In-pipe Pressure Design Guideline for Downward Forced Flow Cooling System in Research Reactor

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1. Introduction

In an open pool type research reactors, cooling methods as flow direction in a reactor core are usually selected one of upward or downward forced flow. In consideration of the advantages for the reactor utilization and operation aspect for the research reactor, the downward forced flow system is applied for the core cooling system. From the reactor operation point of view, the vibration of fuel assemblies and experimental equipment caused by high coolant velocity are not concerns in the downward flow system. And in the downward forced flow system, there is no need for special holding equipment for locking the fuel and irradiation ingots. However, in the research reactor operating at a relatively high thermal power, a high flow velocity through the core provides an adequate heat removal but results in a large pressure loss in the core. For the downward flow system, this large core differential pressure causes the pressure problem in the pipe on the pump inlet. So, it is essential the pressure distribution analysis in the pipe for the downward flow system.

In this study, the model of the downward flow cooling research reactor is assumed and the pressure in the pipe installed the highest height in the core cooling system is analyzed. Also, the design criteria for the stable and conservative design are suggested.

2. Methods and Results

2.1 Downward flow cooling research reactor model

In this study, the model of the downward flow cooling research reactor is assumed and Fig. 1 shows a schematic of the general downward forced flow cooling system which is composed of the reactor pool, core, a cooling pump, and piping. In this paper, all the components for core cooling are not considered but minimum components for pressure calculation are applied.

The assumptions for in-pipe pressure calculation are as follows:

1. Reactor core outlet temperature(T_{in}): 40°C
2. Pool height (h_{pool}): 10m
3. Pipe height(h_{pipe}): 5m
4. Total pipe length: 20m
5. Used elbow: 3 ea
6. Pipe size: 20 inch

In order to analyze the effects of core differential pressure and mass flow rate, they are specified as the dependent variables.

1. Reactor core differential pressure (DP_{core}): 0 ~ 100 kPa
2. System mass flow rate($\dot{m}$) and velocity: 250(1.34 m/s), 300(1.61 m/s), 350(1.87 m/s), 400(2.14 m/s) kg/s

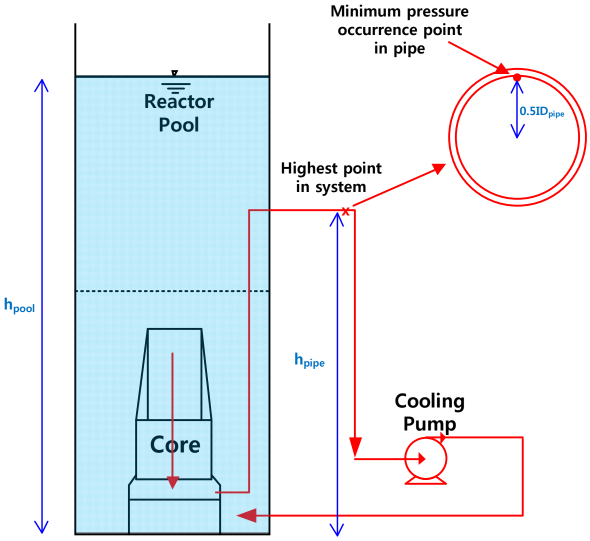

Fig. 1. Schematic of downward forced flow cooling system.

2.2 Calculation of the in-pipe pressure at highest pipe

The hydrostatic pressure can be maintained by the atmospheric pressure and the height of pool. If the height of the pipe penetration is higher than the bottom of reactor pool, the hydrostatic pressure decreases as that height. And since the pipe height is specified the center of pipe (COP) as the base, the highest point in the pipe should be additionally considered the half of the pipe inner diameter. The hydrostatic pressure considered here can be calculated by:

$$h_{hyd} = h_{atm} + h_{pool} - h_{pipe} - \tfrac{1}{2} ID_{pipe}$$

where h_{atm} is head for atmospheric pressure.

While the cooling pump is operating, the pool water is flowed to the pump inlet through the reactor core and the system pipe. In order to analyze the pressure in the pipe, the differential pressure through the reactor core and the head loss in the pipe should be considered. Additionally, the dynamic pressure loss by the flow velocity should be calculated. The lowest pressure in the system pipe will be formed at the highest position in the pipe as seen in Fig. 1. The in-pipe pressure at the highest position can be calculated by:

$$h_{highest} = h_{hyd} - h_{core} - h_{pipe} - h_{dyn}$$

where h_{core} is head loss by the reactor core differential pressure, h_{pipe} is head loss in the pipe, and h_{dyn} is dynamic pressure loss in the pipe.

