Evaluation of the Pump Capability of the Primary Cooling of TRIGA 2000 Research Reactor

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Abstract. The TRIGA 2000 research reactor has been operating since mid 2000. Currently, there are plans to convert the reactor core from cylindrical fuel element to plate type fuel element. The conversion process is expected to not change too many existing systems, including the primary cooling systems. For this reason, it is necessary to evaluate the pump capability of the primary cooling system. Based on experimental studies, then merging with the existing installation system head, it has been obtained the main and the redundant pump mass flow rate of 45 and 45.5 kg/s, respectively. The pump capability decreased by around 5% compared to the results of its commissioning. If the two pumps are combined in parallel, the combined mass flow rate can increase to 62 kg/s. The existing primary pumps cannot be used for primary cooling system if the reactor core is converted into a plate type, even though both pump are installed in parallel. These results need to be considered in designing a new core of the Bandung TRIGA 2000 research reactor with primary cooling systems that are slightly modified because they have to add the decay tank.

Key words: primary pump, reactor conversion, pump capability, pump capability, delay tank

1. Introduction

The TRIGA (Training, Research, Isotopes, General Atomics) reactor is a research reactor designed and manufactured by General Atomics. One of them is the TRIGA 2000 reactor and the reactor has been operating since mid 2000. During this period, the reactor can operate normally, but there are also some cases which are quite difficult, for example, a boiling in the reactor core and the non-functioning of various measuring instruments related to safety. To understand all the problems, various research activities have also been carried out [1-3] and several solutions to overcome the problem have also been obtained.

In recent years, new problem has come and affected the continuity of the reactor operations. The problem is unavailability of new fuel element on the market. During this time, new fuel element supplied by the supplier of international TRIGA fuel element (CERCA). To overcome this problem, BATAN (National Nuclear Energy Agency of Indonesia) plans to change or convert the reactor core of the TRIGA 2000
from cylindrical fuel element to plate type fuel element and from natural convection to forced convection. The conversion process is expected to not change too many existing systems, including the primary cooling systems. For this reason, it is necessary to evaluate the pump capability of the primary cooling system.

To support the conversion program, various activities have been carried out [4,5], including designing the decay tank, modifying the primary cooling system, designing the construction of the reactor structure and the instrumentation system. In additions, various evaluations of the old system also need to be done, whether it can still be used or replaced with a new system, one of which is the performance evaluation of the primary cooling pump. This paper describes the evaluation of the pump capability of the primary cooling system of the TRIGA 2000 research reactor, both the main pump and the redundant pump. Including the possibility of its use in supporting reactor core conversion programs

2. The General Basis Design
The TRIGA 2000 reactor is a pool type reactor and the heat generated by fission in fuel elements is transported to the coolant (pool water) by natural convection. The thermal hydraulic design of TRIGA 2000 can be seen on Table 1.

| Average rate on channel (kg/second) | Average Rod | Maximum Rod |
|-------------------------------------|-------------|-------------|
| The loss of Total Pressure (Pa)     | 75.84       | 141.3       |
| The temperature of outlet cooling (°C) | 79.61       | 98.94       |
| The max. flux heat at cladding (w/cm) | 56.21       | 95.55       |
| The max. flow rate (cm/second)     | 19.2        | 25.24       |
| The max. temperature of cladding (°C) | 131.8       | 134.7       |
| The outlet Cladding Temperature     | 128.8       | 131.3       |

In principle, the pool water is cooled by primary cooling systems and the this system will circulate the water from the reactor tank to a parallel plate of heat exchanger and return it back to the reactor tank with temperature which less than 32°C [6,7]. The function of the primary cooling system is only to transfer the heat contained in the reactor tank to the secondary cooling system through the heat exchanger. The schematic drawing and components of the primary cooling system (Figure 1) of TRIGA 2000 reactor are supplied by General Atomic [8].
2.1. System Head Calculation

By using the water velocities in the primary pipe, we can determine the system head curve of the primary pump of the reactor. For the determination of the required primary pump total head, it is also necessary to calculate friction head losses along pipelines connected to the pump. The friction head loss in the plate and frame heat exchanger is calculated by [9,10]:

\[ h_{fHE} = \frac{\Delta P}{\rho \cdot g} \]  \hspace{1cm} (1)

Where:
- \( \Delta P \) = pressure drop (Pa)
- \( h_{fHE} \) = friction head loss (m)
- \( g \) = gravitational acceleration (m/s\(^2\))
- \( \rho \) = density of fluid (kg/m\(^3\))

