COMPARATIVE ANALYSIS OF COOLANT MASS FLOW RATE FOR PELUIT-40 REACTOR IN ENERGY CONVERSION SYSTEM: A STUDY OF CONCEPTUAL DESIGN WITH AND WITHOUT A SPLITTER

Dhiya Salma Salsabila[1],*, Ign. Djoko Irianto[2], Sukmanto Dibyo[2], Athiek Sri Redjeki[1]
[1] Chemical Engineering Department, Faculty of Engineering - Universitas Muhammadiyah Jakarta, Cempaka Putih Tengah, Jakarta Pusat 10510, Indonesia.
[2] Research Center for Nuclear Reactor Technology, Research Organization for Nuclear Energy (ORTN) - National Research and Innovation Agency, Puspiptek Area, Building 80, Serpong, Tangerang Selatan 15314, Indonesia.

**** Corresponding author:***
e-mail: dhiyasalmas@gmail.com

Received: 31-07-2023
Revision Received: 08-08-2023
Accepted: 20-10-2023
Published: 23-10-2023

DOI :
10.17146/jstni.2023.24.2.6903

***Keywords:** PeLUIt-40, Cogeneration, Energy Utilization Factor, Efficiency, Mass Flow Rate.*

Abstract *PeLUIt-40 is a nuclear reactor being designed in Indonesia for heat utilizing and generating electricity, with a thermal power of 40 MW. To improve energy efficiency, a system of electricity power and heat generation for hydrogen production called a cogeneration system was developed. The purpose of this study is to determine the best design for the cogeneration system. In this study, two conceptual designs of the cogeneration system were simulated, i.e., with and without a splitter system, respectively. The effect of coolant mass flow rate from (5, 6, 7, 8, 9, 10, 11, 12, 13, and 14 kg/s) to the energy utilization factor were analyzed. Calculations were performed using the ChemCAD 6.4.1 program and Python programming. The result shows that an increase of the coolant mass flow rate will increase the exit temperature of the coolant secondary side as a result of the heat transfer in the Intermediate Heat Exchanger (IHX). This temperature impacts an increase in the thermal power used for power generation and heat production. An increase in the mass flow rate in both designs also causes the value of the energy utilization factor (Energy Utilization Factor-EUF) and the value of the thermal efficiency to increase. Using the splitter has an EUF value of 34.51%, while the without splitter design is 33.92%. Likewise, the efficiency value of both with a splitter and without a splitter are 71.02% and 69.92%.*

INTRODUCTION

To realize one of the government's programs, Net Zero Emission Carbon in Indonesia, which states that Nuclear Energy Sources, Hydrogen, Coal Gasification, and Coal Liquefaction are part of New Energy, The Nuclear Energy Research Organization (ORTN) is researching environmentally friendly nuclear energy sources (1).

The ORTN is continuing to develop the design of systems from nuclear energy sources. In addition to being a source of electricity, nuclear energy can also be used to produce hydrogen and water desalination. The reactor design that has been made by ORTN is the PeLUIt-40 reactor. It is the latest generation IV reactor, the High-Temperature Gas Cooled Reactor (HTGR). The selection of the power plant that uses the HTGR cogeneration reactor type is because the fission energy from the reactor fuel in the form of pebble bed is more stable and sustainable and is not affected by weather, climate, season, sun, wind, waves, and does not require a large area for its realization (2). The HTGR reactor uses helium as a coolant, and the temperature outlet from the reactor is 700°C. The heat produced in the reactor can be used for hydrogen production and desalination. Hydrogen is an element that is very needed for the processing of various industries as a coolant and covering, and hydrogen-fueled vehicles are also widely sold in the market (3).

Research on modeling the energy conversion system in the High-Temperature Gas Reactor with a thermal power of 200 MW has been carried out by Djoko Irianto. Using modeling as a Brayton cycle, where the gas turbine is placed in a direct cycle, with varying the reactor outlet temperature. The research result showed that the higher the reactor outlet temperature, the lower the thermal power for electricity generation, while the thermal power for hydrogen production increased (4). To improve system efficiency to reduce the amount of heat wasted during the process of generating electricity, a cogeneration system is created. A cogeneration system is a process of generating and utilizing energy in different forms simultaneously from a single energy source to produce the maximum conversion efficiency, which is economical and more environmental friendly.

In a study conducted by Abdul Hafid, the design of HTGR 200 MW cogeneration system, the outlet temperature of helium reaches 900°C at a pressure of 7 MPa. The heat generated from the helium gas is utilized to drive a gas turbine at a temperature of 850°C with a flow rate of 120 kg/s. The cycle efficiency achieved is approximately 33.45%, resulting in an electrical power output of 117 MW (5).

