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Conceptual Design of the Cooling System for the RPI-2MW Reactor for Radioisotope Production in Indonesia

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Abstract

Medical radioisotopes are in high demand in Indonesian hospitals, with 94 percent still being imported. Nuclear reactors, such as the RPI-2MW, offer a domestic solution for radioisotope production. This study focuses on the conceptual design of the RPI-2MW reactor cooling system, which is an important system in achieving safe radioisotope production. Using ChemCAD6.1.4 software, operational parameters were calculated, ensuring that the primary coolant temperature in the reactor core remains below the safety limit of 40°C. Simulations were conducted considering various secondary coolant temperatures from the cooling towers. If the coolant temperature is maintained below 37°C, the reactor operates safely in terms of core thermal-hydraulic aspects. The secondary cooling system, designed as an atmospheric cooling tower type, offers cost-effective solutions for efficient reactor operation. With the RPI-2MW reactor design, this research is expected to contribute to the progress of domestic radioisotope production.

Keywords: *Design of cooling system, radioisotope production, atmospheric cooling tower, reactor safety.*

Introduction

Medical radioisotopes, essential for radio-pharmacies in Indonesian hospitals, remain predominantly imported, constituting 94 percent of the supply. Therefore, it is necessary to strive for domestic production so that prices can be reduced and access to products becomes easier. As we know, radioisotope production can be produced from nuclear reactors or accelerators.

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There are three Indonesian research reactors: the TRIGA2000 reactor (first criticality in 1964), the Kartini reactor (first criticality in 1979), and the RSG-GAS reactor (first criticality in 1987). Regarding the condition of those reactors, the outdated equipment still being used in the radioisotope production facility is a concern as well.

A revitalization of the Indonesian nuclear reactor could be considerably costly. Given these circumstances, a more practical approach is to develop a new nuclear reactor facility instead of revitalizing the existing one. To address the increasing demand for medical radioisotopes in Indonesia, a new reactor design has been developed the Reaktor Produksi Isotop, 2MW thermal power (RPI-2MW). This conceptual reactor, currently in the design phase, places emphasis on the safety aspects. This design focuses on calculating the operating parameters of the reactor cooling system.

The reactor coolant system for nuclear research reactors usually uses both primary and secondary systems. At normal operation, the coolant water removes the core heat by convection mode through the pumps, heat exchanger, and cooling tower (Dibyo et al.2015, Jean. 2012, Adorni et al., Invap). Generally, there are two types of reactor cooling modes, namely forced convection mode and natural convection mode (Juan et al. 2022, Gaheen, 2020). One of the most important coolant systems of research nuclear reactors is a system that ensures reliable heat removal from the reactor core in normal operation mode and in case of possible emergency situations (Uzikov, 2019). The design of the coolant flow rate of a fueled plate-type reactor must meet the safety criteria of departure from nucleate boiling ratio (DNBR), Onset of Flow Instability Ratio (OFIR), and Onset of Nucleate Boiling (ONB) (Endiah et al. 2018). Another important consideration in the design is the cost of the reactor plant and the operating costs.

Description of the Coolant System:

The RPI-2MW is a plate-type fueled reactor designed to provide neutrons for medical isotope production. The thermal power reactor is rated at 2 MW, this reactor is used as a fission reaction medium that produces material radiation to irradiate isotope materials, while the heat energy from the reactor is released into the environment. The reactor is an open pool type; where the reactor core is positioned at the bottom of the pool and is cooled using natural or forced convection cooling system modes. The reactor core is cooled by the downward flow. The inlet pipe is placed in the plenum below the core, while the outlet pipe is located at the top of the reactor pool. The reactor has two cooling system loops, namely:

1) Primary cooling system

2) Secondary cooling system.

The reactor is a Materials Test Reactor (MTR) type with a core of Low Enriched Uranium (LEU) fuel that is moderated and cooled by light water. Primary and secondary cooling systems act to remove the heat generated in the reactor cores, with external cooling towers acting as the ultimate thermal sink. The primary cooling system uses demineralized pure water. Two loops of the reactor cooling system are function as a decay heat release system, both during reactor operation and shutdown. Two pumps run in parallel, and only one pump operates when the cooling system is in use, with the second pump serving as a backup in line with redundancy systems. As depicted in Figure 1, the concept design includes two centrifugal pumps, one heat exchanger, and a cooling tower system for each cooling system line. The atmospheric cooling towers are situated outside the reactor containment building. Figure 1 provides a simplified diagram illustrating the block diagram of the cooling system concept.