The total pressure drop in the plate and frame heat exchanger (\( \Delta P \)) is composed of the frictional channel flow component (\( \Delta P_c \)) and the port pressure drop (\( \Delta P_p \)). The frictional pressure drop is determined by following equation [9,10]:

\[ \Delta P_c = \frac{0.002 \cdot \varepsilon \cdot (g_c)^2 \cdot (L_{eff}) \cdot (N_p) \cdot \left( \frac{\mu}{\mu_w} \right)^{0.17}}{\rho \cdot D_e} \]  \hspace{1cm} (2)

where:
- \( G_c \) = mass velocity per channel (kg/s.m\(^2\))
- \( D_e \) = equivalent diameter (m)
- \( L_{eff} \) = developed length between vertical port (m)
- \( \rho \) = fluid density (kg/m\(^3\))
- \( \mu \) = fluid viscosity (kg/ms)
- \( f \) = friction factor

**Figure 1.** Pipe and instrumentation diagram of the primary cooling of the TRIGA 2000 reactor
The pressure drop in the port ducts can be roughly estimated as 1.4 velocity head [11].

\[ \Delta P_p = \frac{0.0014 (G_p)^2 (N_p)}{2 \rho} \]  

where: \( G_p \) = port mass velocity (kg/s.m²)

\[ G_p = \frac{4W}{\pi (D_p)^2} \]  

where: \( D_p \) = port diameter (m)

3. Methodology
The theoretical and experimental approaches have been used in the evaluation of the pump capability of the primary cooling of the TRIGA 2000 reactor. Theoretical approach is used to determine the system head curve of the primary cooling system and an experimental approach is carried out to obtain the characteristic curve of the primary cooling pump. In the experimental approach, to obtain a varying mass flow rate is done by adjusting the valve openings located at the pump outlet section.

4. Results and Discussion
By using experimental data that has been obtained, it can be made a characteristic curve of two existing pumps, both for the main pump and for redundant pump. Furthermore, by inserting the head system curve of the primary cooling system, the operating point of two pumps will be obtained, namely the intersection between the characteristic curve of the pump and the head system curve of the primary cooling system installation. Figure 2 and 3 show the operating point for the main pump and the redundant pump respectively. Figures 2 and 3 can also provide information regarding the fluid mass flow rate generated by two pumps, which is about 45 kg/s for the main pump and 45.5 kg/s for the redundant pump.

![Figure 2](image-url)  

**Figure 2.** The operating point of the main pump
Figure 3. The operating point of the redundant pump

Compared with the performance of the two pumps when it first installed in 2000, there is a decrease in performance of around 5%. Figures 4 and 5 provide information regarding the fluid mass flow rate generated by two pumps when it first installed in 2000, which is about 48 kg/s for the main pump and the redundant pump.

Figure 4. The operating point of the main pump in 2000
Meanwhile, the results of a thermal-hydraulic study for the TRIGA 2000 research reactor, which has converted its fuel element from the cylindrical type to the plate type, requires a mass flow rate of around 75 kg/s [12]. If the mass flow rate data according to the result of this study is compared with the mass flow rate of the existing primary pump of the TRIGA 2000 research reactor, the need for mass flow rates to cool the reactor core will not be sufficient. To obtain a higher mass flow rate, it can be done by operating a parallel of two primary pumps (main pump and redundant pump). By using the characteristic curve of the main pump and the redundant pump are shown in Figure 2 and 3, a combined characteristic curve can be determined if the two pump are operated in parallel (Figure 6). The operating point for the parallel pump can also be determined based on the intersection of the parallel pump curve with the head system curve. In Figure 6, it can be showed that the mass flow rate for parallel pump is obtained around 62 kg/s.
Based on these results, it can be concluded that the primary cooling pump, whether it is the main pump or redundant pump, is not enough to support the reactor operation at power of 2000 kW. The same conditions also occurs when both pump are operated in parallel. It means, to support the reactor operation at a power of 2000 kW, a pump with a larger capacity is needed. However, if we still want to use the existing pumps, the power of the reactor must be reduced.

The primary cooling pumps capacity discussed above applies only to the existing installation. The capacity of the pump will be reduced if the pump is used for modified primary cooling system. For example, for an installation that added a decay tank as a component to reduce the concentration of N-16 in the coolant flow.

5. Conclusions

Based on the experimental and theoretical studies of the primary cooling system of the TRIGA 2000 reactor, it can be obtained some conclusions. The mass flow rate for main pump and redundant pump of the primary cooling system of the TRIGA 2000 reactor are 45 and 45.5 kg/s, respectively. If both the primary cooling pumps are operated in parallel, the mass flow rate can increases to 62 kg/s and the mass flow rate is still lower than the mass flow rate needed on the modified (converted) reactor core (75 kg/s). The existing primary pumps cannot be used for the primary cooling system if the reactor core is converted into a plate type, even though both pumps are installed in parallel.

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