Eximia Journal
Vol. 5, 761-769, July, 2022
ISSN: 2784-0735
www.eximiajournal.com

Estimation of Natural Circulation Laminar Flow Rate on FASSIP .test loop 04 Based on slope variations *Loop* 90^o, 75^o, 60^o, 45^o, 30^o

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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 Daiichi boiling water reactor (BWR) in 2011 [2] have become important concerns in the NPP safety system. Referring to the recent accident at Fukushima Daiichi 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]

Eximia Journal
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www.eximiajournal.com

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**.

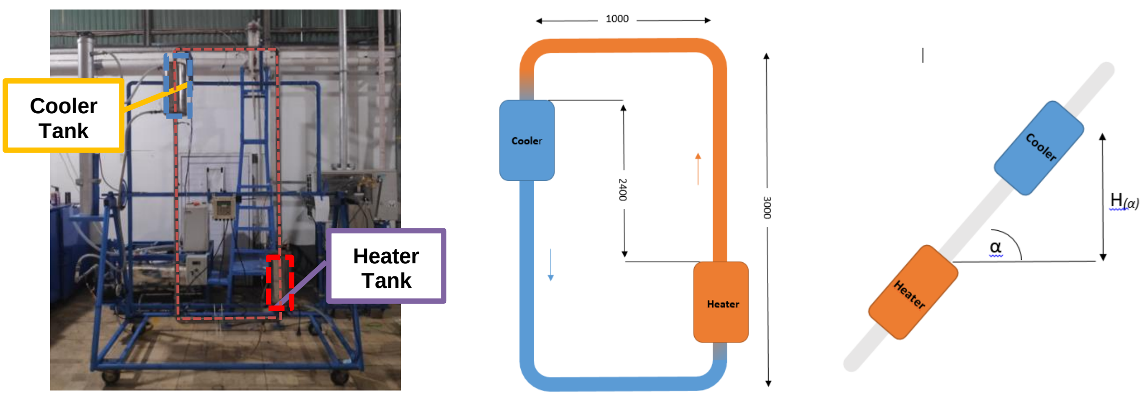

Figure 1 FASSIP-04 experimental apparatus

Eximia Journal
Vol. 5, 761-769, July, 2022
ISSN: 2784-0735
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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

Description	**Specifications**	**Notes**
Martial pipa	SS 201	Rectangular loop FASSIP
Diameter pipa	1 inch	4
Total loop length	8000 mm	

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

Matrial pipa	**Fulida kerja**	**Kemiringan α°**	**Temperatur Water dalam Cooler T_C (°C)**	**Temperatur Water dalam Heater T_H (°C)**
SS 201	water	90	10	50
		75	10	60
		60	10	70
		45	10	80
		30	10	90

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 (v) can be calculated using Equation (4) by first finding the viscosity value of the water coming out of using Equation (1) [4].$\mu(T) = 0.00176 - [4.77581 \times (10^5)T] + [5.9184 \times (10^{-7}) \times T^2] - [2.6459 \times (10^{-9}) \times T^3]$ (1)

After obtaining the viscosity value of water, it is continued by finding the water desity value in the equation (2).

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$$\rho(T) = [999.96124 + (0.01998T)] - [(0.0059T^2) + (1.57658 \times 10^{-5} \times T^3)] \qquad (2)$$

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).

$$H(\alpha) = L \sin \sin \alpha \qquad (3)$$

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).

$$v = \frac{-64\mu L + \sqrt{(64\mu L)^2 + 8gHK\underline{\rho_w}D^4(\rho_C - \rho_H)}}{2K\underline{\rho_w}D^2} \qquad (4)$$

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 m^3) can be seen in Figure 2.

