Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

Thermal Power Calculation in a Research Reactor

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1. Introduction

Research reactors should incorporate the measurement system for the core power to control and regulate the reactor power. The research reactor modeled in this paper is also equipped with three separate and independent detectors to measure the core power; Neutron Measurement System (NMS), Reactor Gamma Monitoring System (RGMS) and Primary coolant Gamma Monitoring System (PGMS). To calibrate these detectors, the thermal power is used as calibration reference. Therefore, it should be ensured that the thermal power be defined to be fully representative of the core power.

The thermal power is calculated based on the thermal balance in the reactor pool where the reactor core and heavy water vessel as the heat source are located. In this paper, the calculation logic for the thermal power is explained in detailed and the precautions for calibration are introduced as well.

2. Thermal Power

2.1 Thermal Power Calculation

The thermal power is derived based on the thermal balance around the reactor pool. The detailed configuration for Primary cooling system (PCS) and Heavy Water System (HWS), which are not specified in detail for the confidential reason, cool down the reactor core and heavy water vessel, respectively. A majority of the energy is assumed to be produced in the core (98%) and the remaining energy is produced in the heavy water vessel (2%). Sum of these two energy sources is the reactor power. Almost all energy produced in the core is transferred to SCS through PCS heat exchangers. In similar way, almost all heat produced in the heavy water vessel is transferred to SCS through the HWS heat exchanger. Therefore, if the system is in a thermal equilibrium state, following balance equations are made:

$$P = P_{core} + P_{D2O}$$

$$= \dot{m}_{PCS}\int_{T_{i,H_2O}}^{T_{O,H_2O}} C_{p,H_2O}(T)dT + \dot{m}_{HWV}\int_{T_{i,D_2O}}^{T_{O,D_2O}} C_{p,D_2O}(T)dT$$

$$= \dot{m}_{PCS}\overline{C_{p,H_2O}}\Delta T_{PCS} + \dot{m}_{HWV}\overline{C_{p,D_2O}}\Delta T_{HWS} \qquad (1)$$

P, P_{core}, P_{D2O} : Reactor power, heat produced in the core and heat produced in the D2O [kW]

$\dot{m}_{PCS}$, $\dot{m}_{HWV}$: Mass flow rates of PCS and HWS [kg/s]

T_{i,H_2O}, T_{o,H_2O} : PCS pool inlet and outlet temperature [℃]

T_{i,D_2O}, T_{o,D_2O} : HWS pool inlet and outlet temperatures [℃]

C_{p,H_2O}, C_{p,D_2O} : Constant pressure specific heats of light water and heavy water [kJ/kg K]

$\overline{C_{p,H_2O}}$, $\overline{C_{p,D_2O}}$: Average constant pressure specific heats of light water and heavy water [kJ/kg ℃] for respective inlet and outlet temperature ranges.

ΔT_{PCS}, ΔT_{HCS} : $T_{o,H_2O} - T_{i,H_2O}$ and $T_{o,D_2O} - T_{i,D_2O}$ [℃]

Constant pressure specific heats of light water and heavy water are shown in Fig. 1 which depicts their variation vs. temperature. It is recommended to keep the usual PCS pool inlet temperature at full power operation within 30 ℃ ~ 35 ℃. As the reactor outlet PCS temperature is 6 ℃ ~ 7 ℃ higher than the PCS pool inlet temperature, it is in the range of 36 ℃ ~ 42 ℃. Therefore, the integrations in Eq. (1) are within 30 ℃ ~ 42 ℃ range. As shown in Fig. 1, the variation of specific heats within this temperature range is very small, about 0.005% and 0.25% for H2O and D2O respectively, and almost linear. Therefore, constant specific heats at 36 ℃ are used for $\overline{C_{p,H_2O}}$ and $\overline{C_{p,D_2O}}$.

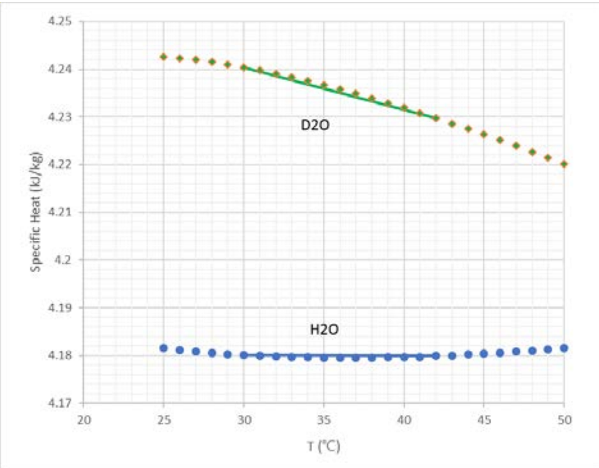

Fig. 1. Specific heats of H2O and D2O vs temperature [1].

2.2 Uncertainty for Thermal Power

There are other heat gain and losses in the pool water. The heat gain is the heat from the hot water layer to the pool water. Heat losses are the exchanged heat in the PWMS (Pool Water Management System) heat exchanger and the heat to the pool wall. The PWMS heat exchanger is considered to dissipate the decay heat from the spent fuels in the service pool and the heat from the hot water layer. Another heat loss is caused from the location of the temperature sensor (RTD) on the PCS pipe. To minimize this effect, the RTD is installed on the possibly nearest location from the pool inlet and exit.

The estimated heat gain and losses are as followings:

(1) The heat gain from the hot water layer down to the pool water
(2) The heat loss in the PWMS heat exchanger
(3) The heat loss to the pool concrete
(4) The heat loss from the pipe between the core and the RTD

These estimated heats related with the energy transfer in the pool water are treated as a portion of the uncertainty in the thermal power calculation. The uncertainty calculated from these estimated heat gain and losses should be smaller than that used in calculation of thermal power.

2.3 Precautions for Thermal Power Calibration

Among NMS, RGMS and PGMS signals, PGMS signals are almost free from the effect of neutron and gamma flux distribution variation in the core as the case of thermal power. Therefore, if the PGMS signals are accurately calibrated with the thermal power, they can be used as reference power signals for the calibration of NMS and RGMS signals. Therefore, calibration for the PGMS signals should be conducted first, and others are calibrated against PGMS.

The NMS signals increases along with the pool water temperature by about 0.8%/℃, which means that NMS signals are lower than actual power if the calibration pool water temperature is lower than the condition of NMS signal calibration. Therefore, the pool water temperature during the power calibration should be close to the usual temperature during the full power operation. The usual temperature may depend on the environmental condition, but operation between 30 ℃ ~ 35 ℃ as possible is recommended. If no special reason exists, the temperature of previous calibration can be applied for the target temperature of current calibration. During the power ascension, if the pool water temperature deviates more than 1 ℃ from the target value, operators should wait at appropriately lower power than the full power until the pool water temperature becomes close to the target value by controlling the operation of cooling fans.

3. Conclusions

The equation for the core thermal power has been derived according to measuring parameters such as mass flow rate, and temperatures. In addition, the precautions for calibration such as calibration sequence and pool water effect are clarified as well.

REFERENCE

[1] Lemmon E.W., Huber M.L., McLindon M.O., NIST Reference Fluid Thermodynamic and Transport Properties, REFPROP Version 8.0, 2007.