Eksakta : Berkala Ilmiah Bidang MIPA
VOLUME 24 NO 01 2023, pp 1-8
ISSN : Print 1411-3724 — Online 2549-7464
DOI : https://doi.org/10.24036/eksakta/vol24-iss01/338

Eksakta
Berkala Ilmiah Bidang MIPA
http://www.eksakta.ppj.unp.ac.id/index.php/eksakta

Article

Inert Gas Axial Flow Analysis on Thermal System with Natural Convection Condition

Rio Anshari[1*], Mairizwan[1], Fandi Oktasendra[2], Debi Rianto[2], Zulhendra[1]

[1]Department of Physics, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Negeri Padang, Padang, Indonesia
[2]Department of Physics, Durham University, South Rd, Durham, DH1 3LE, United Kingdom

Article Info

Article history :

Received September 01, 2022
Revised December 18, 2022
Accepted December 27, 2022
Published March 30, 2023

Keywords :

Coolant, inert gas, natural convection, thermal system, nuclear energy

Abstract. The Fukushima nuclear accident in 2011 became the basis for consideration of the use of gas as a coolant in nuclear reactors. This is because the convection rate of gas flow in the cooling channel can occur naturally due to differences in density and does not require the help of a pumps for the circulation of the coolant. The roles of the pumps can be alternated as flow regulators of the coolant. This study aims to analyze how the flow pattern of an inert gas on a vertical-axial reference by natural convection in a thermal system. The focus of this research is to study the flow parameters of the coolant with a gas phase. This research is an experimental study. The analysis was carried out using a descriptive approach and computer simulation-assisted numerical analysis methods. The results showed that the distribution and variation of heat was radially dominant in the middle so that the coolant channel wall received less heat load. The magnitude of the pressure drop along the vertical-axial channel shows a homogeneous pattern and decreases radially from center to edge. These results indicate the use of inert gas as a coolant can be considered as an alternative coolant in heat systems that do not depend on pumps in operating conditions.

Corresponding Author :
Rio Anshari
Department of Physics, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Negeri Padang, Padang, Indonesia
Email : rioanshari@fmipa.unp.ac.id

1. Introduction

One of the many objects of research that is of concern to world researchers is research on energy. This is to address the scarcity of non-renewable energy sources. Alternative energies are starting to emerge as replacement candidates for non-renewable energy sources [1-3]. One form of energy that has the potential to replace the use of energy from non-renewable sources is nuclear energy. Many studies have been carried out to obtain a nuclear power plant design that is capable of producing large electrical power and a large conversion factor as well [4-6].

The Fukushima nuclear accident that occurred in Japan on March 11, 2011 became a special moment for all researchers in the energy field around the world, especially the specific field of study on nuclear energy. This nuclear accident became the basis for designing and deciding the type and design of nuclear power plants to be developed and built in the future [7-9]. This accident is also used as a basis, one of which is to consider the use of gas as as coolant in nuclear reactors. When this nuclear accident occurred, the Tsunami caused damage and submerged the main and supporting equipment of the nuclear reactor, including the reactor coolant pump. The submersion of the cooling pump by corrosive salt water, causing damage to various reactor equipment, including damage to the reactor cooling pump. The failure of the reactor coolant pump to work then triggers a buildup of heat in the reactor core which leads to the melt of the reactor core and the exposure of nuclear fuel in the reactor core and mixes with the coolant [10-12].

Regarding these conditions, the use of gas as a coolant in the reactor is an option that is of particular concern, because at high temperature conditions, the gas decreases in density and can flow by itself due to this difference in density. This condition is known as natural convection. The hotter the condition of the reactor core, the greater the difference in density of the gas coolant, so that the convection rate also increases. This condition causes the heat that accumulates in the reactor core to be reduced because it is flowed by the coolant by natural convection at a fast speed in the reactor cooling channels [13-15]. The characteristics of the natural convection present in this continuously heat-receiving gas are being studied to maximize it by researchers recently. The configuration of the heat system that applies natural gas convection as a coolant is of particular concern. For the axial reference in the vertical direction there is also the influence of gravity on the movement and speed of the coolant. Even so, the effect is not so pronounced because this gaseous coolant has a relatively small total mass, especially when compared to other coolants such as water which has a large total mass and requires a system of pumps to flow it into the thermal system. The application of gas-type coolant and the application of natural convection can reduce the dependence of the coolant flow on the pump system in the reactor. By using gas as a coolant that does not depend on the presence of pumps for coolant circulation, it can indirectly reduce costs for reactor construction and maintenance costs for the support system of these pumps [11, 16-18]

2. Experimental Section

2.1. Method

This research was carried out in the form of numerical simulation using computer. The research was conducted at the Computing Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang. The research method is a quantitative method with numerical calculations using numerical analysis model to obtain the amount of parameters and research variables according to the conditions to be achieved by the researcher. The variables obtained by this method are temperature variation, temperature distribution and pressure drop in axial orientation. Several studies that carried out system simulations and were used as references in this study were research conducted by Oztop [19], Haskin [20] and Franken [21]. Figure 1 below shows the research scheme.