The pressure criteria for the system design can be the vapor pressure in the pipe and the atmospheric pressure as the reference. During the normal operating, if in-pipe pressure at the highest point is lower than the vapor pressure, the bubble will be formed in the pipe. The formed bubble can go to the cooling pump. It can influence to the integrity of the pump. Due to this reason, the pressure in the system should be maintained more than the vapor pressure.

Secondly, if the in-pipe pressure at the highest point is lower than the atmospheric pressure, the outside air will be come in the pipe in case of the pipe breaking accident. If this air goes to the cooling pump, that can be stopped or malfunctioned. Therefore the pressure in the system should be maintained more than the atmospheric pressure. However, it is difficult to design the pressure in the system in this pressure range due to high core differential pressure and required flow rate such as thermal design flow (TDF).

In summary, the system design criteria can be suggested as follows:

1. During the normal operating without forming the vapor

   $P_{highest} > P_{vapor}$

2. During the LOCA without intake of the outside air

   $P_{highest} > P_{atm} \simeq 101.325kPa$

The in-pipe pressure at the highest point shall be essentially satisfied first requirement. However, occasionally, second requirement can be released as the correspondence scenario in case of the pipe breaking accident.

Fig. 2 shows the calculation results of the in-pipe pressure at the highest point in pipe as a function of the core differential pressure and mass flow rate. As the core differential pressure increases, the in-pipe pressure at the highest point is proportionally decreased. And as the mass flow rate increases, the in-pipe pressure is decreased.

As shown in Fig. 2, at the mass flow rate of 250 kg/s and the core differential pressure of 100 kPa, the vapor in the pipe is not formed during the normal operating, but the outside air can be come to inside the pipe in case of the pipe breaking accident of the highest point. In order to prevent the intake the air, the core differential pressure should be designed lower than about 65 kPa or the mass flow rate should be decreased. At the mass flow rate of 400 kg/s, if the core differential pressure is more than about 75 kPa, the bubble will be made inside pipe during the normal operating. In order to prevent the formation the bubble inside the pipe, the core differential pressure should be designed lower than about 75 kPa. Available design range in these results is marked the blue box in Fig. 2.

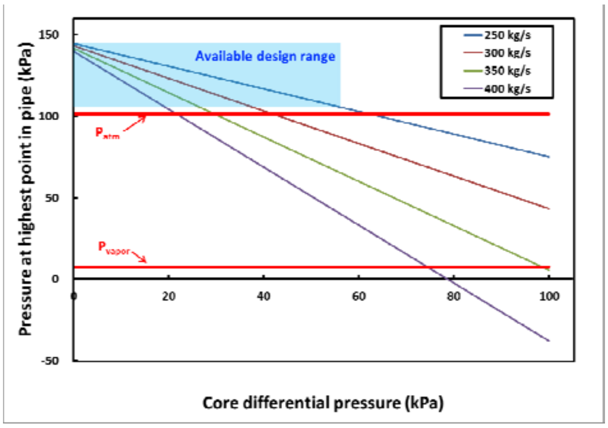

Fig. 2. Calculation of in-pipe pressure at the highest point as a function of the core differential pressure and flow rate.

For the stable and conservative design, the pool height can be increased to retain the hydrostatic pressure or the pipe size can be made larger to decrease the dynamic pressure effect.

3. Conclusions

The model of the downward flow cooling research reactor is assumed and the pressure in the pipe installed the highest height in the core cooling system is analyzed. Also, the design criteria for the stable and conservative design are suggested.

The pressure criteria for the system design can be the vapor pressure in the pipe and the atmospheric pressure as the reference. During the normal operating, if in-pipe pressure at the highest point is lower than the vapor pressure, the vapor will be formed in the pipe. Secondly, if the in-pipe pressure at the highest point is lower than the atmospheric pressure, the outside air will be come in the pipe in case of the pipe breaking accident.

This result means the design limit of the vapor pressure in the pipe and the atmospheric pressure should be applied for the stable design of the cooling pump operation. If the design value is over the requirements, the integrity of the pump cannot be guaranteed.

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