Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Experimental Approach of the Inner Flow in Decay Tank of Research Reactor

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1. Introduction

Research reactor is aimed for getting neutrons while nuclear power plants for electrical power. Neutron is applied to various fields, such as a non-destructive inspection and a development of medical medicine for cancer or incurable disease.

Radionuclides are produced in a research reactor after nuclear reactions. N-16 is the main radionuclide generated in the reactor core which emits the strongest ɤ-rays among the various radionuclides, so it can damage to other equipment such as pipe, valve, and pump. To reduce the radioactivity of N-16, a decay tank is installed in the Primary Cooling System (PCS) of research reactor. The decay tank is designed to ensure the sufficient residence time of approximately 60 seconds. After 60 seconds, N-16 of which half-life is 7.13 seconds comes to have lower activity level as the other radionuclides.

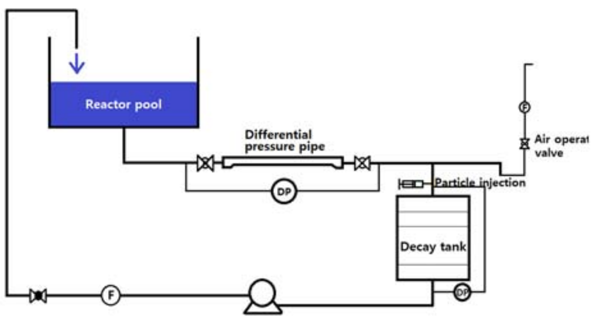
Several researches have focused on the safety of research reactors in terms of the decay tank. There is a research about the assessment of the decay tank's stability. Kwak et al. [1] conducted the structure evaluation using ANSYS FLUENT tools to confirm whether the decay tank satisfies the allowable stress and the fatigue strength based on the material. Jung et al. [2] estimated the residence time and the flow distribution using ANSYS Fluent. By using Discrete Phase Method (DPM) the residence time is calculated by utilizing virtual particles like a streamline. Also, User Defined Scalar (UDS) method calculates using tracer as virtual scalar. As a result, DPM has less calculational cost and robustness, UDS has accurate residence time.

If there is a crack or pipe rupture on the apex of the PCS pipe, ambient air will flow into the pipe since the inner pressure is lower than the atmospheric pressure due to the pressure drop in the reactor core. Consequently, the inner flow becomes two-phase flow. This influx of air may influence the interior structure of the decay tank, or the air could move to PCS pumps, which causes to damage the pump blades.

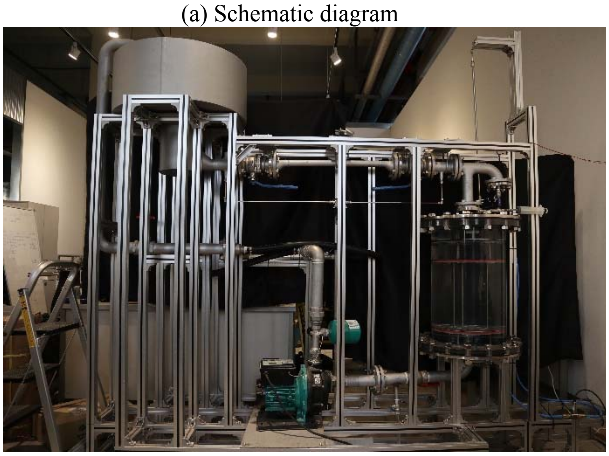
For these reasons, the experimental research will be conducted to analyze behavior of the two-phase flow inside of the decay tank. Through this research, it is expected that the simple detection system which prevents pump malfunction accidents in advance.

2. Design of the experimental facility

Generally, PCS removes fission heat by driving downward flow in the reactor core. Pressure drop occurs through the fuel rods in the core. To replicate this situation, reactor pool and Differential Pressure Pipe (DPP) were installed as Fig. 1. (a). The main pipe diameter was installed into 2 inches. The water flows from the bottom pump to the reactor pool which is open to atmosphere. In the apex of decay tank pipe, there is pressure drop by passing through DPP which its diameter is 3/4 inches. Thus, to adjust the air inflow rate, the additional line was installed with nozzle which is possible to change the diameter. The differential transmitter was equipped to measure the differential pressure between inlet and outlet of the decay tank. Due to this transmitter, it is expected to be a system that is able to detect immediately occurrence of formation of two-phase flow and pipe rupture accident.