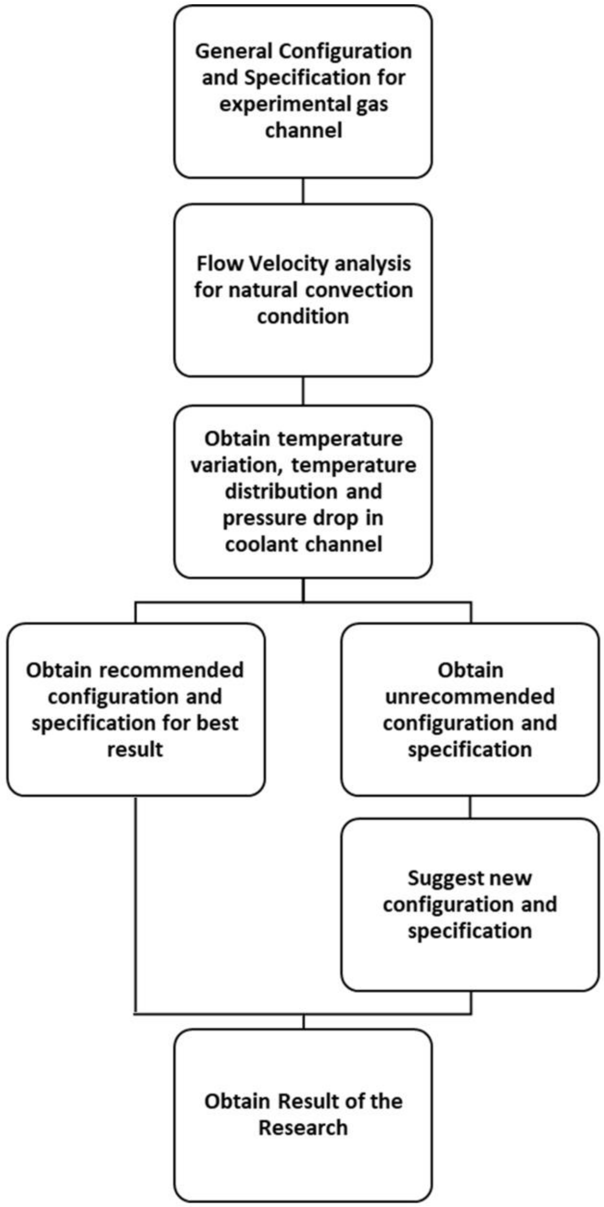

Figure 1. Research scheme

This research aims to analyze the pattern of temperature variation, temperature distribution and pressure drop in the cooling channel with axial reference, then after that, find the right configuration and specifications of the cooling channel that gives the targeted variable value. For initial benchmarks of configurations and general specifications of cooling channels, the configuration found in Waltar [22] is used.

2.2. Coolant

Coolants are used to remove heat from the core of a nuclear reactor as well as to transfer energy to an electric generator or to the environment. Some of the requirements that must be possessed by coolants are that they must have weak neutron absorption, have high chemical resistance when exposed to strong and prolonged radiation, not corrosion-causing substances, high heat transfer coefficient, large heat capacity and have low working pressure at high temperatures [23-25]. The coolant used in this study is a gas-phase coolant. The gas used as a coolant in this study is an inert gas. The use of inert gases is based on the objective of minimizing contamination of the nuclear reaction with the coolant. As is known, an inert gas is a gas that is not reactive or does not react with other substances around it [26-27]. Inert gases that are often used as coolants in gas-cooled reactors are Helium and Carbon dioxide. The inert gas used in the numerical analysis in this research is Helium gas. Helium gas as a coolant works in natural convection conditions [28-31].

3. Results and Discussion

3.1. Temperature Variation

Temperature variation is a pattern that shows the temperature range of the gas in the cooling channel. In this study, several parameters were adjusted for the thermal system in order to obtain the value of the intended temperature variation. Stable, effective and efficient conditions obtained from the numerical analysis that were successfully obtained can be seen in Figure 2 below.