Previous research has been carried out by Dedy Priambodo by conducting energy analysis on the HTGR steam turbine cycle to find out the heat loss that occurs in the power plant components. The results of the analysis and evaluation show that the reactor is the least efficient component, with a percentage of irreversibility of 61.8%, among all the components in the system. This is due to the irreversibility that occurs in the transfer of energy from the fission reaction to the helium coolant. The steam generator, turbine, and condenser are the next largest contributors to losses. The study results also show that the efficiency of the HTGR steam turbine cycle has the potential to be improved so that it can provide a significant effect on improving system efficiency (3,6).

The study conducted by Djoko Irianto includes simulations of an experimental power reactor (RDE) performance under varying reactor power levels (ranging from 0 MW to 10 MW) while maintaining a constant mass flow rate and pressure. The outcomes reveal that at reactor power levels up to 3 MW, the steam generator's effluent retains a consistent phase. However, within the reactor power range of 3 MW to 7.5 MW, a mixture of water and steam emerges at the steam generator's outlet. Beyond 7.5 MW reactor power, the effluent transforms into saturated steam. In another study led by Djoko Irianto, the simulation focuses on a primary coolant mass flow rate of 4.4 kg/s, with variations in the secondary coolant mass flow rate from 3.0 kg/s to 6.0 kg/s. Notably, the findings reveal that a thermal efficiency of 29% is achieved when the steam mass flow rate reaches 3.2 kg/s. However, beyond this point, increasing the steam mass flow rate results in a decrease in thermal efficiency. Furthermore, the Energy Utilization Factor (EUF) experiences a substantial increase, rising from 40% to 66.0% as the fluid mass flow rate is raised. In a study involving variations in pressure within the secondary cooling system, specifically vapor pressures of 60 bar, 90 bar, and 120 bar, alongside a constant primary coolant mass flow rate of 4.4 kg/s and a range of secondary mass flow rates from 3 kg/s to 4.5 kg/s, notable findings emerged. At a vapor pressure of 60 bar, the highest recorded thermal efficiency reached 29.01% with a steam mass flow rate of 3.2 kg/s. When the vapor pressure was increased to 90 bar, the highest thermal efficiency observed was 29.21%, with a corresponding steam mass flow rate of 3.3 kg/s. Lastly, at a vapor pressure of 120 bar, the peak thermal efficiency value reached 29.19%, occurring at a steam mass flow rate of 3.5 kg/s (7–9).

The design concept of the RDE, with a thermal power of 10 MW, was initially developed as PeLUIt-40, with a thermal power of 40 MW. The increase in thermal power for the reactor is necessary because, for system cogeneration, the thermal power of the RDE cannot produce enough saturated steam for hydrogen production, so the thermal power must be scaled up. By replicating and modifying the model and design from the 10 MW thermal RDE co-generation prototype, there was an increase in fuel capacity to generate 40 MW of power (10).

The commercially available hydrogen production methods include steam methane reforming and electrolysis. Steam methane reforming offers advantages such as widespread use in many countries, high efficiency, low capital costs, and compatibility with nuclear reactors. However, it emits CO_2, which contradicts Indonesia's goal of achieving net-zero carbon emissions by 2060. To address this issue, additional technologies are needed to reduce CO_2 emissions. Another available hydrogen production technology is electrolysis, which uses water or steam as a raw material. There are three types: Proton Exchange Membrane (PEM) Electrolysis, alkaline water electrolysis (AWE), and Solid Oxide Electrolysis Cell (SOEC) (11).

The purpose of this study is to determine the best design for the cogeneration system. In this study, there are two conceptual designs of the cogeneration system were simulated, i.e., with and without a splitter system, respectively. The effect of various coolant mass flow rate for energy utilization factor were analyzed.

EXPERIMENTAL SECTION

In this study, the process was conducted in three stages, design parameter determination, design creation, simulation process, and result analysis. Each process is explained as follows:

Design Parameter Determination

A literature review was conducted to select the most suitable hydrogen production process for cogeneration with PeLUIt-40. During this literature review, several design concepts that meet cogeneration standards with a nuclear reactor were identified (11).