(a) Schematic diagram



(b) Manufactured apparatus
Fig. 1. Experimental facility

2.1. Decay tank

In this research, a small size decay tank was designed by considering similarity. It was referred to the decay tank in Jordan Research Training Reactor (JRTR). This decay tank diameter was 3.6 m, and the height was 6.7 m including inlet and outlet. The modeled decay tank was scaled down into 1/10 of the JRTR by considering geometrical similarity, and the inner diameter and height of modeled decay tank were set at 380 mm and 670 mm respectively, excluding the inlet and outlet. The assembly of decay tank is shown in Fig. 2. To visualize the inner flow of decay tank, it was manufactured in acrylic, and Fig. 1 (b) shows the experimental facility and transparent decay tank.

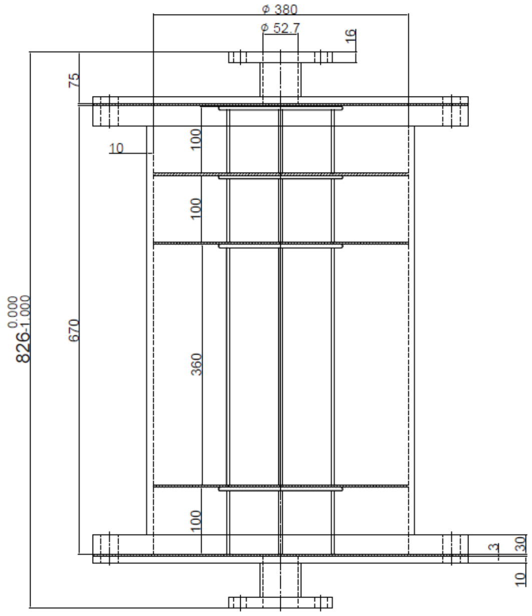


Fig. 2. Assembly of decay tank

2.2. Perforated plates

According to Jung et al. [2], the area ratio of a perforated plates to hole on the plates was 64:1. The plates were referred to determine the area occupied by holes, as a result, it was designed as shown in Fig. 3. To prevent scratches on acryl surface that may occur during installation, the diameter of three perforated plates was designed as 370 mm, which was 10 mm less than the inner diameter of decay tank. The gap was sealed by using O-ring and silicon to prevent bypass flow and make water flow only along the holes. In addition, the perforated plates were composed into three plates according to research of Jung et al. [2], those intervals of plates were 100 mm, 100 mm, and 360 mm as shown in Fig. 2. Overall, the scaling ratio and values of the decay tank and perforated plate compared with prototype, JRTR, are listed on Table 1.

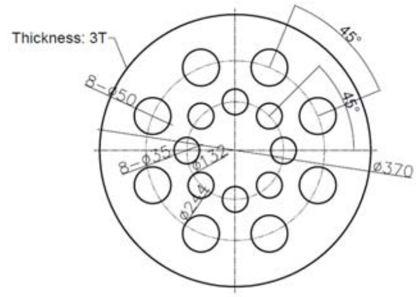


Fig. 3. Design of perforated plate

Table 1. A list of scaling

Parameters	Prototype (JRTR)	Model
Length [mm]	6700	670
Tank diameter [mm]	3600	380
Main pipe diameter [inches]	16	2
The perforated plate area to hole area ratio	64:1	73.5:1

3. Results

3.1 Simulated results

In this research, the residence time and differential pressure through decay tank were simulated in theoretical way. According to Jeong et al. [3], the residence time in the decay tank requires at least 60 seconds in the ideal case with a uniform velocity inside the tank. As inlet velocity of the water flow gets faster, the residence time becomes shorter. The scale-down tank should guarantee the low level of the radioactivity, so the range of the flow rate was calculated according to equation (1) and the result is shown in Fig. 4. Q indicates the inlet flow rate in LPM, v indicates water velocity in m/s, A indicates a cross section area of decay tank in m^2, h indicates a height of decay tank, and t indicates the residence time. When the residence time is about 60 seconds, the inlet flow rate is required around 80 LPM.

