooting height with the various height of the pipe. In the early state of the siphon break, velocity of the water is maximum because of the hydraulic pressure. And velocity of the water decrease rapidly and finally 0 with final siphon break. In large undershooting case, maximum velocity water is large so large amount of the water goes outside of the pool and final pool level decreases. In this results, siphon break has the effect with maximum water velocity. So to reduce the undershooting height when design the siphon break, maximum velocity of the water should be reduced with pressure loss.

Height of the pipe	Final pool level	Undershooting height
0.71	1.07	0
0.78	1.02	0.65
0.89	1.01	0.8
1	1	1

Table 1. Undershooting height with various height of the pipe

Undershooting height	Maximum water velocity
0	0.84
0.65	0.88
0.8	0.94
1	1

Table 2. Relation with undershooting height and maximum water velocity

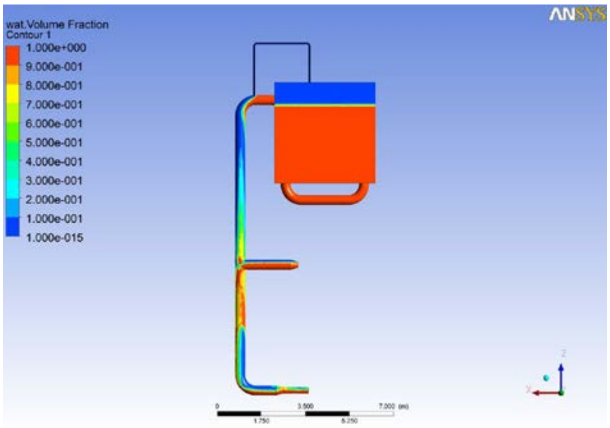

Fig. 2. Contour of water volume fraction when siphon breaking

Siphon line size	Undershooting height
1	1
1.3	0

Table 3. Undershooting height with various siphon break line size

3.2 Results about size of the siphon break line

In middle power research reactor design, undershooting height should be 0 when siphon break occurs. But the results in 3.1 shows there is undershooting height when loss of coolant accident in the lowest pipe of the primary cooling system. Cases with various sizes of the siphon break line are selected. With the large siphon break line size, the undershooting height reduces to 0. With the large siphon break line size, amount of air through the siphon break line increases. So siphon can be break easily with much air. In this cases, to reduce the undershooting height, air through the siphon break line should increase.

4. Conclusions

In siphon break design of research reactor, various height of the pipe were compared to analyze the effect when loss of coolant accident occurs to the components of the primary cooling system. The results show undershooting height is largest when loss of coolant accident occurs in the lowest pipe of the primary cooling system.

To reduce the undershooting height, siphon break line size was increased. With large siphon break line size, undershooting height can be reduced to 0. But it is needed to be optimized because of the financial and spatial effect.

Siphon break phenomena is affected from maximum water velocity and the amount of the air. With large maximum velocity, undershooting height increases because more water goes outside of the pool. With large amount of the air, undershooting height decreases because siphon phenomena can be easily break because of large amount air.

Based on a numerical simulation, it was evaluated that various parameters had effect on siphon break and it would help the design of the siphon break

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