Estimation of Natural Circulation Laminar Flow Rate on FASSIP-test loop 04 Based on slope variations Loop 90°, 75°, 60°, 45°, 30°

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Abstract. FASSIP-04 Test Loop is a facility for the investigation of natural circulation flow. Natural circulation flow occurs by different density of fluid with difference temperatures from heat source and heat sink. It is important to investigate capability of heat transfer natural circulation flow with effect variation inclination and variation saturated temperature. Preliminary of flowrate aimed to calculate flow in the FASSIP-04 test loop before the experimental study. Temperature variation of preliminary use saturated water temperature in the heating tank is 50°C, 60°C, 70°C, 80°C, and 90°C also the temperature in cooling tank maintains 10°C every variation experiment. Variation inclination of experiment facility in 45°, 65°, 70°, and 90°. The results of the calculation flowrate shown value is influenced by the difference in temperature in the heater area and cooler area, for the smallest flow rate value is found in the variation of rectangular loop slope of 30° with temperature in the heater area 50°C = 0.22 m/s. while the largest flow rate value is found in the variation of rectangular loop slope 90° with temperature in the heater area 90°C = 0.22 m/s and the maximum Reynolds number in temperature variations 90°C with slope 90°.

Keywords. preliminary, flowrate, natural circulation, FASSIP-04 test loop, inclination, temperature difference

Introduction

Nuclear Power Plane (NPP) accidents that have occurred and are categorized as severe accidents at the Three Mile Island Unit 2 (TMI-2) pressurized water reactor (PWR) in 1979 [1], and the Fukushima Daichii boiling water reactor (BWR) in 2011 [2] have become important concerns in the NPP safety system. Referring to the recent accident at Fukushima Daichii Japan, which was caused by a natural disaster in the form of an earthquake and tsunami resulted in an inactive reactor cooling system, due to pump failure and immersion of generators or emergency coolers. This is due to the blackout of electricity due to the natural disaster, therefore the residual heat in the reactor accumulates so that a hydrogen explosion occurs, where the hydrogen combines with oxygen compounds so that it spreads into the atmosphere so that the explosion contains radioactive material [3]
So research and development in the field of reactor thermo hydraulics to prevent thermal management failures in nuclear power plants and research reactors need to be done based on natural laws and minimize the intervention of tools or forces from outside [4]. The method used to absorb thermals that rely on natural law-based performance (gravity and buoyancy forces) is called a passive cooling system (PCS). This research uses the Passive System Simulation Facility 04 (FASSIP 04) experimental tool to determine the estimated flow rate of PCS moving in laminar flow by using two main parameters that affect, namely, differences due to geometric changes (boundary conditions, BC) and changes due to initial conditions (IC).

Natural circulation is a passive cooling system concept that affects the flow of fluid that moves without the intervention of external forces and is based on applicable natural laws. The phenomenon of fluid flow rates in passive systems is called natural circulation, which arises based on differences in fluid density [5]. Meanwhile, thermosyphon flow in general geometry and its applications have been studied by [6], [7], [8]. Their research was conducted on rectangular test loops with open-loop and closed-loop conditions. The investigation has been carried out for steady flow and transient flow by analyzing the stability of the system based on the variation of heating in the heater region and cooling in the cooler region. Later researchers [9] have considered different thermal boundary conditions, such as height difference between the heater and cooler regions. The effect of heat transfer in the pipe on mass flow rate parameters during natural circulation has been studied by several researchers [10], [11], [13], as for some research that has been done by the Center for Nuclear Reactor Safety Technology (PTKRN) BATAN which is now changing its name to the Center for Nuclear Technology Research, Nuclear Technology Research Organization (PRTN-ORTN) BRIN conducted by Mulya Juarsa from 2011 and 2014-2016 which started research to investigate the phenomenon of natural circulation using rectangular test loops [4], [14]. However, the conditions referred to for research are still in a steady state.

**Methodology**

The experimental design consists of a rectangular loop with dimensions of 3 meters long and 1 meter wide. The heater and cooler are attached to the loop with a height difference set at 2.4 meters. To obtain variations in the height difference (H) between the heater and cooler, the rectangular loop of FASSIP 04 can be changed in its tilt angle according to the research matrix. The following schematic of the tool that will be used for experiments can be seen in Figure 1.
The specifications of the experiment apparatus that will be used in the natural circulation narrative experiment that will be used can be seen in Table 1.

**Table 1 Specifications of the experimental apparatus FASSIP-04**

<table>
<thead>
<tr>
<th>Description</th>
<th>Specifications</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Martial pipa</td>
<td>SS 201</td>
<td>Rectangular loop FASSIP</td>
</tr>
<tr>
<td>Diameter pipa</td>
<td>1 inch</td>
<td>4</td>
</tr>
<tr>
<td>Total loop length</td>
<td>8000 mm</td>
<td></td>
</tr>
</tbody>
</table>

**Experimental Setup**

The experimental plan to be carried out this time several parameters are considered fixed, namely, pipe materials, work fluid, and water temperature in the cooler tank (TC) are considered fixed. While the angle of inclination of the rectangular loop (α), and the water temperature in the heater tank (TH) change according to the experimental matrix which can be seen in Table 2.

