Design of the Demineralized Water Make-up Line to Maintain the Normal Pool Water Level of the Reactor Pool in the Research Reactor

Hyun-Gi Yoon [*], Jungwoon Choi, juhyeon Yoon, Dae-Young Chi
Division for Research Reactor System Design, KAERI, Daejeon
[*]*Corresponding author: hyungi@kaeri.re.kr*

1. Introduction

In many research reactors, hot water layer system (HWLS) is used to minimize the pool top radiation level. Reactor pool divided into the hot water layer at the upper part of pool and the cold part below the hot water layer with lower temperature during normal operation. Water mixing between these layers is minimized because the hot water layer is formed above cold water. Therefore the hot water layer suppresses floatation of cold water and reduces the pool top radiation level.

Pool water is evaporated form the surface to the building hall because of high temperature of the hot water layer; consequently the pool level is continuously fallen. Therefore, make-up water is necessary to maintain the normal pool level. There are two way to supply demineralized water to the pool, continuous and intermittent methods. In this system design, the continuous water make-up method is adopted to minimize the disturbance of the reactor pool flow. Also, demineralized water make-up is connected to the suction line of the hot water layer system to raise the temperature of make-up water. In conclusion, make-up demineralized water with high temperature is continuously supplied to the hot water layer in the pool.

2. System Design

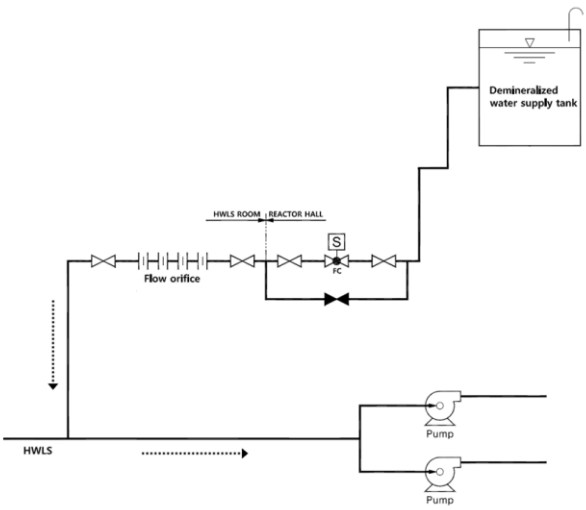

Fig. 1. Schematic diagram of the DWML

Demineralized water make-up line (DWML) is designed as an open loop system and consists of demineralized water supply tank (DWST), solenoid valve, flow orifice and other equipments as shown in Fig. 1.

DWML is designed as a passive system by gravity and its flow rate is controlled by orifice to meet the design flow rate.

In the normal operation, operator opens the solenoid valve to establish the flow path from the DWST to the HWLS.

2.1 Design flow rate

The flow rate of the make-up water is determined by hydrostatic head and orifice design. Object of solenoid and gate vales in the DWML is to establish or isolate the system. Also, the constant water level of the DWST is maintained by the feedback control. So, flow rate of the make-up water is not changed with time.

Flow rate of the DWML is decided based on the evaporation rate and the pool level range for normal operation. Evaporation rate is calculated from the evaporation heat loss as following equation.

$$Q_{evap}[W] = A_h(95 + 0.425V_a)(P_h - P_a)C \tag{1}$$

Here,

- A_h Area of pool surfaces, [ft^2]
- V_a Air velocity above the pool surfaces, [ft/min]
- P_h Saturated vapor pressure at the hot water layer temperature, [inHg]
- P_a Saturated vapor pressure at the dew point temperature in the building hall, [inHg]
- C Unit conversion factor, $0.293\frac{W}{Btu/hr}$

Equation (1) is the evaporation heat loss equation which comes from ASHRAE handbooks and it is based on experiments.