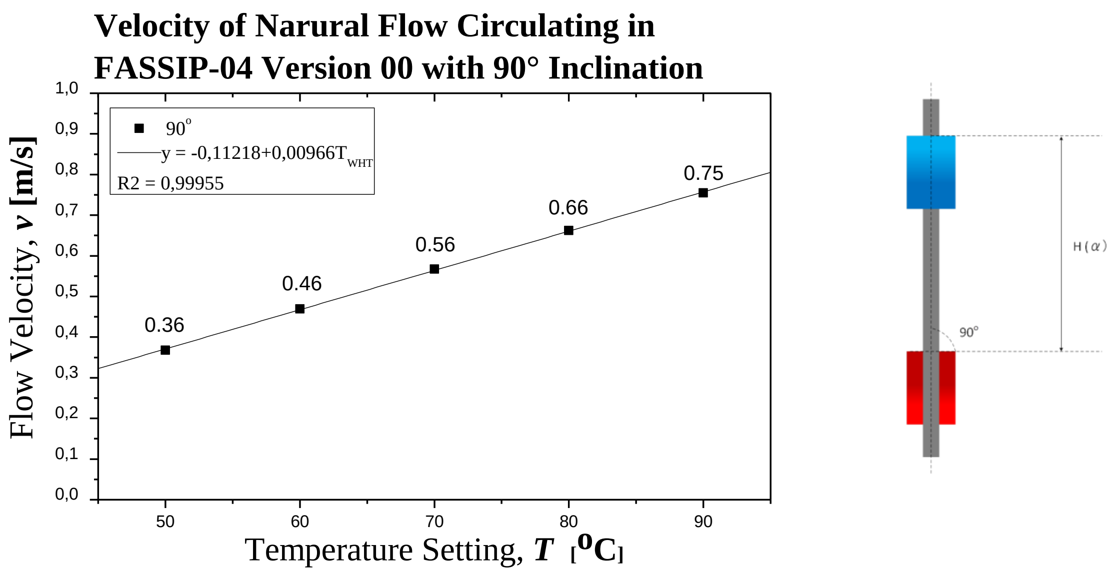


Figure 2 Graph of the flow rate of the tilt angle of 90°.

Based on Figure 2, it shows a flow rate graph with variations in the inclination angle of the loop (α = 90o). 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 50oC are 0.36 m/s, at 60oC are 0.46 