Estimation of Siphon Break in a Research Reactor using CFD analysis

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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 pool water also behaves as a shielding barrier for many kinds of radio-nuclides from the reactor core and the spent fuel. Pool water is essential for nuclear safety. So 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(NPSH) 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.

In this study, 3D numerical simulations are performed to be applicable to the siphon breaker design for a research reactor because undershooting(height between the end of siphon break line and the final pool water level) is expected for a large pipe break(Fig. 1). ANSYS CFD is used to solve the Navier-Stokes equation with the turbulent model and two-phase model.

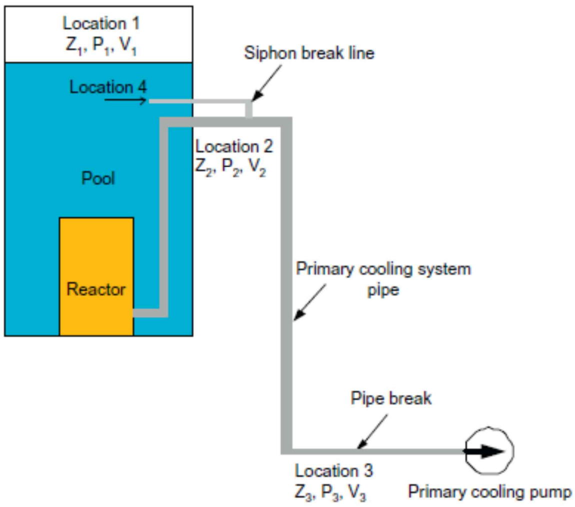

Fig. 1. Schematic diagram of the siphon break phenomena

2. Methods and Results

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

2.1 Numerical Model

In order to simulate two-phase phenomena, two-phase model is used. The ANSYS CFD employs homogeneous model. Since the homogeneous model assumes that both phases are moving with same velocity. It solves the bulk transport equation.

$$\frac{\partial}{\partial t}(\rho\varphi) + \nabla\cdot(\rho U\varphi - \Gamma\nabla\varphi) = S$$

2.2 Mesh and boundary condition

Fig.2 shows mesh of siphon break simulation. The number of mesh is above 1 million. The meshes are composed of hexagonal type and tetrahedral type. The pool water surface is modeled by the standard free surface model and the opening type boundary condition with atmosphere pressure. The fluid flows out through bottom pipe with pressure outlet. Simulation starts from the initial condition of the stagnant flow of the pool water and is progressed by the head of the pool water.

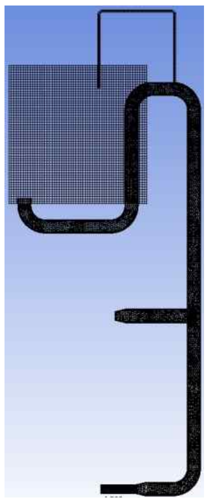

Fig. 2. Mesh of siphon break

Table 1: Comparison of undershooting height with various rupture (outlet) size

Main pipe size	Rupture (outlet) size	Siphon break line size	Turbulence model	Two phase model	Undershooting height ratio
1(designed)	0.625	1(designed)	SST model	Homogeneous	0
1(designed)	0.75	1(designed)	SST model	Homogeneous	0
1(designed)	0.875	1(designed)	SST model	Homogeneous	0.78
1(designed)	1(designed)	1(designed)	SST model	Homogeneous	1(criterion)

2.3 Results

Table 1 shows comparison of undershooting height with various rupture size. Main pipe size and siphon break line size are designed size. Undershooting height decreases with decreasing rupture size. Because when rupture size decreases, flow rate through rupture also decreases. With 0.625 and 0.75 rupture size, undershooting height is 0 from certain criteria. In these cases, air flow through siphon break line can break water flow easily. When water flow increases, water flow can't be broken easily and water level decreases.

Table 2 is comparison of undershooting height with various siphon break line size. Main pipe size and rupture size are designed size. Undershooting height increases with decreasing siphon break line size. Because when siphon break line size decreases, air flow from siphon break line decreases so water flow can't be broken easily and water level decreases. With 0.5 siphon break line size, undershooting height is greatly increased from certain criteria.

Table 3 is comparison of undershooting height with changed main pipe size. Changed main pipe size is 1.125 times of existing main pipe size. Trend of undershooting height is similar with table 1, but height is larger than table 1. Because main pipe size increases so water flow increases and can't be broken easily.

Table 2: Comparison of undershooting height with various siphon break line size

Main pipe size	Rupture (outlet) size	Siphon break line size	Turbulence model	Two phase model	Undershooting height ratio
1(designed)	1(designed)	1(designed)	SST model	Homogeneous	1(criterion)
1(designed)	1(designed)	0.83	SST model	Homogeneous	1.25
1(designed)	1(designed)	0.67	SST model	Homogeneous	1.92
1(designed)	1(designed)	0.5	SST model	Homogeneous	7.83

Table 3: Comparison of undershooting height with changed main pipe size

Main pipe size	Rupture (outlet) size	Siphon break line size	Undershooting height ratio
1.125	0.625	1(designed)	0
1.125	0.875	1(designed)	0.64
1.125	1.125	1(designed)	0.8
1.125	1.5	1(designed)	1(criterion)

Table 4: Comparison of undershooting height with various loss coefficient near outlet

Main pipe size	Rupture size	SB line size	Loss coefficient	Undershooting height ratio
1.125	0.875	1(designed)	1(designed)	0
1.125	0.875	1(designed)	0.83	0
1.125	0.875	1(designed)	0.67	0
1.125	0.875	1(designed)	0.56	0

Table 4 is comparison of undershooting height with various loss coefficient near outlet. Base case is second case in Table 3 because this case is new designed case. With designed loss coefficient of pipe system, there is no undershooting height. It is also smaller loss coefficient case. With loss coefficient, water flows out slowly so undershooting height can decrease.

3. Conclusions

Siphon breaker was designed to satisfy the minimum pool water level requirement during pipe break in a research reactor, and it is necessary to analyze siphon break phenomena.

The results employing the various rupture size and siphon break line size were compared. Undershooting height increased with increasing rupture size and decreasing siphon break line size. In larger main pipe size, trend was similar and undershooting height increased. With loss coefficient near outlet region, undershooting height decreased.

Based on a numerical simulation, it was evaluated that various parameters had effect on siphon break performance and it would help design of primary cooling system.

ACKNOWLEDGEMENT

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