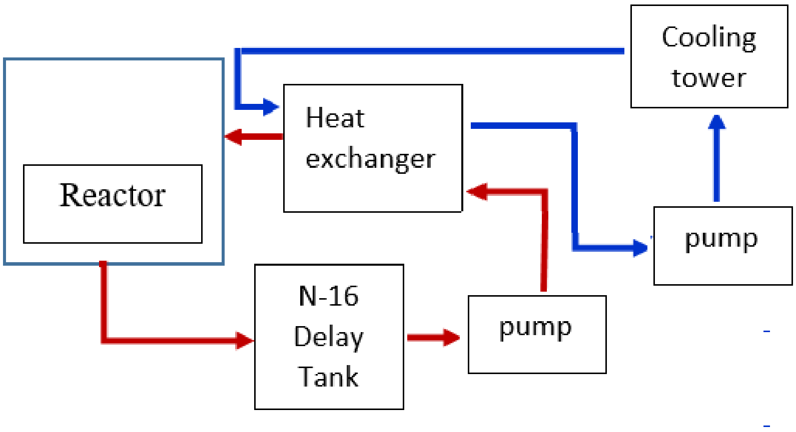

Figure 1 Block diagram of the Reactor Cooling System

Methodology

In the design calculation, temperature, pressure, and coolant mass flow rate for all streams are considered. There are several conditions used to define the input parameters. The boundary parameter for calculation are as follows: thermal power is 2 MW, inlet coolant temperature to the reactor maximum of 40oC, primary coolant mass flow rate is determined of 80 kg/s, and water minimum temperature from the cooling tower is 29oC. and secondary coolant mass flow rate is 130 kg/s.

Based on the process flow diagram of the cooling system developed, the operating parameters are calculated using ChemCAD 6.1.4 software. Notably, ChemCAD software has been successfully utilized in designing the cooling system for the OPAL Research Reactor (20 MW) in Australia (Dibyo et al., 2015; Solanki, 2014). Furthermore, the simulation of the primary coolant temperature is conducted in relation to various secondary coolant temperatures from the cooling towers.

Meanwhile, the following conditions are used as assumptions:

1. The cooling operation is in normal condition/steady state.
2. The cooling process is adiabatic, meaning it occurs without the exchange of heat with the surroundings.
3. Heat generated from the reactor core is solely released by the cooling tower to the environment.
4. The reactor coolant system is in a liquid single-phase, with no boiling.
5. The heat exchanger performance (overall heat transfer) remains constant."

Results and Discussion

The calculation was carried out using the ChemCAD software, the operating parameter based on mass balance and heat balance for each flow stream was obtained. Figure 2 shows the result of the operating parameter calculation.

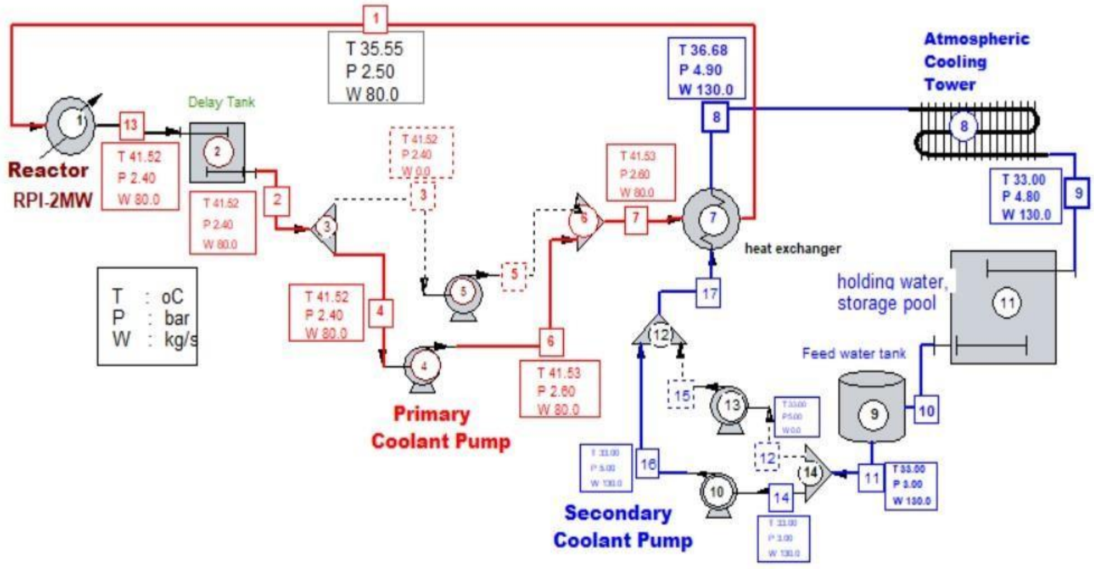

Figure 2 Parameter Operating Calculation of RPI-2MW

The steady-state design includes temperature, pressure, and mass flow rate of the coolant in both the primary and secondary cooling systems. The ChemCAD simulation was executed by configuring appropriate initial input data to ensure convergence during the calculation process.