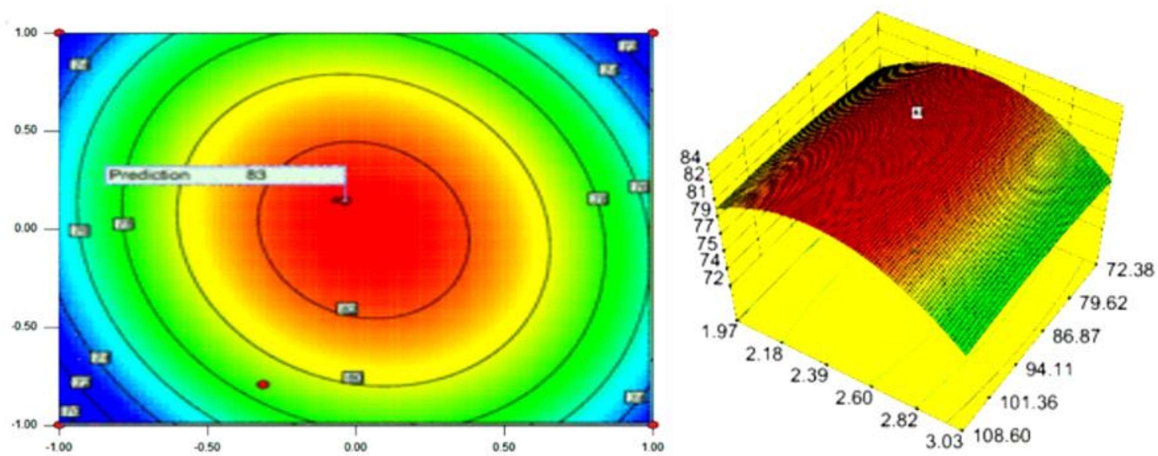

Figure 2. Temperature variation of the coolant inside the channel of research's thermal system

Figure 2 above shows a description of the temperature variation of the system under the conditions intended for this study. From the figure, it can be seen that the variation of gas temperature in the cooling channel with axial orientation provides stable, effective and efficient conditions for the system to work in natural convection conditions. This pattern is the intended result of this study. From the results, it can be seen that there is a temperature variation of the system which is homogeneously distributed in a radial orientation. The radial condition was deliberately taken to show the variation of heat from the center of the coolant channel to the edge of the coolant channel. It can be seen that the dominance of heat is concentrated in the center of the reactor and decreases gradually until it reaches the edge of the coolant channel.

3.2. Temperature Distribution

The temperature distribution is a pattern showing the temperature fraction of the coolant gas in the cooling channel in an axial reference. In this study, several changes in the parameters of the thermal system were carried out in order to obtain the value of the intended temperature distribution. The stable, effective and efficient condition obtained from the numerical analysis that was successfully obtained can be seen in Figure 3 below.

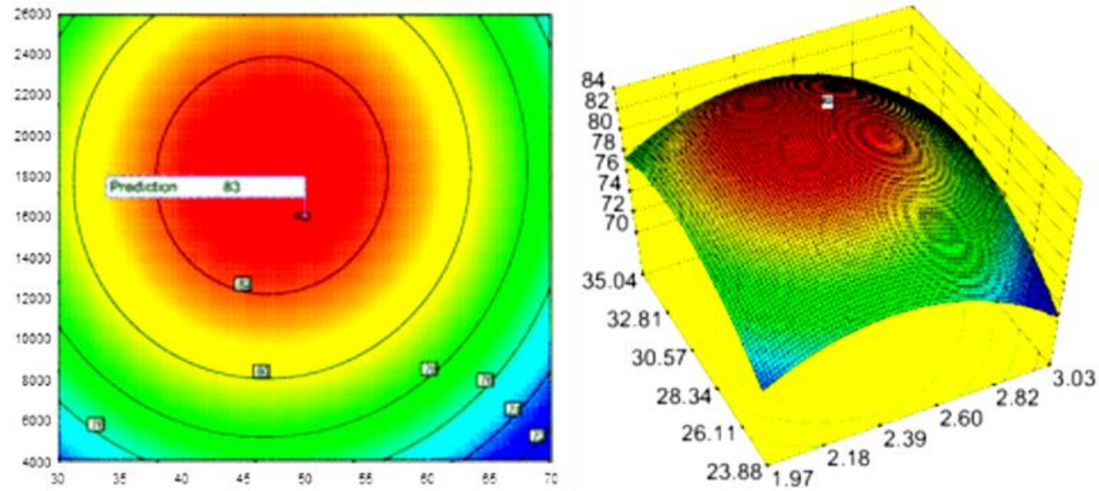

Figure 3. Temperature distribution of the coolant inside the channel of research's thermal system

Figure 3 above shows a description of the temperature distribution of the system at the conditions intended for this study. From the figure, it can be seen that the variation of gas temperature in the cooling channel with axial orientation provides stable, effective and efficient conditions for the system to work in natural convection conditions. This pattern is the intended result of this study. Axically, the temperature decreases with increasing height of the coolant from the reactor core.