$$Q = vA = \frac{h}{t}A = 77.4 \text{ [LPM]} \quad (1)$$

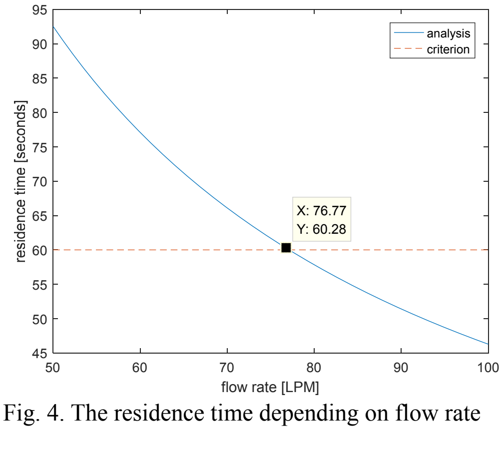
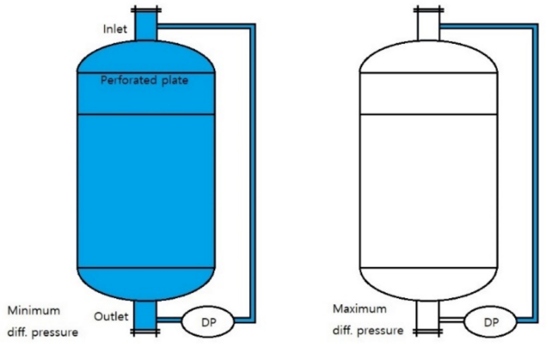


Fig. 4. The residence time depending on flow rate

In general, the differential pressure will be merely about the head loss due to the geometry inside of the decay tank including perforated plates as shown in Fig. 5 (a). However, if the air starts to flow into the decay tank, then the differential pressure in the decay tank will be increasing. The maximum differential pressure was estimated in case that air invades and is trapped in the decay tank. In an extreme case, the decay tank may be full of the air like Fig. 5 (b). The maximum differential pressure is estimated to 6.7 kPa as the following equation (2). The symbol ρ indicates the density of water in kg/m^3, and g indicates gravitational acceleration in m/s^2.

$$\Delta P = \rho g h = 6.7 \text{ [kPa]} \quad (2)$$



(a) Normal operation (b) Extremely accident case

Fig. 5. Pressure difference due to the influx of air

Therefore, in order to observe effect of the two-phase flow inside of the decay tank, nozzle size and DPP size will be independent variables as Table 2, and the experimental research is planned to be conducted.

Table 2. Test matrix of air trap experiment

Nozzle size [inches]	DPP size [inches]
1/4	3/4
	1
3/8	3/4
	1
1/2	3/4
	1

3.2 Experimental results

After manufacturing apparatus, there was an experiment to observe the aspect of inner flow due to the influx of air. This experiment was conducted with 1/4 inches nozzle, 3/4 inches DPP, and 60 Hz of the pump. As a result, the influx of air was trapped as shown in Fig. 6.

There will be conducted more experiments to obtain precise results by using flow meters and pressure transmitter. Moreover, the residence time will be measured in experimental way based on simulated results.

(a) 2 seconds (b) 70 seconds (c) 100 second

Fig. 6. Trapped air inside of the decay tank

4. Conclusion

If the apex of PCS pipe gets cracked, the air flows into the pipe. Since the flowing becomes to two-phase flow, it may incur pump malfunction. Hence, observing the influence of influx of air in PCS, it is able to attribute to increase the safety of PCS.

Evaluating the residence time is crucial in eliminating radionuclide. There are many articles about the residence time using CFD program, however, it is less to measure the residence time in experimental way.

In this research, the experimental facility was designed by considering similarity, and the criterion have been set through the theoretical method. These results will be utilized to conduct experiments in regard to air trap experiment and measuring the residence time.

The residence time following the flow rate was theoretically evaluated in the modeled decay tank to insure primary function of decay tank that is to disturb the activity of radionuclides. To guarantee the safety of research reactors, it is necessary to study the behavior of two-phase flow inside decay tank which is formed due to the pipe rupture on the apex of PCS pipe. In addition, it will be estimated the differential pressure change to observe the influence of two-phase flow by using various nozzle size and DPP size.

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