Design parameters were established based on references, with a variation in the coolant mass flow rate in the form of helium. The following lists the specified parameters and those that were varied:

Table 1. Characteristic of each cycle parameters (7)

Parameters Value of Primary Cycle	
Fluid	Helium
Reactor operation condition	700°C, 30 bar
Power	40 MWt
Reactor coolant's rate of mass flow	5 to 14 $kg.s^{-1}$
Parameters Value of Secondary Cycle	
Fluid	Water/steam
Mass flow rate	12 $kg.s^{-1}$

Table 2. Component parameters for energy conversion system (15)

Parameter	Value
Pressure drop in shell and tube side of IHX	0.1 bar
Heat transfer area (A) of IHX	500.796 m^2
Heat transfer coefficient (U) of IHX	796.391 $W.m^{-2}.K^{-1}$
Gas turbine efficiency	0.85
Heat transfer area (A) of hydrogen production	166.32 m^2
Heat transfer coefficient (U) of hydrogen production	502.56 $W.m^{-2}.K^{-1}$
Heat transfer area (A) of condenser	830.7 m^2
Heat transfer coefficient (U) of condenser	2320 $W.m^{-2}.K^{-1}$

Design Preparation

The design concept was developed based on the literature review. The concept of the cogeneration system PeLUIt-40 begins with preparing the process flow diagram (PFD) using ChemCAD 6.1.4, based on the block diagram (Figure 1, 2).

Two indirect cycle designs were created. The primary cycle uses helium as a coolant for the PeLUIt-40 reactor, and the secondary cycle uses water as the heat carrier. In the first design, the steam generated by the IHX in the secondary cycle will be fed into the cogeneration system and then to the turbine. Figure 1 shows the first design of the indirect cycle (12–14).

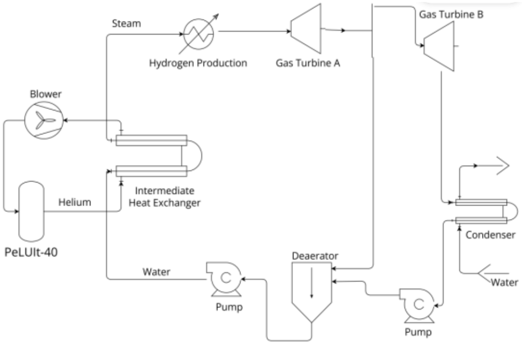

Figure 1. The first design of the indirect cycle.

In the second design on the secondary cycle, the steam generated by the IHX will pass through the splitter, where it will be split into two streams at a ratio of 9:1. The larger stream will enter the turbine, while the smaller stream will enter to the cogeneration system. This design can be seen in Figure 2.

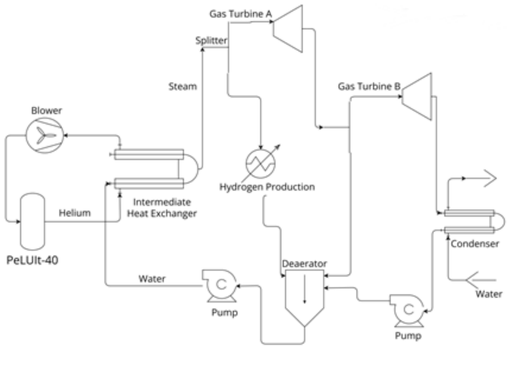

Figure 2. The second design of the indirect cycle.

Simulation Process

The first step of the simulation involves selecting the components to be simulated, which are Helium in the primary cycle and water/steam in the secondary cycle. The helium mass flow rate of the coolant in the reactor are varies from 5 kg/s to 14 kg/s, and the water/steam flow rate is at the secondary cycle is 12 kg/s. The condition operator of reactor is 700°C at the outlet. Suitable equipment is used for the design, including a fired heater assumed to be PeLUIt-40, a turbine, blower, pump, condenser, deaerator, and IHX.

In the simulation process, the designed system was run until convergent results were obtained. Variations were made in both designs by changing the helium mass flow rate in the PeLUIt-40 reactor. The simulation results were reported in Excel files and converted to .csv format for calculating the EUF and thermal efficiency values using Python.

Design Parameter Determination

Random number selection shall be taken into account in the statistical sampling process. It follows each of many particles from a source throughout its life to its death, whether absorbed or escapes from a system, as shown in Figure 1. The figure explains the probability of neutrons entering the material and the life of the neutron in the material is traced. For the purpose of determining the result in each stage of life, probability distribution shall be randomized by means of transport data.