3.3. Pressure Drop

The pressure drop is a pattern or picture that shows how much the coolant pressure decreases along the channel in the axial reference. In this study, several changes were made to the parameters of the thermal system in order to obtain the value of the intended pressure drop. The stable, effective and efficient condition obtained from the numerical analysis that was successfully obtained can be seen in Figure 4 below.

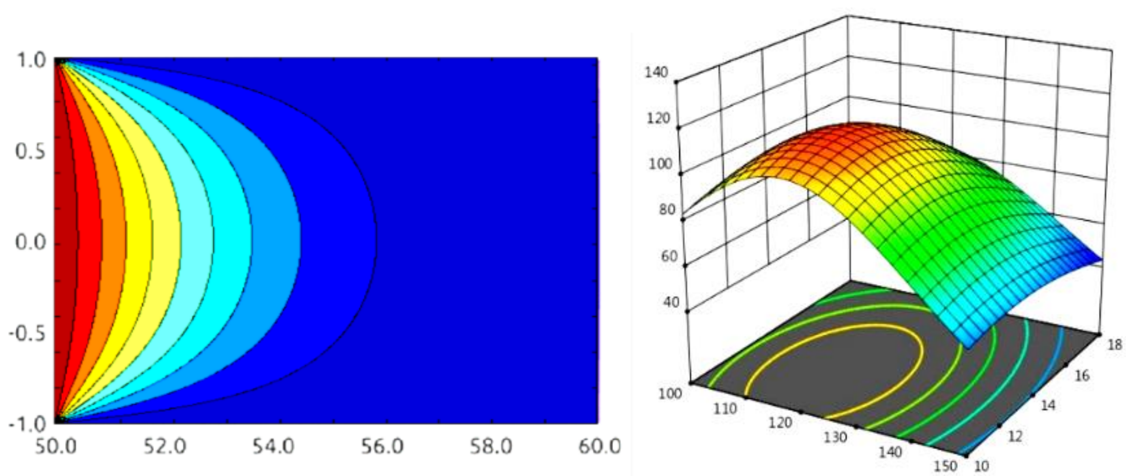

Figure 4. Pressure drop of the coolant inside the channel of research's thermal system

Figure 4 above shows an overview of the pressure drop of the system at the conditions targeted in this study. From the figure, it can be seen that the coolant pressure drop in the cooling channel with an axial orientation provides a stable, effective and efficient condition for the system to work under natural convection conditions. From the pattern obtained, it can be seen that the magnitude of the decrease in the coolant pressure decreases homogeneously from the center to the edge of the cooling channel. This pattern is the intended result of this research.

3.4. Channel configuration and specification

The final result obtained from this research is the configuration and specifications of the cooling channel in the thermal system which can be recommended because it provides a stable, effective and efficient value of temperature variation, temperature distribution and pressure drop. From several configurations and specifications of the cooling channel that have been tested, the recommended configuration and channel specifications are obtained as shown in table 1 below.

Table 1. Configuration and specification of coolant channel that recommended for best result of tested research variables.

Parameters	Unit	Value
Shell's inside diameter	mm	3950
Outside diameter of tube	mm	30
Tube effective length	mm	4000
Tubes total	-	800
Pitch of tubes	mm	70
Area of center region	%	3
Total of flow channel	-	3

From the various configurations and specifications of the cooling channel in the thermal system studied, the configuration and specifications of the thermal system that provide the best conditions for the coolant can work optimally in dissipating system heat as the results obtained in sections 3.1 to 3.3. This condition acts on the axial reference and supports the natural convection flow pattern of the coolant.

4. Conclusion

Numerical simulation of a thermal system using an inert gas as a coolant under natural convection conditions has been successfully carried out. The recommended configuration and specifications that support the implementation of the coolant flow process with natural convection conditions have been obtained. The optimal configuration and specifications that have been obtained are presented in table 1 above.

5. Acknowledgement

This study was supported and funded by Hibah Penelitian Dosen Pemula (PDP) PNBP UNP. Author also thanks all those who have helped in this research.

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