**Table 2 matrix of experiments**

<table>
<thead>
<tr>
<th>Material pipa</th>
<th>Fulida kerja</th>
<th>Kemiringan α°</th>
<th>Temperatur Water dalam Cooler TC (°C)</th>
<th>Temperatur Water dalam Heater TH (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS 201</td>
<td>water</td>
<td>90</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45</td>
<td>10</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>10</td>
<td>90</td>
</tr>
</tbody>
</table>

**Analytical Methods**

To obtain the flow rate influenced by BC parameters, the loop total length (L), the height difference of the heater tank tube and the cooler tank tube (H), the flow pipe diameter (D), and IC parameters, namely the working fluid temperature in the heater tank tube (TH) and in the cooler tank tube TC in the rectangular loop FASSIP-04, the laminar flow rate (ν) can be calculated using Equation (4) by first finding the viscosity value of the water coming out of using Equation (1) [4].

\[
\mu(T) = 0.00176 - [4.77581 \times (10^5)T] + [5.9184 \times (10^{-7}) \times T^2] - [2.6459 \times (10^{-9}) \times T^3]
\]

After obtaining the viscosity value of water, it is continued by finding the water density value in the equation (2).
\[ \rho(T) = [999.96124 + (0.019987)] - [(0.0059T^2) + (1.57658 \times 10^{-5} \times T^3)] \quad (2) \]

Then to find out the value of the difference in height caused by a change in the angle of inclination in the loop, you can use equation (3).

\[ H(\alpha) = L \sin \sin \alpha \quad (3) \]

From the calculations that have been carried out, you can then find the value of the flow rate that is found in the loop using equation (4).

\[
\nu = \frac{-64\mu L + \sqrt{(64\mu L)^2 + 8gHK\rho_wD^4(\rho_C - \rho_H)}}{2K\rho_wD^2} 
\]

(4)

So that the results of the flow rate calculation that has been carried out using the above experience will be displayed in the form of a graph.

Results and discussion
The calculation was carried out to find the natural flow rate of circulation that occurred in the FASSIP-04 experimental tool with variations in temperature changes in the heater area and cooler area maintained at a fixed temperature. Another variation change that is carried out is to change the angle of inclination of the rectangular loop which results in the difference in height between the heater and cooler areas with a total loop length \( (L = 8m) \) and the volume of water in the loop of \( (V = 0.0041 \text{ m}^3) \) can be seen in Figure 2.

Velocity of Natural Flow Circulating in FASSIP-04 Version 00 with 90° Inclination

![Graph of flow rate](image)

**Figure 2** Graph of the flow rate of the tilt angle of 90°.

Based on Figure 2, it shows a flow rate graph with variations in the inclination angle of the loop \( (\alpha = 90^o) \). It can be observed that there is a flow for every temperature change in the
heating area caused by the temperature difference between the hot and cold areas. Therefore, the flow rate values at a temperature of 50°C are 0.36 m/s, at 60°C are 0.46 m/s, at 70°C are 0.56 m/s, at 80°C are 0.66 m/s, and at 90°C are 0.75 m/s. From the obtained flow rate values, a linear fitting analysis can be performed with an R² value of 0.99955, resulting in the equation \( y = -0.111209 + 0.00949T \). The changes in flow rate for an inclination angle of 75° can be seen in Figure 3.

![Graph of the flow rate of the tilt angle of 75°.](image)

**Figure 3** Graph of the flow rate of the tilt angle of 75°.

In Figure 3, it can be seen that the flow rate occurs due to the temperature difference between the hot heater area and the cooler area with a 75° rectangular loop inclination. For variations in the WHT temperature at 50°C, 60°C, 70°C, 80°C, and 90°C, there is a maximum flow rate at a temperature of 90°C, which is 0.73 m/s, and a minimum flow rate at a temperature of 50°C, which is 0.35 m/s. Therefore, based on the obtained flow rate values, a linear fitting analysis can be performed with an R² value of 0.99956, resulting in the correlation equation \( y = -0.111209 + 0.00949T \). The changes in flow rate for an inclination angle of 60° are shown in Figure 4.
In Figure 4, it can be seen that the flow rate occurs due to the temperature difference between the hot heater area and the cooler area with a 60° rectangular loop inclination. With variations in the WHT temperature at 50°C, 60°C, 70°C, 80°C, and 90°C, the maximum flow rate is obtained at a temperature of 90°C, which is 0.73 m/s, and the minimum flow rate is obtained at a temperature of 50°C, which is 0.35 m/s. Based on the obtained flow rate values, a linear relationship with a coefficient of determination $R^2 = 0.99959$ is obtained, resulting in the correlation equation $y = -0.11209 + 0.00949TWHT$. The changes in flow rate for a 60° inclination angle can be seen in Figure 5.