Evaporation rate is calculated by using the enthalpy and above heat loss as following equation (2).

$$Q_{evap} = \dot{m} \cdot h_{fg} \tag{2}$$

Here,

- $\dot{m}$ Evaporation rate, [g/s]
- h_{fg} Enthalpy of vaporization, [J/g]

Even thought there are several terms to affect the evaporation rate, the temperature and humidity of the building hall are the main factors to determine the evaporation rate because the pool surface area, air velocity and hot water layer temperature are fixed values in this system design. Therefore, a change of the environmental conditions of the building hall with the season should be carefully considered. Also, the flow rate of the DWML should be greater than that of the evaporation rate.

Figure 2 shows changes of the pool water level during normal operation of reactor. When the pool water level is dropped by evaporation on the pool surface, DWML is isolated by solenoid valve. Over time, when the pool water level drops to low level, the solenoid valve is opened and the pool water level is gradually raised. The time for pool make-up is longer than the time for evaporation loss as shown in Fig. 2 because actual make-up water is the difference between the flow rate of make-up water from the DWST and the evaporation rate. In Fig. 2, there are two kinds of pool water level range for normal operation. Larger pool level range makes the longer operation cycle. Also, Fig. 2 shows the different operation cycle between summer and winter. Operation cycle during summer is longer than the cycle in winter.

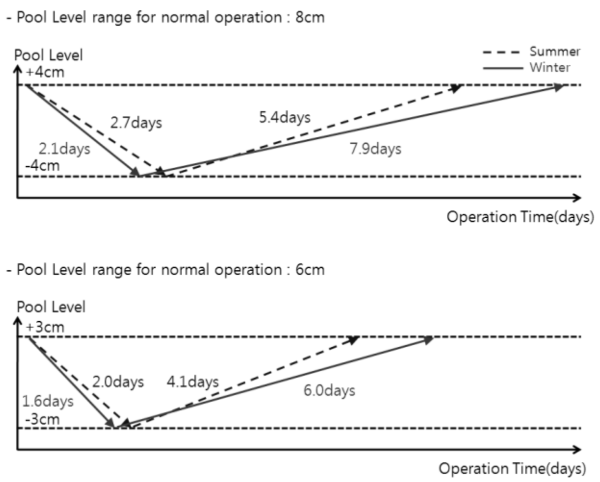

Fig. 2. Change of the pool water level with the DWML

2.2 Orifice design

Main factors to determine the flow rate of the make-up water are the hydrostatic head and loss coefficient of the orifice. System pressure drop in the DWML is not dominant because the velocity in the pipe is slow and most pressure drop is occurred through the orifice. The target loss coefficient of the orifice is calculated as equation (3).

$$k_{orifice} = \frac{2H_{static}}{\rho V^2} \tag{3}$$

Here,

H_{static} Hydrostatic head considering the system loss, [kPa]

ρ Density of water, [kg/m^3]

V Velocity in the pipe, [m/s]

The loss coefficient of the orifice is about 2.0e+4. Therefore, three orifices are connected serially to meet the design flow rate. In this case, location of the orifice is also important because large pressure drop could cause the cavitation in the orifice. Therefore, orifice is located at the low point in the DWML to prevent the damage of the orifice and bubble generation.

2.3 Heat load

Temperature of the make-up water is raised through the heater of the HWLS. Heat load is calculated as equation (4).

$$Q_{heater} = \dot{m} \cdot c_p \cdot \left(T_{HWL} - T_{DWM}\right) \tag{4}$$

Here,

c_p Heat capacity, [kJ/kg·K]

T_{HWL} Temperature of the hot water layer, [K]

T_{DWM} Temperature of the make-up water, [k]

Heat load should be considered to determine the capacity of the HWLS heater.

3. Conclusions

The DWML is designed to supply the demineralized make-up water with high temperature into the hot water layer in the reactor pool.

Flow rate is determined based on the evaporation rate on the pool surface. The loss coefficient of the orifice is calculated by using the flow rate and DWML system.

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