Experiments on Natural Convection as Cooling System Mechanism on Nuclear Reactors

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Abstract. The nuclear reactor accident at Fukushima occurred because the pump on the cooling system did not work. Next-generation nuclear reactors are expected to have a cooling system that remains functional even when the pump is not working. Natural convection becomes an option that can be used to flow the coolant without using a pump. Natural convection is a fluid flow phenomenon that occurs due to differences in density. The research was conducted to study the effect of the temperature difference on the flow rate of coolant. Previous experiments have been carried out to determine the flow rate of refrigerant to the height of the cooling system, but have deficiencies in the measurement of the flow rate of the coolant.

1. Introduction

Nuclear reactor accidents in Fukushima Japan became one of the reasons for the importance of inherent safety in nuclear reactors. One important part of inherent safety is the cooling system. Nuclear reactors are usually cooled by a fluid-cooled cooler that flows with a pump.

In this study, we will design a cooling circulation device using the concept of natural convection. Using natural convection, the coolant flows due to the temperature difference in the fluid. Previously conducted research, we get temperature data against time, data flow velocity cannot be obtained. This research is expected to observe the influence of temperature difference to coolant flow velocity.

2. Natural Convection

Natural convection is the mechanism of fluid flow generation along with the heat flow that occurs due to the temperature difference in the fluid. In natural convection, no external force is required from the pump or fan as it is for forced convection to drain the fluid.

The fluid flow in natural convection is caused by the lifting force of the fluid. This fluid lift force is produced by a different density which is a function of temperature. Here is the relationship of lift and temperature on the fluid [1].

\[ \vec{f}_a = (\rho - \rho_0) \vec{g} \]  
\[ \rho = \rho_0 (1 - \beta \Delta T) \]  
\[ f_a = \rho_0 \beta \vec{g} \Delta T \]
\( f_b \) is buoyancy force, \( \rho \) is density, \( \beta \) is thermal expansion coefficient, \( g \) is acceleration of gravity, and \( \Delta T \) is temperature difference.

3. Closed Loop System Natural Convection

The natural convection system can be divided into three parts, that are closed loop system, control system, and measurement system. The closed-loop system is a vertical loop with the bottom there is a heater and the top there is a cooler. Heating and cooling can change the mass of the fluid types present in it, so that fluid flow can occur. The fluid used in this system is water.

![Figure 1 Closed Loop System Schematic](image1)

![Figure 2 Closed Loop System](image2)

In the heating and cooling section, there is a control system, which can maintain the temperature according to the set temperature. The control system used is the on-off control system.

![Figure 3 Heater](image3)

![Figure 4 Cooler](image4)

The data to be taken is the temperature and speed data of water flow in the circulation system. The temperature sensor used is LM35 protected with a cover so that water does not enter. As for the flow of water, used cameras and trackers. Previously used turbine flowmeter can’t read the flow [2], because the flow of water in natural convection is too small.
4. Experiment

In this experiment, five sensors are placed, four temperature sensors and one flow sensor. The location of the sensor can be seen in the picture.

Variable varied is the temperature difference between heater and coolant. The temperature differences used in the experiment is in the Table 1. The flow velocity is measured when the temperature difference between the heater and the coolant is stable, at 300 to 350 seconds since the experiment begins.

| T_{HEATER} (°C) | T_{COOLER} (°C) | ΔT (°C) |
|----------------|----------------|---------|
| 40             | 10             | 30      |
| 50             | 10             | 40      |
| 70             | 10             | 60      |
| 90             | 10             | 80      |
5. Results

From the four variations of the temperature difference of the experiments conducted, the following graphs are obtained. **Figure 9** (a) to (c) are graphs of temperature over time, at the locations shown in **Figure 7**.

![Graph of temperature vs. time](image)

**Figure 9** Graph of temperature against time

(a) $\Delta T = 30^\circ C$ (b) $\Delta T = 40^\circ C$ (c) $\Delta T = 60^\circ C$ (d) $\Delta T = 80^\circ C$

![Graph of flow velocity vs. $\Delta T$](image)

**Figure 10** Graph of flow velocity against $\Delta T$

From the experiments performed, the flow velocity can be observed by using the camera and tracker. However, with this method, the flow velocity can only be measured once only, due to the limitations of the tracker. The flow velocity data obtained from the four variations of the temperature difference of heater and coolant can be seen in **Figure 10**. From the figure, it can be seen that the higher the temperature difference, the higher the flow rate at the location in the **Figure 8**. This is related to the buoyancy force resulting from the temperature difference, especially in the heating
section. The higher the temperature difference, the higher the resulting density change. In other words, the lift style generated greater. Buoyancy force is related to the acceleration and final velocity that the fluid can achieve.

From the graph in Figure 9, although the temperature difference between the heater and the coolant is getting bigger, the difference temperature in water after exiting the heater and cooling (position B and D in Figure 7) is relatively the same. This is caused by heaters that are not thermally insulated.

![Figure 11. Heater (before thermal insulation)](image)

![Figure 12. Heater (after thermal insulation)](image)

After the addition of glass-wool to isolate the heat, an increase in water temperature after passing through the heater (see Figure 14).

![Figure 13 Graph of temperature data against time for ΔT 80 (before thermal insulation on heater)](image)

![Figure 14 Graph of temperature data against time for ΔT 80 (after thermal insulation on heater)](image)

6. Conclusions
The development of flow sensors using the camera successfully detects the flow in the natural convection system. Water flow in the natural convection system gets bigger when the temperature difference between the heater and cooler is getting bigger. However, for better observation, we need flow sensors that can read the flow of water in the natural convection system in real time.

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References
[1] Adrian Bejan, Allan D. Kraus. 2003. Heat Transfer Handbook. John Wiley and Sons : New Jersey. Page 531-532.
[2] Habibi Abdillah, Suprijadi, Novitrian. 2013. Design of Instrumentation System and Detection System of Velocity and Temperature of Water on Natural Circulation System. Physics Department of Institut Teknologi Bandung, Bandung. Page 28-31.