m/s, at 70oC are 0.56 m/s, at 80oC are 0.66 m/s, and at 90oC 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 = -0.11218 + 0.00966TWHT. The changes in flow rate for an inclination angle of 75o can be seen in Figure 3.

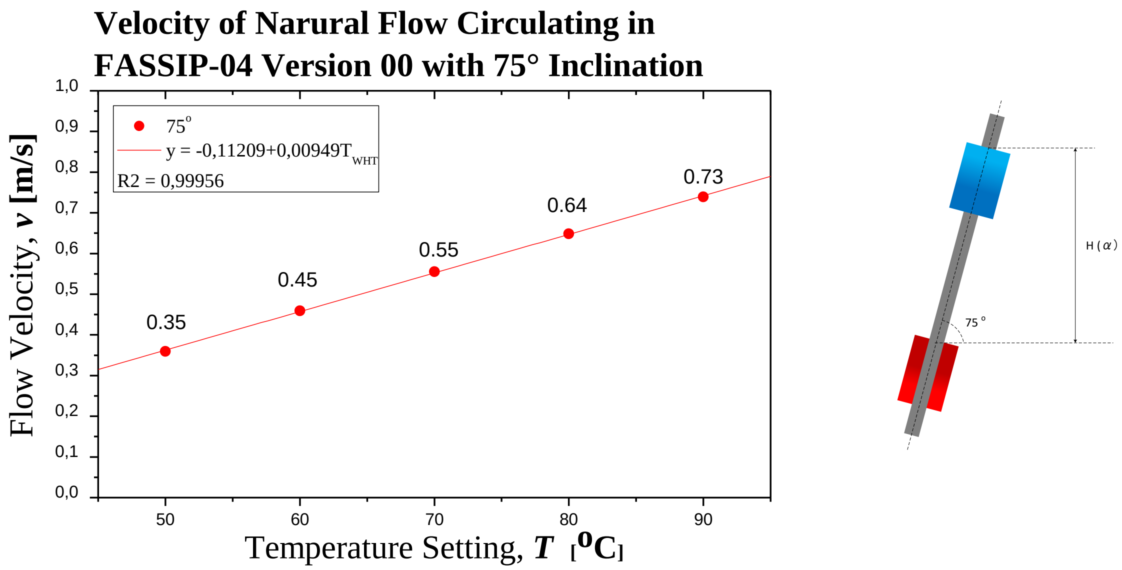
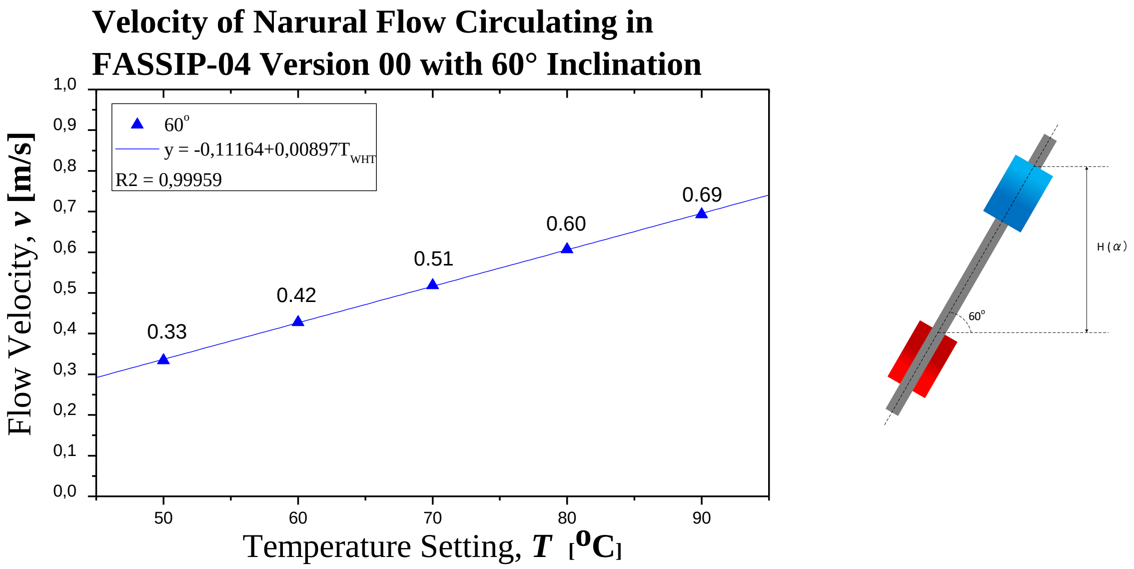