In this study, data analysis is conducted by configuring the designed system and calculating the Energy Utilization Factor (EUF) and thermal efficiency. The value of the thermal energy utilization factor (EUF) describes the amount of heat energy that can be utilized. The EUF value provides an overview of the percentage of heat energy that can be utilized and not lost to the environment. The EUF value in a cogeneration energy conversion system can be calculated using the following equation (1) (9) :

$$EUF = \frac{W+Q_u}{Q_{in}} \tag{1}$$

Where,

EUF : energy utilization factor

W : work results from cogeneration system for electricity generation

Q_u : thermal power used in cogeneration system

Q_{in} : total power supplied to the cogeneration system

The thermal efficiency of electric power generation, known as thermal power efficiency, is defined as the efficiency used exclusively for generating electricity and encompasses all components of the energy conversion system. This thermal efficiency is also equal to the result of multiplying the efficiency of an electric generator by the mechanical power produced by the rotating turbine. The efficiency of electricity generation on its own will be higher than the efficiency of electricity generation in a cogeneration configuration. The total thermal efficiency value is determined by dividing the thermal power used for electricity generation in all components of the energy conversion system by the thermal power generated by the reactor. The value of the thermal efficiency can be calculated using the following equation (2) (9):

$$\eta = \frac{\Sigma W_T - \Sigma W_C - W_S - \Sigma W_{CIR}}{Q_{th} - Q_{H_2}} \tag{2}$$

Where,

η : Thermal efficiency,

ΣW_T : work-load for the turbine,

ΣW_C : work-load for the compressor,

W_s : work-load of all system,

ΣW_{CIR} : work-load for circulator,

Q_{th} : thermal power by reactor,

Q_{H_2} : Power for cogeneration system to hydrogen production

The simulation results will subsequently yield the power or work produced by each component used. Afterward, Python will be used to calculate the efficiency and thermal energy utilization factor values for each design.

RESULTS AND DISCUSSION

The energy conversion system of Peluit-40 has been represented through modelling in ChemCAD, as shown in Figures 3 to 4.

The simulation was conducted by varying the coolant mass flow rate in the primary cycle from 5 kg/s to 14 kg/s, increasing by one unit in each simulation. The mass flow rate in the secondary cycle remained constant at 12 kg/s. The range of coolant mass flow rates in the primary cycle was determined because a pitch zone occurred in the IHX in both designs (with and without a splitter) when the flow rate was set to 4 kg/s. A pitch zone is a condition where the temperature difference between the hot and cold fluids at that location is minimized. This can occur when one or more fluids between the ends of the heat exchanger are undergoing a phase change.

Conversely, when the mass flow rate of the coolant in the reactor is set to 15 kg/s, the first design (without a splitter) of the pump to deaerator contains vapor. At a coolant mass flow rate greater than 15 kg/s, the temperature of the outlet from the reactor will decrease because the reactor couldn't produce enough power. The temperature outlet from the reactor for 15 kg/s is 699.79°C, and for 16 kg/s, the temperature is 685.74°C. So, the maximum temperature in this study is 14 kg/s.

The thermodynamic calculations of the PeLUIt-40 energy conversion system as shown in Figures 5 to 8. In Table 3, it is shown that the reactor outlet temperature data is compared with the hydrogen gas production outlet temperature data for each design. In the range of coolant mass flow rates in the reactor, from 5 kg/s to 8 kg/s, the IHX outlet temperature remains constant at 339.25°C. This is because, in the secondary cycle, the mass flow rate of water is a constant 12 kg/s. Therefore, at coolant mass flow rates in the reactor from 5 kg/s to 8 kg/s, there is not enough thermal energy to heat the mass flow rate in the secondary cycle.

