Natural Convection Flapper Valve Design for the Bandung Research Reactor Conversion

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Abstract. National Nuclear Energy Agency has planned to convert the Bandung TRIGA reactor by replacing the rod-type into plate-type fuel elements. The calculation results show that Bandung TRIGA Plate reactor with 2000 kW power requires forced convection cooling system. According to the calculation results using the Coolod-N2 computer program the minimum required cooling flow rate is 70 kg/s. Consequently, it is necessary to modify the reactor primary cooling system. In this modification required a flapper valve design that can a double function. The valve closed when the primary pump is powered and the flow rate on the primary coolant is 70 kg/s. However, when the pump is off because of the power outages and the reactor will scram, so the flapper valve will open. The residual heat in the reactor core will be cooled by natural convection. There is reversal flow from a downward to an upward cooling direction, and the upward natural convection heat removal throughout the flapper valve. In addition, the reactor also will scram if the cooling flow rate drops below 85% of 70 kg/s. The flapper valve is equipped with a ballast pendulum to open the flapper valve. The pendulum load must be greater than the flapper valve force plus the pump force due to forced flow. The flapper valve will open, if the flow rate is smaller than 85% of the required flow. Conversely, the flapper valve load must be smaller than the amount of flapper valve force and flow due to the pumps attractiveness, so that the flapper valve can be closed tightly and the reactor can operate with a forced convection flow. The design of natural convection flapper valve considers the following of a reliable, a work based on passive systems, a simple, an easy to make, an easy maintenance and it can be observed from the top of the reactor tank deck. As a redundancy, the operation of natural convection a flapper valve is added by mechanical operation, so the operation of the valve is truly reliable.

Keywords: Force convection, Natural convection, flapper valve

1. Introduction
BATAN has planned to convert the Bandung TRIGA reactor by replacing the rod-type into plate-type fuel element. The calculation results show that Bandung TRIGA Plates reactor with 2000 kW power requires forced convection cooling system. According to the calculation results using the Coolod-N2 computer program the minimum required cooling flow rate is 70 kg/s. Consequently, it is necessary to modify the reactor primary cooling system. In this modification required a flapper valve design that can a double function. The valve closed when the primary pump is powered and the flow rate on the primary coolant is 70 kg/s. In shutdown operation mode where there is no more fission reaction, the fuel can be cooled using forced convection or natural convection. When the pump is off because of the power outages, the reactor will scram, so the flapper valve will open to remove the decay heat. Consequently, it is necessary to modify the primary cooling system. In this modification required a valve design that
can double function. The valve closed when the primary pump is powered and the flow on the primary cooler is forced convection. However, when the pump is off so the valve will open, the reactor core will be cooled by natural convection. The cooling water in the reactor tank flows upward through the reactor core.

Currently the Bandung TRIGA reactor is operated by using natural convection, the direction of the coolant fluid flow from the bottom up. This natural convection flow occurs because of the difference in density of the coolant fluid. The fluid temperature inside the reactor core is higher than the fluid temperature at the other position, so its density is lower than the mass of the surrounding fluid type resulting in natural convection. Bandung TRIGA Reactor Plate being designed, the cooling system will use forced convection, fluid flow from top to bottom. This flow may occur due to the pump is power that pulls the cooling fluid down. According to calculations by using Coolod-N2 computer program, the minimum coolant flow rate required is 70 kg/s of forced cooling mode. This forced cooling will always continue as long as the primary pump is functioning, but during interruptions, such as power outages, the forced convection flow will stop. In addition, the reactor also will scram if the cooling flow rate drops below 85% of 70 kg/s. Although the reactor has been shut down or scram, it still needs to be cooled because of the residual heat inside the reactor core. This residual heat will be cooled by natural convection.

In the RSG-GAS, the reactor will be shut down and natural circulation flapper will be open when the coolant flow rate becomes smaller than approximately 90 ± 5% and 15% of their nominal values, respectively [1]. Kazem Ardaneh and Salman Zaferanlouei stated that in the nuclear reactors, natural circulation is an important passive mechanism for heat removing. After the pump is off or the natural circulation in the core is a normal operation mode, the core is cooled by the natural circulation mechanism. Some pool type research reactors use top-down cooling with a forced convection mode, passing through the decay tank and then pumped back into the pool through a heat exchanger. A flapper valve is embedded in the bottom of the lower core plenum which enables natural convection through the core without the forced flow convection [2]. In his paper, Talal Mohamed Mahmoud Abou Elmaaty even stated that natural convection is a preferable heat transfer method wherever possible due to its simplicity, reliability, and cost effectiveness [3]. Some pool type research reactors can operate under either forced or natural convection modes. Under forced convection, the primary cooling system removes the heat generated in the reactor core through a heat exchanger to the secondary cooling system. And then, the secondary cooling system releases this thermal energy through the cooling tower to the atmosphere. In case of loss of primary flow under forced convection operating mode, and due to the decreasing pressure in the primary circuit the natural convection flapper valve opens automatically leading to the reverse flow in the reactor core [1-9].

