Operating Condition Analysis for Closed Flushing of Primary Cooling System in the KJRR

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1. Introduction

During the commissioning of a research reactor, flushing is performed before and after reactor installation to remove foreign materials from the primary cooling system and ensure system cleanliness. Following flushing, system performance tests are conducted to verify the flow rate, pressure loss, and functionality of major components.

Research reactors are utilized for various purposes, including education and training, neutron activation analysis, radioisotope production, neutron radiography, and materials testing [1].

In the commissioning of the Jordan Research and Training Reactor (JRTR), closed-loop flushing was performed before reactor installation, followed by open-loop flushing after reactor installation. Subsequently, foreign materials from the primary cooling system are removed and ensure system cleanliness.

In this study, the flow rate and pressure conditions during single-pump operation were investigated for an orifice designed based on the operating flow rate of two pumps under normal operating conditions. In addition, quantitative valve throttling conditions were determined to prevent excessive flow operation of the pump.

2. Methods and Results

2.1 *Purpose and Method of Closed-Loop Flushing*

The overall configuration of the primary cooling system, including the primary cooling system of the KiJang Research Reactor (KJRR), is shown in Fig. 1. The coolant leaving the reactor passes through the decay tank and is then circulated back to the reactor by the primary cooling system (PCS) pumps. Before reactor installation, closed-loop flushing of the primary cooling system is performed through the primary cooling system piping.

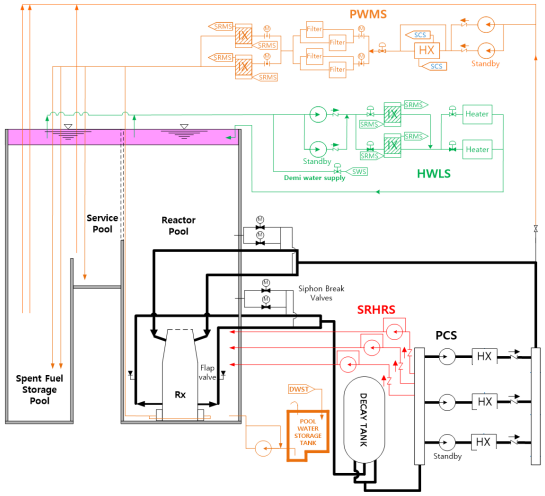


Fig. 1. Schematic diagram of the KJRR

(HWLS: Hot Water Layer System, PWMS: Pool Water Management System, SRHRS: Safety Residual Heat Removal System, DWMS: Demi Water Supply Tank)

The purpose of this process is to ensure the cleanliness of the primary cooling system piping through initial cleaning before the actual reactor flow path is established, thereby preventing potential damage to system components caused by foreign materials. The initial closed-loop flushing also provides an opportunity to verify the basic performance of individual system components.

Accordingly, as shown in Fig. 2, a closed-loop flow path is established by connecting the inlet and outlet of the primary cooling system piping while excluding the reactor core, in order to achieve the required cleanliness of the primary cooling system piping.

After completion of the closed-loop flushing, the reactor is installed, and flushing is subsequently performed with the final flow path configured to include the reactor and its connecting piping.

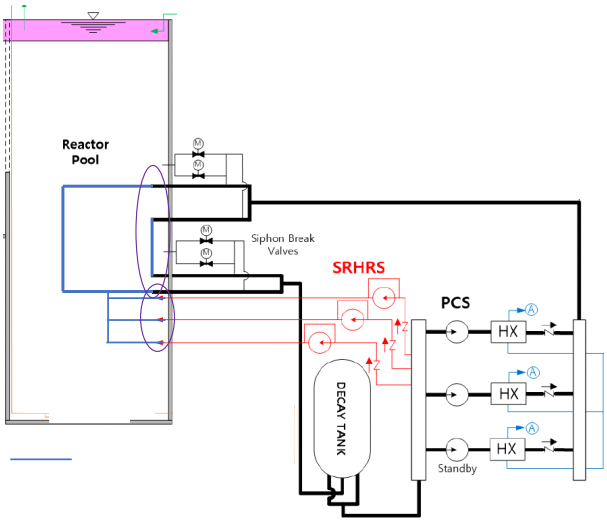


Fig. 2. Temporary piping for a closed flushing of PCS

2.1 Orifice Design for Closed-loop Flushing

In particular, during pre-installation closed-loop flushing, the hydraulic resistance of the system may differ from that under actual operating conditions with the reactor installed, which can result in an increase in the pump operating flow rate.

In the JRTR commissioning case, the reduction in system pressure loss and the resulting increase in flow rate due to the exclusion of the reactor core from the flow path during closed-loop flushing were also considered [2].

Therefore, an orifice that provides a pressure drop equivalent to that of the reactor core should be designed and installed to simulate the hydraulic resistance of the reactor core as equations below.

$$\Delta p_{system} = \Delta p_{pipe} + \Delta p_{valve} + \Delta p_{equipment} + \Delta p_{core} \quad (1)$$

$$\Delta p_{core} = \Delta p_{orifice} \quad (2)$$

The orifice diameter (A_o) is determined using the following equation [3].

$$Q_{orifice} = C_d A_o \epsilon \sqrt{\frac{2\Delta p_{orifice}}{\rho(1-\beta^4)}} \quad (3)$$

Where,
$Q_{orifice}$: volumetric flowrate
C_d: Discharge coefficient
A_o: diameter of orifice
ρ: density
ϵ: expansion factor (1, for water)

$$\Delta p_V = K_V \frac{\rho v^2}{2} \quad (4)$$

Where, Δp_V : pressure drop through a valve
K_V : the resistance coefficient of a valve
v : the velocity through a valve

Threrefore, at norminal flow rate, the orifice designed to simulate the pressure drop of the reactor core is installed at the section where the required pressure drop needs to be established.