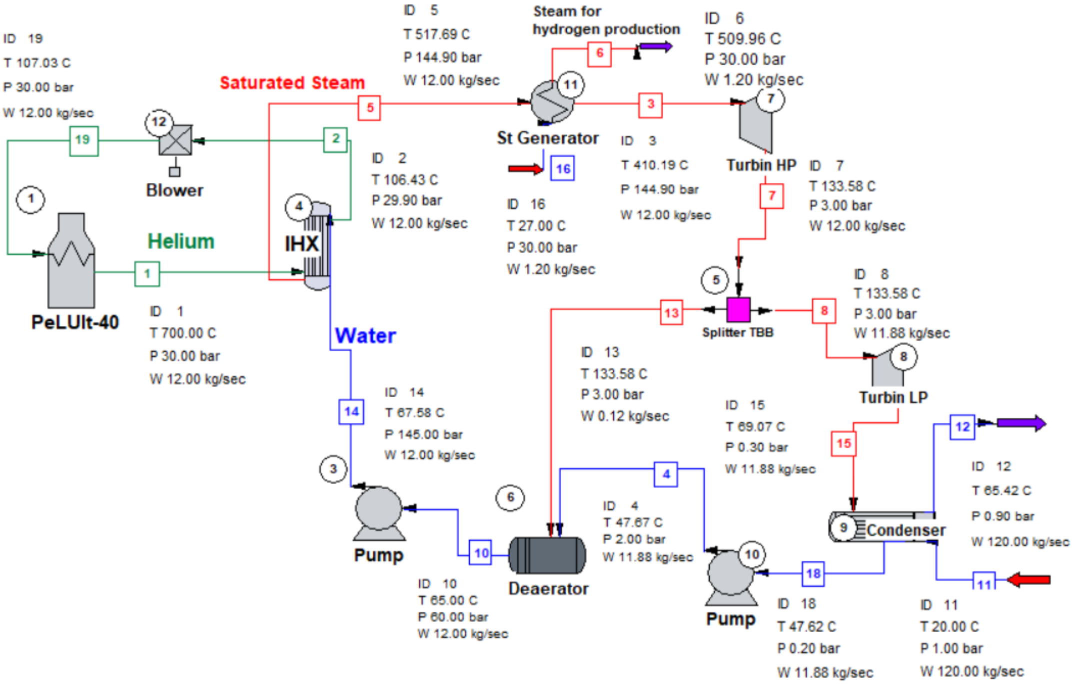

Figure 3. ChemCAD simulation for the first design.

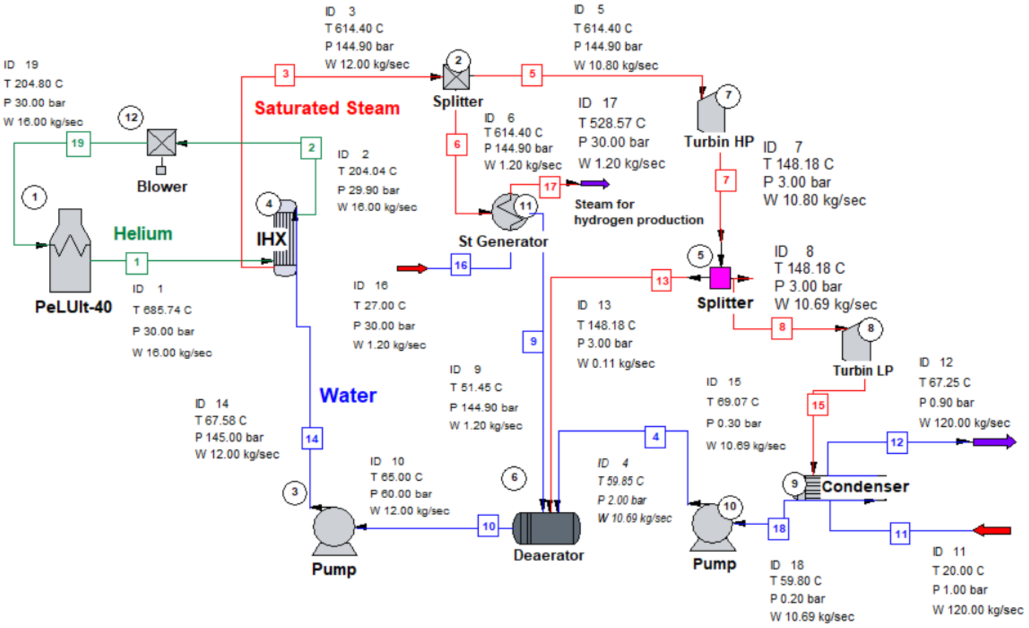

Figure 4. ChemCAD Simulation for second design.

Table 3. Temperature outlet from each design

Mass flow rate of the reactor coolant (Kg/s)	Temperature outlet for IHX (°C)	Design 1, Temperature outlet for hydrogen production (°C)	Design 2, Temperature outlet for hydrogen production (°C)
5	339.2555	338.784	233.891
6	339.2555	339.045	233.891
7	339.2555	339.045	233.891
8	339.2555	339.045	233.891
9	350.394	350.17	233.891
10	398.8606	391.725	283.72
11	460.5108	460.308	361.854
12	517.6917	509.964	426.405
13	561.4996	561.394	473.399
14	592.9631	592.88	506.368

In the range of coolant mass flow rates in the reactor, from 9 kg/s to 14 kg/s, the IHX outlet temperature increases as the coolant mass flow rate in the reactor increases. With a constant mass flow rate of 12 kg/s in the secondary cycle and variations in with and without a splitter, we conducted experiments varying the mass flow rate of reactor coolant in the primary cycle. We observed that the temperature in design 2 was lower than in design 1. This difference can be attributed to the use of a splitter in design 2, which divides the steam flow rate in the secondary cycle into two streams, one for hydrogen gas production and the other for the turbine. The system is split with a ratio of 1:9 between the flow rates for hydrogen gas production and the turbine. In design 2, the flow rate for hydrogen production is 1.2 kg/s, while for the turbine, it is 10.8 kg/s. In contrast, in design 1, the mass flow rate in the secondary cycle remains constant at 12 kg/s, supplying both hydrogen production and the turbine.