Figure 3 Graph of the flow rate of the tilt angle of 75°.

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 75o rectangular loop inclination. For variations in the WHT temperature at 50oC, 60oC, 70oC, 80oC, and 90oC, there is a maximum flow rate at a temperature of 90oC, which is 0.73 m/s, and a minimum flow rate at a temperature of 50oC, 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 = -0.11209 + 0.00949TWHT. The changes in flow rate for an inclination angle of 60o are shown in Figure 4.



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

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 60o rectangular loop inclination. With variations in the WHT temperature at 50oC, 60oC, 70oC, 80oC, and 90oC, the maximum flow rate is obtained at a temperature of 90oC, which is 0.73 m/s, and the minimum flow rate is obtained at a temperature of 50oC, which is 0.35 m/s. Based on the obtained flow rate values, a linear relationship with a coefficient of determination of R2=0.99959 is obtained, resulting in the correlation equation y = -0.11209 + 0.00949TWHT. The changes in flow rate for a 60o inclination angle can be seen in Figure 5.

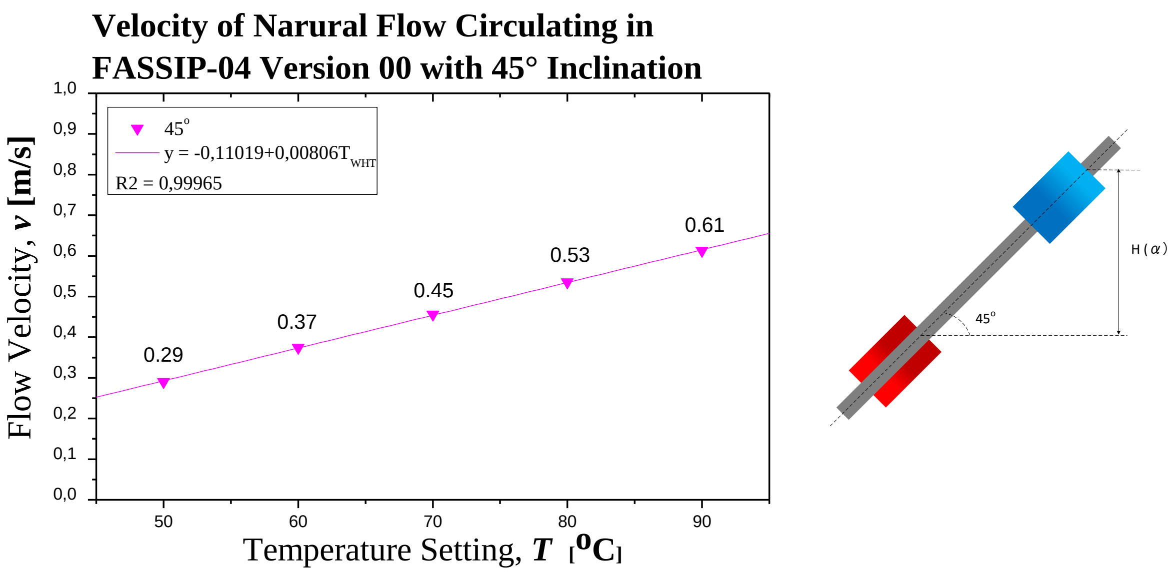


Figure 6 Graph of the flow rate of the tilt angle 45°.

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

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Vol. 5, 761-769, July, 2022
ISSN: 2784-0735
www.eximiajournal.com

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.

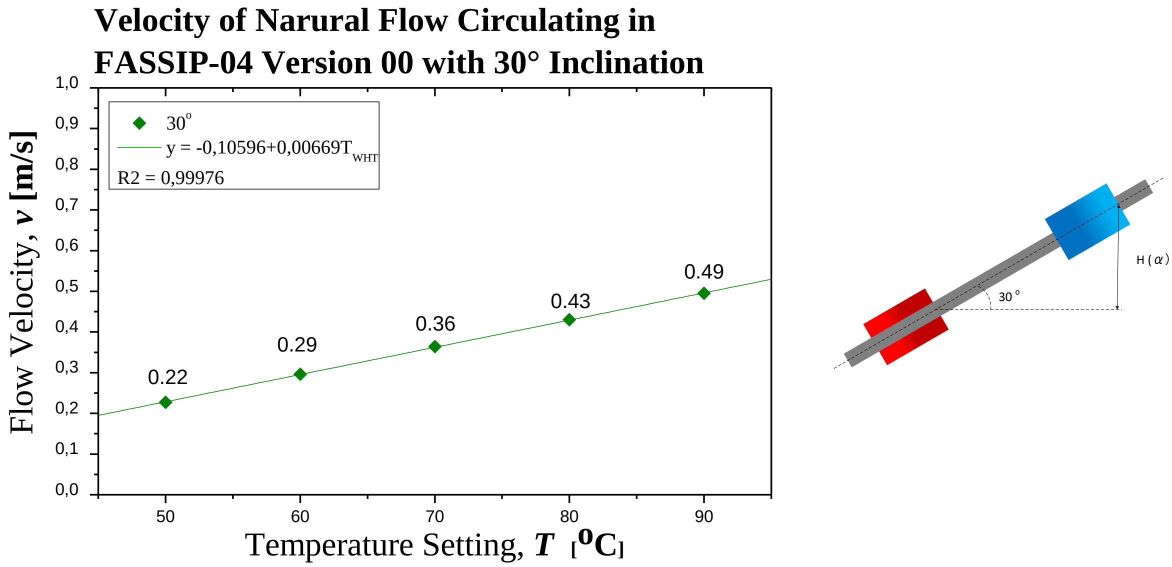

Figure 7 Graph of the flow rate of the tilt angle of 30°.

Based on Figure 7 of the natural circulation flow rate graph in variations the angle of inclination of the rectangular loop ($\alpha = 30^o$) 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_{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.