An important parameter in this coolant design is the temperature of the coolant to the reactor (component no. 1) which does not exceed 40oC (stream no. 1) to comply with the core thermal-hydraulic safety limit. Therefore, this value must be considered with the thermal-hydraulic safety aspects of the reactor core. Further, the reactor can be operated safely and reliably. The mass flow rate of the primary coolant is determined to be 80 kg/sin which refers to a similar design (Endiah et al. 2018, Altaf et al. 2014). The performance of the heat exchanger and secondary cooling system plays a very important role. In this design, the heat transfer coefficient in the heat exchanger (component no. 7) which uses water as the working fluid is determined to be 1400 w/m2 K (Cao). Figure 2 illustrates the primary cooling loop (red line), featuring a delay tank (component no. 2) to reduce exposure to N16 radioisotope radiation from nuclear fission reactions (Dibyo et al. 2018, Sadeghi 2010, Lee et al. 2017). Pressure drop in stream number 13 due to the delay tank is calculated to prevent cavitation in the pump (component no. 4) (Cucit, 2018). Under normal conditions, one pump operates, and the second pump serves as a backup, mirroring the pump backup system in the secondary loop. Meanwhile, considering investment costs, cheaper operational costs, and the availability of space plant layout, the secondary cooling loop (blue line) is equipped with an atmospheric cooling tower, water pool storage, and feed water tank. In this calculation, the primary cooling system operates one coolant pump with a capacity of 80 kg/s at the reactor power of 2 MW. Streamline no. 3 is simulated with a mass flow rate of w = 0 kg/s, indicating the pump is inactive. Similarly, streamline no. 12 in the secondary loop is simulated with a mass flow rate of w = 0 kg/s. Table 1 outlines the general parameters for a heat exchanger based on the output from ChemCAD, serving as an interface between the primary and secondary loops.

Table 1. Main Parameter of Heat Exchanger

Job Name: RPI-2MW-EEE Date: 11/22/2023 Time: 15:49:59

Equipment	No.	7
Name		
1st Stream ΔP	bar	0.1000
2nd Stream ΔP	bar	0.1000

Overall heat transfer coefficient Uo	W/m^2-K	1400.00
Area/shell	m^2	400.00
Calc. Heat Duty	MJ/sec	1.9948
LMTD (End points)	°C	3.5622
Calculation Uo	W/m^2-K	1400.00
Calculation Area	m^2	400.00
1st Stream Pout	bar	2.5000
2nd Stream Pout	bar	1.9000

The temperature of the coolant flowing from the cooling tower is contingent upon the environmental temperature outside the reactor building. Figure 3 depicts simulations that explore variations in the water temperature from the cooling tower, ranging from 29°C to 37°C. The objective of these simulations is to determine whether the coolant temperature to the reactor remains below the established safety limit.

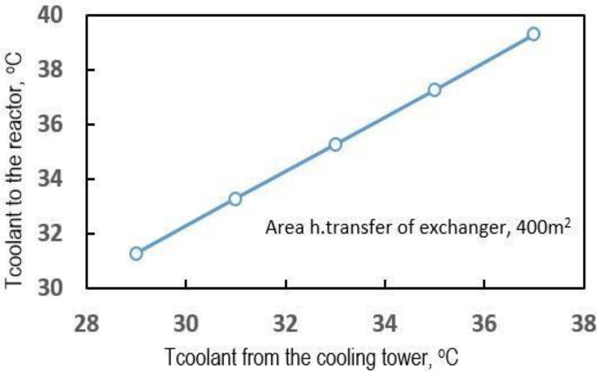

Figure 3. Diagram T cooling Tower vs. T inlet to the reactor

Figure 4 illustrates the relationship between the coolant inlet temperature to the reactor and the surface area of the heat exchanger. The curve shows that, as the surface area increases, the coolant temperature to the reactor decreases. However, it's important to note that this relationship is not linearly depicted in the curve. The illustration is based on a realistic assumption that considers the temperature of water flowing from the cooling tower, typically around 33°C, approximately 4°C above the wet bulb temperature of the environment (Clark, Mashaf et al., 2020).

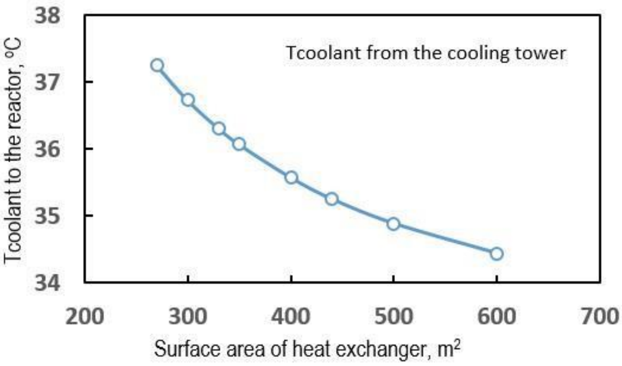

Figure 4. Surface Area Exchanger vs. T inlet to the Reactor

Conclusion

The calculation of the cooling system for the RPI reactor plate-type fuel was carried out under steady-state operation using the ChemCAD software. The results of design calculations state that the reactor can be operated safely and reliably as expected. However, it is not recommended that the coolant temperature from the cooling tower not exceed 37oC. This temperature must be considered because it is related to the thermal-hydraulic safety aspects of the reactor core. The design calculation results indicate the feasibility of applying the relatively cost-effective atmospheric cooling tower type to the RPI-2MW reactor cooling system. This opens up the possibility of realizing a new reactor for domestic radioisotope production.

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