In the hydrogen production process, the feed of saturated steam in the secondary cycle transfers heat to a steam generator that receives water with a mass flow rate of 1.2 kg/s. In order for the hydrogen gas production to proceed using the Solid Oxide Electrolysis Cell (SOEC) method, it is crucial that the outlet temperature of the steam generator for hydrogen production is not fall below 500°C.

Based on Table 4, it can be concluded that as the mass flow rate of coolant in the reactor increases, both the power for electricity generation and hydrogen gas production also increases. In design 1, when the mass flow rate of coolant in the reactor is 5 kg/s, the thermal power for hydrogen gas production is 3.5708 MW. However, at the same flow rate in design 2, the thermal power for hydrogen gas production is 1.8251 MW. This difference can be attributed to variations in the steam flow rate entering the heat exchanger for hydrogen gas production. However, the power for electricity generation in design 1 is smaller than in design 2. In design 1, the power for electricity is 5.0781 MW, while in design 2, it is 7.3562 MW. This difference in power generation arises because, in design 1, the saturated steam that has already passed through hydrogen production causes a decrease in temperature. In contrast, in design 2, the temperature of saturated steam remains the same, but the flow rate is split.

Table 4. Power for each thermal energy utilization

Mass flow rate of the reactor coolant (Kg/s)	Design 1, Power for electricity (MW)	Design 2, Power for electricity (MW)	Design 1, Power for hydrogen production (MW)	Design 2, Power for hydrogen production (MW)
5	5.0781	7.3562	3.5708	1.8251
6	7.6428	7.369	3.5715	2.1652
7	7.9242	7.6944	3.5715	2.4847
8	8.2125	7.9308	3.5715	2.7872
9	8.2596	7.9596	3.6031	3.1164
10	8.6345	8.1639	3.7181	3.4054
11	8.6381	8.4184	3.903	3.6358
12	8.9584	8.9397	4.0357	3.812
13	9.0267	9.3882	4.1734	3.938
14	9.3126	9.7811	4.2582	4.0261

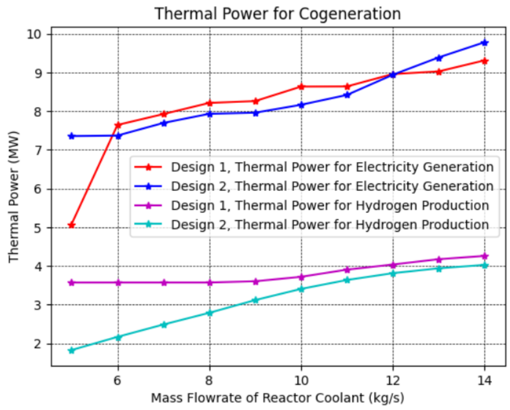

Figure 5. Power of each thermal energy utilization.

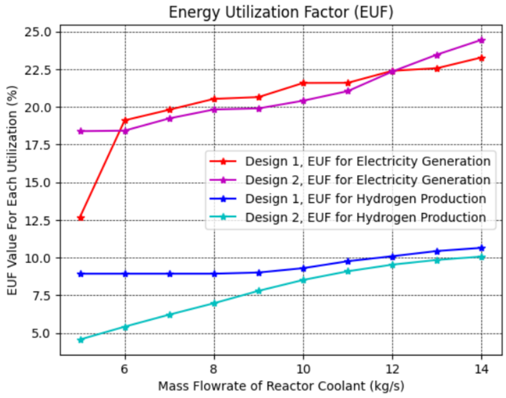

Figure 6. EUF for each thermal energy utilization.

At a coolant mass flow rate of 12 kg/s in the reactor, the thermal power for electricity in design 2 finally reaches an equivalent value to that of design 1. As seen in Table 4, the value for design 1 at a reactor mass flow rate of 12 kg/s is 8.9584 MW, while for design 2, it is 8.9397 MW. This equivalence occurs because both the reactor coolant and the secondary cycle have a mass flow rate of 12 kg/s. Consequently, the outlet temperature from the IHX increases significantly when the mass flow rates in the primary cycle are greater than the mass flow rate in the secondary cycle.