In this design, a convection of a natural convection has been designed. At the pipe of the primary cooling system is installed a valve that can be open or closed passively, without the need for electrical energy. This valve will be closed if the pump is still powered, so inside the reactor core there is forced convection and the valve will open if the pump is off and so there will be natural convection.

The objective of designing this natural convection cooling valve, to get a reliable valve, easy to create and maintain and work based on a passive system, does not require electrical energy or human action.

2. Natural Convection Design

The design of natural convection valves considers the following:

- Reliable, it can work well without experiencing many obstacles.
- Changed as few possible existing design, so the existing system can still be used
- Valves can work based on passive systems, to open or close the valve do not require electrical energy.
- Simple, uncomplicated, easy to make, easy maintenance and it can be observed from the top of the reactor tank deck
During normal operation, heat generated by nuclear reactions is removed by the downward forced flow of cooling water circulated by a primary cooling system. The water flows downward through the core, passes through a decay tank and then pumped back to the pool through the heat exchangers. During shutdown stage, the core is possible cooled by downward forced flow or by upward natural convection flow through a safety flapper valve.

But, when the pump is off because of the power outages, the reactor will scram, the reactor core is cooled by an upward natural convection flow throughout a safety flapper valve. Under natural convection operating mode, heat generated by decay heat is removed by the pool water. All decay heat can be absorbed by the large water inventory of the reactor pool with no need for further external cooling.
To ensure valve reliability, using redundancy principles, 2 natural convection valves have been designed, which are placed on the output pipe above the reactor core (Figure 1). Act of Indonesian Regulatory Body No.1 2011 states that reactors designed using passive valves (flapper) as part of the safety system should be applied to the principle of redundancy [10]. The Egypt Test and Research Reactor Number 2 (ETRR-2) has two flapper valves, each is placed on return pipe lines of the primary cooling system [5]. In some reactor the safety flapper valve located below the core grid plate [6, 9].

As seen in the Figure 1 and Figure 2, the flapper valve is equipped with a ballast pendulum to open the flapper valve. So, valves can work based on passive systems, to open or close the valve do not require electrical energy. The pendulum load must be greater than the flapper valve force plus the pump force due to forced flow. The flapper valve will open, if the flow rate is smaller than 85% of the required flow. Conversely, the flapper valve load must be smaller than the amount of flapper valve force and flow due to the pumps attractiveness, so that the flapper valve can be closed tightly and the reactor can operate with a forced convection flow.

![Figure 3. Moment of Flapper valve](image)

As seen in Figure 3, when the primary pump is ON, the natural flow valve must be closed due to the suction power of the pump in the natural convection pipe and due to the load on the natural flow pipe cap.

- G1 = Suction power on the pipe
- G2 = Down valve forced
- G3 = moment pendulum in water. $G1 + G2 > G3$

When the primary pump is OFF, the natural flow valve will open because of the suction power of the pump ($G1 = 0$)

So that the valve is open $\rightarrow G3 > G2$

It should be noted that the valve opening should be $< 90^\circ$ in order to close when the primary pump is ON. $\rightarrow \sim 60^\circ$

Between the pipe and the cap be assembled rubber seals to keep the cap tight and no leakage occurs. The malfunction of the opening the flapper valve can leading to fuel plate damage. The failure in the flapper valve opening reduces the coolant flow rate of the core and fuel assembly temperature rise.
To overcome this, redundancy is made to open the valve with the help of the operator. The flapper valve will be opened mechanically from the control room.

![Figure 4. Instrumentation and Control system for detecting and controlling of natural convection flapper valve](image)

Figure 4, shows the instrumentation and control system for detecting and controlling of natural convection flapper valve. This circuit functions as a monitor and controller of the flapper valve if a malfunction occurs when the system opens the flapper valve, which works on the principle of a passive system. When the valve is open, the wire loosens and triggers the micro switch to be an open condition and gives a signal to the light and sound indicators in the control room. If the valve fails, the indicator will turn off and activate the alarm as a warning. So the valve needs to be opened manually by the operator in the control room by pressing a button connected to the circuit that drives the motor.

3. Conclusion
The design of this natural convection valve is reliable because it works based on a passive system, is equipped with a redundancy valve and besides that it is also equipped with redundancy of how to operate the flapper valve. This valve is easy to make because of its simple design. Maintenance and repair of the valve is also easy because the valve is located above the reactor core. Because the valve is located above the reactor core, it can be seen directly from the reactor tank deck.

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