A Study Of Characteristic On The Samop Core Cooling System Using Fluent CFD

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Abstract. Safety study of the cooling system of the SAMOP facility has been done. The thermal-hydraulics is required to evaluate the heat removal system in order to exhibit that sufficient cooling capacity to prevent fuel solution overheating. In this study, the inlet velocities have been varied namely 0 to 0.522 cm/s and 2.090 to 4.179 cm/s. The modelling and numerical simulation had been carried out using the Computational Fluid Dynamic (CFD) employing FLUENT 6.3.26 software. The results of water velocities were 0 – 1.045 cm/s or natural convection. The simulated maximum water temperature was (39.39 ± 0.07) °C for the inlet velocities of 0 cm/s and (32.34 ± 0.85) °C for 0.104 cm/s, respectively. The maximum water temperature was located in the channel between the central tube wall and the inner annular tube wall. The average water temperature was 27.76 °C for the inlet velocities of water from 0.209 to 4.179 cm/s. It could be concluded that the SAMOP core cooling system using natural convection was capable and optimal to prevent the fuel overheating even the value of water inlet velocity of 0.209 cm/s.

1. Introduction
Techninium-99 metastable (⁹⁹ᵐ₉₉Tc) is one of the most important isotopes for medical diagnostics which is obtained from the decay of ⁹⁹Mo. ⁹⁹ᵐ₉₉Tc decays to ⁹⁸Tc with a half-life of 6 hours by emitting a 140 keV gamma rays [1]. According to The Nuclear Energy Agency (NEA) from France, the consumption of ⁹⁹ᵐ₉₉Tc isotope all the world is approximately 10 kCi every week [2]. It is an urgent need for constant supply of ⁹⁹ᵐ₉₉Tc by increase production of ⁹⁹Mo. The world research reactor facility as a ⁹⁹Mo producer is Aqueous Homogeneous Reactors (AHR). AHR has a potentially advantageous method of ⁹⁹Mo production because all of the ⁹⁹Mo can be extracted from the fuel solution without shutdown a reactor [3].

Indonesia is encouraged to carry out a safety study of the Subcritical Assembly for ⁹⁹Mo Production (SAMOP), one type of AHR. One of the safety aspects that must be reviewed is thermal-hydraulics. It is required to evaluate the heat removal system in order to exhibit that sufficient cooling capacity to prevent fuel solution overheating. The safety limit of the reactor operation refers to the safety regulations in operating the TRIGA Mark II reactor by General Atomic. The regulation states that to limit the ¹⁶N radiation level on the surface of the tank, it is not permitted the fuel boiled [4].

According to the previous results of the study, it has been reported that the SAMOP at PSTA-BATAN has been designed having a power range from 563.2 to 860.8 W. It should be noted that the power of 563.2 W is equivalent to heat of 398.39 °C [5]. In other result SAMOP reactor core cooling
system using the design of forced convection is able to provide sufficient cooling capacity to prevent fuel solution overheating [6]. In order for the SAMOP not damaged, the core should be cooled.

2. Numerical Method

This research was carried out by making the SAMOP geometry using GAMBIT 2.3.6 software and analyzing thermal-hydraulics parameters using Computational Fluids Dynamic (CFD) method based on FLUENT 6.3.26 software. CFD techniques are very reliable and have been used for thermal-hydraulics nuclear reactor systems [7,8]. The geometry design has been made according to the SAMOP geometry developed by PSTA-BATAN (Figure 1). The core consists of an aqueous uranyl nitrate. The fuel is marked with orange color and that of water with white color at figure 1. The uranium concentration was 300 g U/L and the core volume was 22,382 cm$^3$. The uranyl nitrate volume was 226 cm$^3$. The water flow rate was set up 0 to 0.522 cm/s and 2.090 to 4.179 cm/s.

![Figure 1](image)

*Figure 1.* The core design scheme of the SAMOP facility [5].

The main reactor core parameters are written in Table 1.