For mass flow rate of reactor coolant are 13 kg/s and 14 kg/s, and the value of the power for electricity of design 2 greater than design 1. This proves that the design 2 (with splitter), the thermal power in the secondary cycle can perform more effectively. By using a splitter, the mass flow of saturated steam maintains the same level of heat between entering the turbine and the steam generator (to produce the hydrogen gas feed).

From figure 5, it can be seen that the thermal power for electricity generation in the first and second designs increases with the increasing mass flow rate of coolant in the reactor. The thermal power used for hydrogen gas production in the first design increases with a relatively insignificant change. However, in the second design, because a splitter was used, the steam flow rate entering the hydrogen gas production system is split with a ratio of 1:9 between the flow rate for hydrogen gas production and the turbine. This results in a significant increase in thermal power because the ratio of steam flow rate entering the hydrogen gas production system is comparable to the secondary flow rate in the system.

Therefore, in a cogeneration system, using a splitter with the appropriate mass flow rate ratio it can increase the electrical power output. This is because the thermal energy in the mass flow rate is conserved to enter the turbine and is utilized as needed for hydrogen production. With a higher amount of thermal energy entering the turbine, the electrical energy output is also increased.

To calculate the total EUF shown in Figure 7, we use equation (1). In Figure 6, to calculate the value of each EUF power, we divide each thermal energy utilization by the thermal power of the PeLUIt-40 reactor. However, there is a slight difference when calculating EUF electricity generation. The thermal energy for electricity is reduced by circulators, such as blowers and pumps, and then the result is divided by the thermal power of the PeLUIt-40.

The EUF values for each design can be depicted in Figure 6. In the first design, with a mass flow rate of coolant in the reactor of 14 kg/s, the EUF values for electricity generation and hydrogen production are 23.28% and 10.64%, respectively. In the second design, the EUF values are 24.45% and 10.06%, respectively.

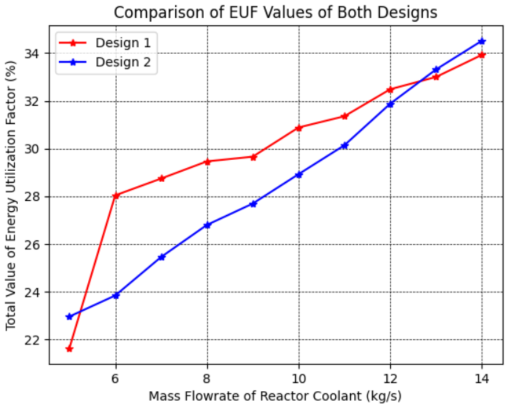

Figure 7. Total EUF value as a function of reactor coolant mass flow rate.

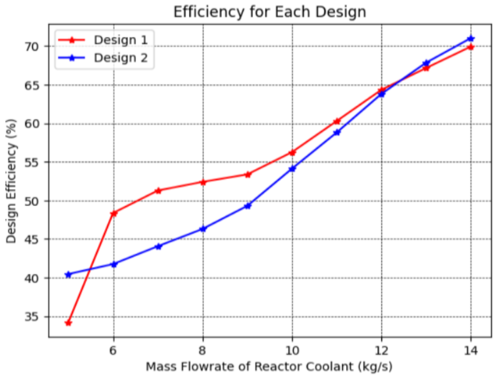

Figure 8. Thermal efficiency graph as a function of reactor coolant mass flow rate.

The total EUF value of the two designs was calculated, in which can be seen in Figure 7. The total EUF value is the sum of the individual EUF values in thermal energy utilization. It is indicating that the EUF value increases with the increasing mass flow rate of coolant in the reactor. In the first design, when the mass flow rate of coolant in the reactor is 14 kg/s, the total EUF value is 33.92%. While at the same flow rate in the second design, the total EUF value is 34.51%. This means that the amount of heat energy that can be utilized is 33.92% for the first design and 34.51% for the second design.

In previous research conducted by Djoko Irianto, the EUF value of RDE was achieved at 66% with a reactor power of 10 MW (8). In this study, the EUF value of PeLUIt-40 was achieved at 34.51% for the second design with a reactor power of 40 MW. This occurred because the priority in this study was to generate electricity rather than prioritize hydrogen production. The purpose of this study is to scale up steam production for hydrogen and optimize electricity generation. The hydrogen production is already at 1.2 kg/s in the steam generator with a temperature of 506.36°C, which qualifies it for the use of the SOEC method for hydrogen gas production.