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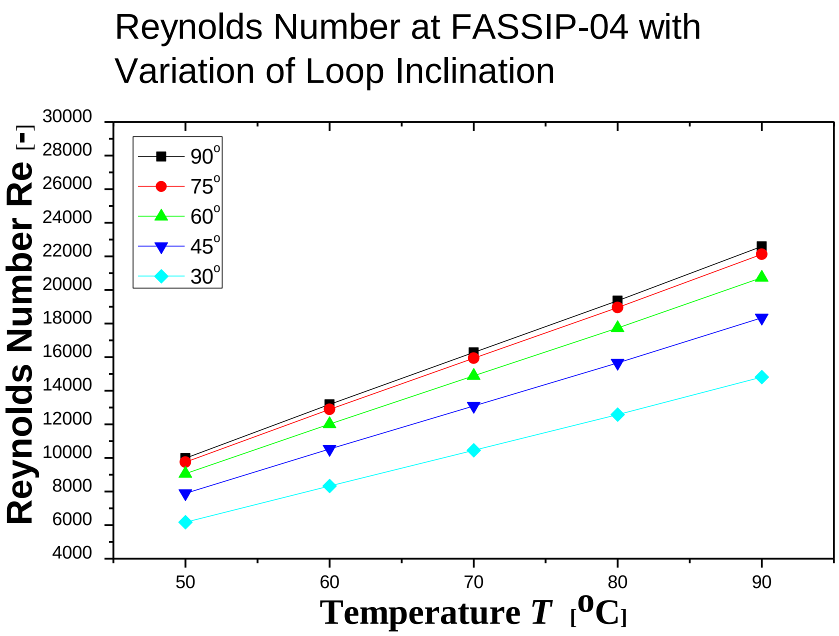

Figure 8 shown the relationship of Reynold's number to HT temperature variation and loop slope obtained based on the increase in temperature variation in HT increases also its Reynolds number which from temperature variation of 50°C enters the turbulent flow regime to temperature variation of 90°C and 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.

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

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°

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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

[1] Broughton, J. M., Kuan, P., David, A. P. & Tolman, E. L., 1989. A Scenario of the Three Mile Island Unit 2 Accident. Nuclear Technology, 87 (1), pp. 34-53.
[2] IAEA Tecdoc, S.-1., 2014. Progress in Methodologies for the Assessment of Passive Safety Sistem Reliability in Advanced Reaktors. IAEA.
[3] IAEA Tecdoc Series, 1., 2013. Passive Safety Sistems in Advanced Water Cooled Reaktors (AWCRs), Case Studies A Report of the International Project on Innovative Nuclear Reaktors and Fuel Cycles (INPRO). IAEA.
[4] Juarsa, M. et al., 2014. Preliminary Study on Mass Flow Rate in Passive Cooling Experimental Simulation During Transient Using NC-Queen Apparatus. Atom Indonesia, 40, pp. 141-147.
[5] Jain, V. et al., 2018. Experimental investigation on the flow instability behavior of a multi-channel boiling natural. Experimental Thermal and Fluid Science, pp. 776-787.
[6] Vijayan, P., 1992. Effect of loop diameter on the stability of single-phase. pp. 261-267.
[7] Greif, R., 1988. Natural circulation loops. ASME Journal of Heat Transfer, Volume 110, pp. 1243-1257.
[8] Zvirin, Y., 1981. A review of N. C. loops in PWR and other systems. Nuclear Engineering and Design, Volume 67, pp. 203-225.
[9] Misale, M., Devia, F. & & Garibaldi, P., 2005. Some considerations on the interaction between the fluid and wall tube during experiments in a single-phase natural circulation loops. Thermal Engineering and Environment, pp. pp. 128-133.
[10] Jiang, Y. & Shoji, M., 2003. Flow stability in a natural circulation loop: influence of wall thermal conductivity. Nuclear Engineering Design, Volume 222 (1), pp. 6-28.
[11] Misale, M., Garibaldi, P., Passos, J. & Bitencourt, G., 2007. Experiments in a single-phase natural circulation mini-loop. Experiment Thermal Fluid Science, Volume 31, pp. 1111-1120.
[12] Vijayan, P., 2002. Experimental observations on the general trends of the steady state and stability behaviour of single-phase natural circulation loops. Nuclear Engineering and Design, Volume 215, pp. 139-152.D'Auria, F. & Frogheri, M., 2002. Use of a natural circulation map for assessing PWR performance. Nuclear Engineering Design, Volume 215, pp. 111-126.
[13] D'Auria, F., Galassi, G., Vigni, P. & Calastri, A., 1991. Scaling of natural circulation in PWR sistems. Nuclear Engineering and Design, Volume 132, pp. 187-205.
[14] Gaos, Y., Juarsa, M., Marzuki, E. & Akbar, J., 2012. Efek Perubahan Sudut Kemiringan Terhadapcperpindahan Kalor dan Laju Aliran Air Pada Untai Sirkulasi Alamiah. Jurnal Teknologi Reaktor Nuklir Tri Dasa Mega, Vol.14, No.1, pp. 39-53.