**Table 1.** The SAMOP reactor core parameters [5].

| Parameter               | Value                  |
|-------------------------|------------------------|
| Fuel solution           | $\text{UO}_2(\text{NO}_3)_2$ |
| Uranyl nitrate tube diameter | 3.7 cm          |
| Reflector               | Graphite               |
| Reactor vessel          | Stainless steel       |
| Thermal power (kW)      | 1                      |

In this simulation, it has been assumed that the fluid flow was laminar, steady and incompressible conditions. The characteristic of the cooling system was obtained by calculating the Richardson number (Ri), [9]

$$Ri = \frac{Gr}{Re^2}$$  \hspace{1cm} (1)

$$Gr = \left(\frac{\beta g d^3}{\nu^2}\right) (T_{wall} - T_{bulk})$$  \hspace{1cm} (2)

$$Re = \frac{\rho \nu d}{\mu}$$  \hspace{1cm} (3)

$\beta$ is liquid expansion coefficient ($/\text{K}$), $g$ is gravitational acceleration ($\text{m/s}^2$), $d$ is gravitational acceleration ($\text{m/s}^2$), $d$ is pipe diameter (m), $\nu$ is kinematic viscosity ($\text{m}^2/\text{s}$), $T$ is temperature (T), $\rho$ is water density ($\text{kg/m}^3$), $\nu$ is fluid flow rate ($\text{m/s}$), $\mu$ is fluid viscosity ($\text{kg/m s}$), Gr is Grashof number.
and Re is Reynolds number.

3. Result and Discussion

The SAMOP geometry in the XY field has been successfully modeled using the GAMBIT software. The results are shown in Figure 2.a and the geometric mesh in Figure 2.b where the water is marked with yellow area. The geometry on FLUENT is shown in Figure 3.

![Figure 2. The SAMOP Geometry [10]](image)

![Figure 3. SAMOP geometry on FLUENT [10]](image)

Figure 3 explain that the water as the cooling enters from the inlet flows to the left along the negative x-axis and exits through the outlet. Figure 3 is equivalent to Figure 4.

![Figure 4. SAMOP Geometry [10]](image)

In Figure 4 it has been shown the parts of the geometry being analyzed. The inlet and outlet can be seen in Figures 3 and 4. In Figure 4, the orange color is fuel of uranyl nitrate solution, a graphite reflector with black striped, and water with white color. The color of the line as a symbol for the parts of the geometry that has been made, namely:

- Red : central tube wall
The results of the maximum and minimum temperature water are presented in Table 2. The maximum water temperature was located in the channel between the central tube wall and the inner annular tube wall. From the Table 2, it can be seen that the operation of the reactor is safe because the maximum water temperature on the core is only \((39.39 \pm 0.07)\) °C. Even when the water velocity is 0, the reactor safety limit is still fulfilled. This means that the temperature of the fuel is below the permissible temperature limit under normal operating conditions.

| Water velocities (cm/s) | Maximum Temperature (°C) | Minimum Temperature (°C) |
|------------------------|---------------------------|---------------------------|
| 0                      | 39.39 ± 0.07              | 34.24 ± 0.07              |
| 0.104                  | 32.34 ± 0.85              | 27.00 ± 0.85              |
| 0.209                  | 29.78 ± 0.28              | 26.99 ± 0.28              |
| 0.313                  | 29.76 ± 0.19              | 26.99 ± 0.19              |
| 0.418                  | 29.76 ± 0.19              | 26.99 ± 0.19              |
| 0.522                  | 29.76 ± 0.19              | 26.99 ± 0.19              |
| 2.090                  | 29.68 ± 0.17              | 26.99 ± 0.17              |
| 3.135                  | 29.62 ± 0.16              | 26.99 ± 0.16              |
| 4.179                  | 29.56 ± 0.15              | 26.99 ± 0.15              |

The simulation results of the SAMOP characteristic of the cooling system are written in Table 3. It can be seen that the obtained Ri numbers are greater than 1 for the velocities of water from 0.104 - 1.045 cm/s so it can be concluded as natural convection. Combined convection must be used when the water inlet velocity is 2.090 cm/s while the force starts at 3.135 cm/s and above. From the results it can be seen the design of SAMOP cooling by natural convection has been able to transfer of heat due to fission reactions.

| Water velocities (cm/s) | Richardson Number | Natural/Combined/Forced |
|------------------------|-------------------|-------------------------|
| 0.104                  | 68 ± 6            | Natural                 |
| 0.209                  | 127 ± 6           | Natural                 |
| 0.313                  | 88 ± 3            | Natural                 |
| 0.418                  | 56 ± 2            | Natural                 |
| 0.522                  | 568 ± 16          | Natural                 |
| 2.090                  | 1.07 ± 0.03       | Combined                |
| 3.135                  | 0.44 ± 0.01       | Forced                  |
| 4.179                  | 0.24 ± 0.01       | Forced                  |
4. Conclusion
The calculation results show that the SAMOP heat removal systems, designed natural convection is capable and optimal to prevent the fuel overheating. The maximum water temperature was (39.39 ± 0.07) °C for the inlet velocities of 0 cm/s and (32.34 ± 0.85) °C for 0.104 cm/s, respectively. The maximum water temperature was located in the channel between the central tube wall and the inner annular tube wall.

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