Study on Purification Efficiency along System Designs in an Open-pool Research Reactor

Jungwoon Choi*, Dayong Kim, and KyoungWoo Seo
KAERI, Research Reactor System Design Div., #111, 989 St., Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: ex-jwchoi@kaeri.re.kr*

1. Introduction

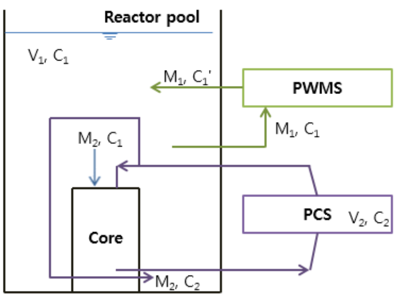
For the multi-purposes utilization, such as neutron beam utilization research, radio-isotope production for medical treatment, irradiation facility for other objectives, etc., research reactors are generally designed with a nuclear core in an open pool. The main fluid systems are composed of a primary cooling system (PCS) for a core cooling, a pool water management system (PWMS) for purification, and a hot water layer system (HWLS) to minimize the radiation level at the pool top. The pool water and primary coolant should be managed within the allowable water chemistry limits to minimize the corrosion of the nuclear fuel cladding and systems through the operation of the pool water management system.

According to the intake points for the purification, the purification flow rate of the PWMS should be designed differently and should be found at an optimal value for the economic efficiency. The intake points for purification can be considered as two cases: one branched from the PCS and the other from the reactor pool. The considered PCS is designed with a quasi-closed loop due to a grid plate cooling flow supplied at the lower section of a reactor structure assembly.

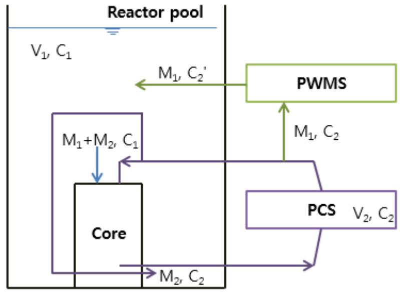
In this paper, the purification efficiency using the flow rate parameter is discussed in the above-mentioned two cases to find the optimized intake point at the economic aspect.

2. Results and Discussion

A research reactor generally has three sections of the pool: the reactor pool, the service pool, and the spent fuel storage pool. The reactor pool, the service pool, the spent fuel storage pool, and primary coolant are purified by the PWMS. Depending on the intake point for purification of the reactor pool and primary coolant, the flow paths can be different as shown in Fig. 1.



(a) Intake from the reactor pool



(b) Intake from the PCS

Fig. 1. Flow paths in the reactor pool

As shown in Fig.1, the primary coolant flows from the bottom of the core and goes to the components of the primary cooling system to remove the heat delivered from the core, and then flows back to the top of the core. Before flowing back to the core, a small portion of the primary coolant flows for the grid plate cooling. In the case (a), the PWMS intakes small portion of the reactor pool water; in the case (b), small portion of the cooled primary coolant is supplied to the PWMS to purify the radioactive ionic impurities.

As the general approach to the research reactor design, the purification half-life is 6 hours in the reactor pool with the primary coolant in the PCS since the major contamination source is impurities in the PCS flow through the core. Since the sizing of the filter and ion exchanger depends on the purification flow rate, the optimized purification flow rate shall be determined at the aspect of the economic capital cost. From the following Eq.1, an initial purification flow rate can be calculated. [1]

$$\text{purification flow rate} = \frac{total\ inventory}{purification\ half\ life \times ln2} \qquad \text{(Eq.1)}$$

Upon the two cases, the governing equations follow under the basis of the flow pattern as shown in Fig. 1. Eq.2 is based on the conductivity variation of the PCS coolant loop. Eq.3 presents the conductivity variation of the pool water of the reactor pool. The decontamination factor (DF) of the PWMS ion exchanger is considered as 1.0 for simplicity of the equations; the exit conductivity of C_1' and C_2' becomes “0”.

$$\rho_1 V_1 \frac{dC_1}{dt} = -AC_1 + BC_2 \qquad \text{(Eq.2)}$$

$$\rho_2 V_2 \frac{dC_2}{dt} = DC_1 - EC_2 \qquad \text{(Eq.3)}$$

Here, ρ is a pool water or primary coolant density, M is the flow rate, C is the conductivity, V is the purification volume, and t is the elapsed time.

Table I: Constant in Eq.2 and Eq.3

	Case (a)	Case (b)
A	$M_1 + M_2$	$M_1 + M_2$
B	M_2	M_2
D	M_2	$M_1 + M_2$
E	M_2	$M_1 + M_2$

From Eq. 2 and Eq. 3, the exponential functions of C_1 and C_2 can be drawn with the initial conductivities of the reactor pool and PCS coolant (1:2), referenced from the HANARO operation data. Fig. 2 shows the conductivity trends of the reactor pool water and the primary coolant. When the contaminated water comes directly into the pool water like the case (a), the initially designed flow rate is not enough to maintain the water chemistry within the allowable limit because the initial conductivity of the pool water and primary coolant aren't reduced into a half within the purification half-life, 6 hours.