Based on Figure 6 of the natural flow rate graph of circulation with variations in the angle of inclination of the rectangular loop ($\alpha = 45^\circ$) shown that at each temperature change in

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**Gambar 4** Graph of the flow rate of the tilt angle of 60°.

**Figure 6** Graph of the flow rate of the tilt angle 45°.
the heater area there is a flow rate. So for temperature values of 50 °C = 0.29 m / s, 60 °C = 0.37 m / s, 70 °C = 0.45 m / s, 80 °C = 0.53 m / s, and 90 °C = 0.61 m / s. As for the value of the change in flow rate for the angle of inclination of 30° can be seen in Figure 7.

**Velocity of Natural Flow Circulating in FASSIP-04 Version 00 with 30° Inclination**

<table>
<thead>
<tr>
<th>Temperature Setting, $T$ [°C]</th>
<th>Flow Velocity, $v$ [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.22</td>
</tr>
<tr>
<td>60</td>
<td>0.29</td>
</tr>
<tr>
<td>70</td>
<td>0.36</td>
</tr>
<tr>
<td>80</td>
<td>0.43</td>
</tr>
<tr>
<td>90</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Based on Figure 7 of the natural circulation flow rate graph in variations the angle of inclination of the rectangular loop ($\alpha = 30^\circ$) shown that in each temperature setting heating area there is a flow rate for temperature values of 50° C = 0.22 m / s, 60° C = 0.29 m / s, 70° C = 0.36 m / s, 80° C = 0.43 m / s, and 90°C = 0.49 m/s. The graph shown linear correlation with $y = -0.10596+0.000669T_{\text{WHT}}$ and determinant coefficient in $R^2=0.99976$. Based on the calculation of flow velocity on temperature and slope variations, the Reynolds number can be obtained which expresses the ratio of inertia and viscosity of water in the FASSIP-04 Test .test loop shown in Figure 8.
Figure 8 shown the relationship of Reynold's number to HT temperature variation and loop slope obtained based on the increase in temperature variation in HT increases also its Reynolds number which from temperature variation of 50°C enters the turbulent flow regime to temperature variation of 90°C and based on the increase in temperature variation the viscosity of water decreases, while the influence of loop slope on Reynolds' number is quantitatively shown in Table 2.

<table>
<thead>
<tr>
<th>TH [°C]</th>
<th>90°</th>
<th>75°</th>
<th>60°</th>
<th>45°</th>
<th>30°</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>9983,663</td>
<td>9754,770</td>
<td>9062,293</td>
<td>7884,488</td>
<td>6165,244</td>
</tr>
<tr>
<td>60</td>
<td>13182,303</td>
<td>12893,312</td>
<td>12017,834</td>
<td>10523,995</td>
<td>8328,962</td>
</tr>
<tr>
<td>70</td>
<td>16287,949</td>
<td>15942,076</td>
<td>14893,465</td>
<td>13100,884</td>
<td>10456,594</td>
</tr>
<tr>
<td>80</td>
<td>19357,059</td>
<td>18955,850</td>
<td>17738,872</td>
<td>15655,991</td>
<td>12575,694</td>
</tr>
<tr>
<td>90</td>
<td>22586,043</td>
<td>22127,238</td>
<td>20735,060</td>
<td>18350,289</td>
<td>14817,098</td>
</tr>
</tbody>
</table>

Table 2 shown the relationship of the influence of loop slope on Reynold's number. The influence of loop slope affects the height difference between HT and CT, so that Reynold's number at a temperature variation of 50°C at a slope of 90° Reynold's number is greater than the slope of 30° this is due to the difference in height between HT and CT so that the increase in maximum flow at each temperature variation occurs at a slope of 90°.

**Conclusion**

The results of the analysis of the flow rate value based on changes in the angle of inclination of the loop concluded that the flow rate value will decrease as the loop tilt angle decreases by 90°, 75°, 60°, 45°, and 30° which causes a height difference between the heater and cooler. As for other values that cause an increase in the flow rate value is influenced by the difference in temperature in the heater area and cooler area, for the smallest flow rate value is found in the variation of rectangular loop slope of 30° with temperature in the heater area 50°.
C = 0.22 m/s. While the largest flow rate value is found in the variation of rectangular loop slope 90° with temperature in the heater area 90°C = 0.22 m/s. Based on the influence of temperature increase and loop slope shown its effect on the maximum Reynolds number in temperature variations 90°C with slope 90°.

References