2.2 *System Behavior Analysis under Different Operating Conditions*

The KJRR primary cooling system is normally operated with two out of three 50% capacity pumps in operation. If two pumps are operated simultaneously from the beginning of the flushing process to establish the full flow rate, the system differential pressure may increase rapidly due to the accumulation of foreign materials and dust in the PCS strainer or decay tank. Therefore, during the initial stage of flushing, it is necessary to operate one pump at a relatively low flow rate to remove foreign materials from the system, followed by sequential operation of two pumps.

The orifice designed for the flushing operation was selected based on the flow rate and differential pressure conditions established during two-pump operation. Therefore, as shown in Fig. 2, when only one pump is operated with the same orifice installed (Fig. 2-(1)), the system resistance decreases compared with the two-pump operating condition (Fig. 2-(2)), causing the pump operating point to shift toward the higher-flow region (Fig. 2-(3)). Under this condition, the flow rate may exceed the allowable maximum operating flow rate of the pump (so called run-out condition), potentially resulting in motor overload.

The corresponding operating conditions are summarized in Table 1. Therefore, rather than operating under the Flushing 1 and Flushing 2 conditions, the Flushing 1 and Flushing 3 operating sequence is required. The additional differential pressure required for Flushing 3 can be established by throttling the valve.

Table. 1. Pumps according to operation condition

Condition	Operation method	System head (normalized)	Pump condition
Normal Operation	2 pumps	1.0	normal
Flushing-1	2 pumps	1.0	normal
Flushing-2	1pump	0.77	run-out
Flushing-3	1pump +v/v throttling	0.77	normal

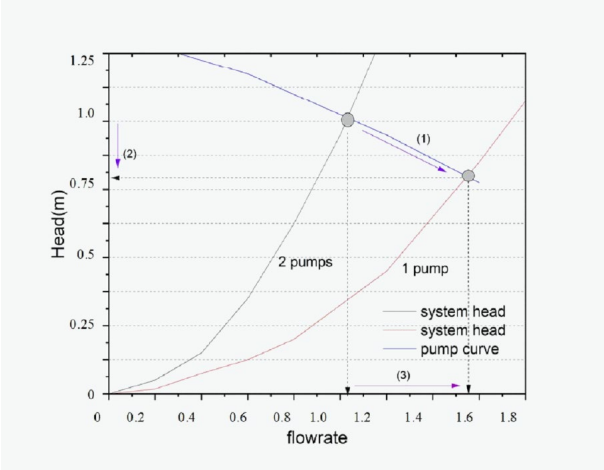


Fig. 3. System Behavior Curve under Different Operating Conditions (normalized)

2.3 *Estimation of manual valve opening according to operating conditions*

There is no dedicated flow control valve installed in the relevant KJRR system. Therefore, the required differential pressure must be established using the existing manual valve. In particular, a conventional gate valve is primarily designed for isolation rather than flow regulation. Therefore, its flow characteristics are nonlinear with respect to valve opening, and the flow rate can change rapidly over certain ranges of valve opening, as shown in Fig. 4. The characteristics of the gate valve shown in this figure indicate that the resistance changes significantly when the valve is closed beyond approximately 30% of its stroke, making precise flow control difficult.

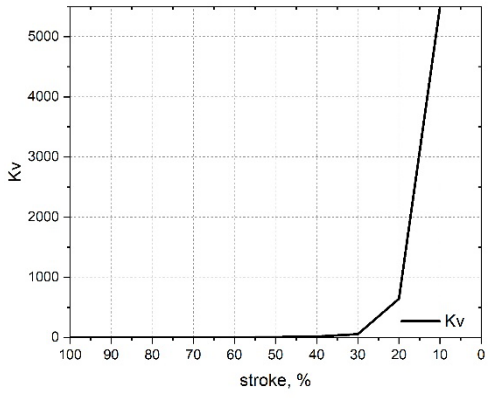


Fig. 4. Conventional Gate Valve Loss Coefficient (K_v) Curve

For the KJRR, as shown above, the additional differential pressure required is approximately 10 m based on the pump best efficiency flow (BEF). The valve resistance is calculated using the equation below. the resulting Kv is approximately 40, which correspond to the valve opening range for flow control to be approximately 30–40% opening.

$$\Delta p_V = K_V \frac{\rho v^2}{2} \quad (4)$$

Therefore, when using the gate valve to establish the required additional differential pressure, an appropriate throttling range should be selected, taking into account the possibility of rapid changes in flow rate and differential pressure due to small changes in valve opening, as well as potential valve chattering.

3. Conclusions

This study reviewed the purpose and methodology of closed flushing performed prior to reactor installation. The flow rate and differential pressure under one- and two-pump operating conditions were analyzed based on the system resistance and pump performance curves, and appropriate operating conditions for stable flushing were determined for each operating condition.

The results showed that an appropriate operating point was established by the temporary orifice under the two-pump operating condition, whereas the operating point shifted toward the high-flow region under the one-pump operating condition due to the reduced system resistance. Accordingly, an approach using gate valve throttling to provide additional system resistance during one-pump operation was applied. The analysis confirmed that the required operating conditions could be satisfied with a valve opening of approximately 30–40%.

In future work, the operating conditions and procedures derived in this study should be applied to actual flushing operations to verify whether the system flow rate and differential pressure agree with the analytical results. In addition, differential pressure variations and valve operating characteristics that may arise during actual operation should be further investigated. These efforts are expected to provide additional operational considerations and improvements for the flushing process and to contribute to the refinement of operating procedures and design criteria applicable to pre-installation closed flushing of research reactors.

4. Acknowledgement

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