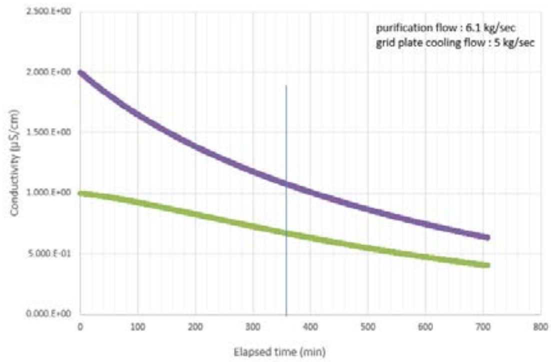


Fig. 2. Conductivity trends of the reactor pool (C_1) and PCS coolant (C_2) in the Case (a)

Unlike, when the small portion of primary coolant is purified through the PWMS and discharged into the reactor pool, the designed flow rate is slightly insufficient to meet the water chemistry requirement because the conductivity of the pool water approaches almost a half within 6 hours as shown Fig. 3.

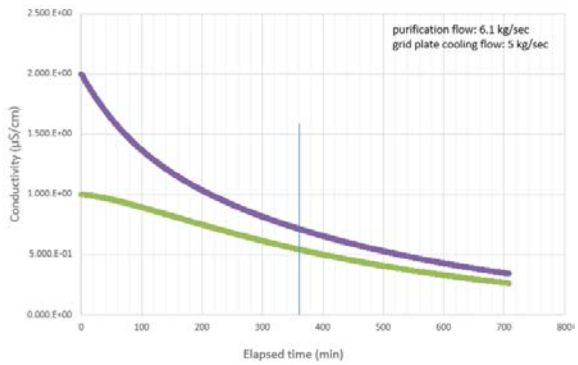


Fig. 3. Conductivity trends of the reactor pool (C_1) and PCS coolant (C_2) in the Case (b)

In the case (a), the purification flow rate shall be increased from 6.1 kg/s to 9 kg/s to have a half of initial conductivity in reactor pool within the purification half-life as shown in Fig. 4. In contrast, Fig. 5 shows that the flow rate for the case (b) shall be increased slightly to 6.6 kg/s to satisfy with the designed condition. From the additionally required purification flow rate in each case, the intake from the PCS loop has better purification efficiency than the intake from the reactor pool with the small grid plate cooling flow rate.

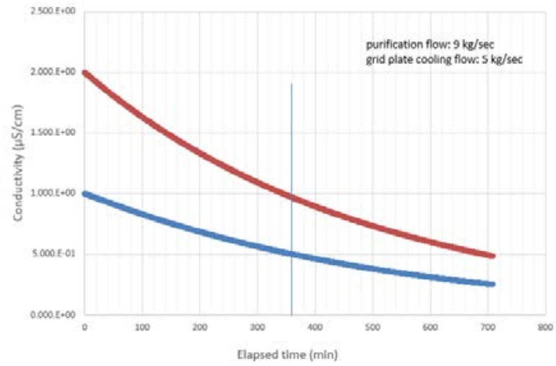


Fig. 4 Conductivity trends of the reactor pool (C_1) and PCS coolant (C_2) at flow rate 9 kg/s in the Case (a)

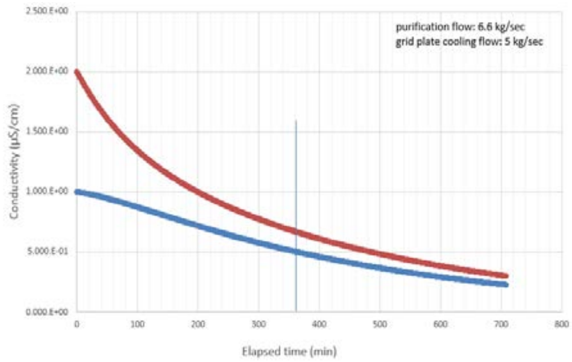


Fig. 5 Conductivity trends of the reactor pool (C_1) and PCS coolant (C_2) at flow rate 6.6 kg/s in the Case (b)

3. Conclusions

Under a quasi-close loop of the PCS design and 6 hours of the purification half-life, the required purification flow rate in the case of the intake from the PCS is calculated much smaller than that in the other case. Accordingly, the sizing of the purification unit in the case (b) can be smaller and the installation and maintenance area can be smaller. From these results, the PWMS can be designed more efficient with the intake from the PCS loop to purify the reactor pool water and primary coolant from the purification and economic capital cost points of view.

ACKNOWLEDGEMENT

This Work was supported by the Research and Development grant funded by the Ministry of Science, ICT and Future Planning of Korea.

REFERENCE

[1] KM-333-DD-P001, "Design Manual for KMRR Primary Purification System: Part B.", Rev.1.