System efficiency is a measure of system performance, as described in equation (2). It can be seen in Figure 8 that system efficiency increases with increasing mass flow rate of coolant in the reactor. In the first design, with a mass flow rate of coolant in the reactor of 14 kg/s, the efficiency value is 69.92%. While at the same flow rate in the second design, the efficiency value is 71.02%. This means the efficiency used exclusively for generating electricity is 69.92% for the first design and 71.02% for the second design.

Djoko Irianto also revealed that the highest thermal efficiency for RDE was achieved at 29%, with a reactor power of 10 MW. In that study, in the cycle design without using a splitter, when compared to design 1 with a reactor power of 40 MW, the efficiency value for electricity generation was 69.92%. This indicates that an increase in power in the reactor leads to an increase in the efficiency value for electricity generation.

CONCLUSION

From this study, it can be concluded that an increase of the coolant mass flow rate will increase the exit temperature of the coolant secondary side as a result of the heat transfer in the Intermediate Heat Exchanger (IHX). This temperature impacts an increase in the thermal power used for power generation and heat production. An increase in the mass flow rate in both designs also causes the value of the EUF and the value of the thermal efficiency to increase.

The first design has a higher value of total EUF is 33.92%, while the second design has a total EUF value of 34.51%. Both are at a mass flow rate of coolant in the reactor of 14 kg/s. The system performance, as measured by the efficiency parameter, shows that the first design outperforms the second design. The efficiency value of the first design is 69.92%, whereas the efficiency value of the second design is 71.02%, both with a mass flow rate of coolant in the reactor of 14 kg/s. Therefore, the second design is preferable for implementation cause by using a splitter, the thermal power in the secondary cycle can perform more effectively.

ACKNOWLEDGEMENTS

The authors express gratitude to the Research Center for Nuclear Reactor Technology (PRTRN), Nuclear Energy Research Organization (ORTN), National Research and Innovation Agency (BRIN) for enabling the research, as well as to the Chemical Engineering Department of Universitas Muhammadiyah Jakarta for their assistance in writing this paper. Additionally, thanks to Mr. Marliyadi Pancoko, who provided the authors with access to the licensed version of ChemCAD 6.4.1. Each author has contributed equally as a primary contributor to this paper. All authors have reviewed and given their approval to the final version of the paper.

REFERENCES

1. Silalahi DF, Gunawan D, Wahyuni E, Dipayana GF, Hardhi M, Winofa NC, et al. Indonesia Post-Pandemic Outlook: Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspectives. Indonesia Post-Pandemic Outlook: Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspectives. Penerbit BRIN; 2022.
2. Armanita D, Fitriyani D, Setiadipura T. Optimisasi Ukuran Teras High Temperature Gass-cooled Reactor (HTGR) dengan Daya 30 MWt Tipe Pebble Bed Berbasis Bahan Bakar Uranium. Jurnal Fisika Unand. 2020 Feb 11;9(1):100–9.
3. Irianto IgnD, Sriyono S, Dibyo S, Salimy DH, Surbakti T, Kusumastuti R. Analysis of Cogeneration Energy Conversion System Design in IPWR Reactor. JURNAL TEKNOLOGI REAKTOR NUKLIR TRI DASA MEGA. 2022 Mar 7;24(1):19.
4. Ign. Djoko Irianto. Pemodelan Sistem Konversi Energi RGTT200K Untuk Memperoleh Kinerja Yang Optimum. Vol. 16. 2012.
5. Abdul H. Pemodelan siklus Temodinamik Turbin Gas RGTT KOGENERASI. Vol. 15. 2011.
6. Pancoko M, Priambodo D, Tenaga B, Nasional N, Setiadipura T, Nugroho A. Design study of a straight tube bundle steam generator for reaktor daya eksperimental. International Journal of Mechanical Engineering and Technology (IJMET) [Internet]. 2018;9(5):9–14.
7. Irianto ID, Dibyo S, Sriyono S, Salimy DH, Kusumastuti R, Pancoko M. Performance Analysis of RDE Energy Conversion System in Various Reactor Power Condition. JURNAL TEKNOLOGI REAKTOR NUKLIR TRI DASA MEGA. 2019 Oct 25;21(3):99.
8. Irianto ID, Dibyo S, Sriyono S, Salimy DH, Kusumastuti R, Pancoko M. Performance analysis of cogeneration energy conversion system design for RDE. In: IOP Conference Series: Materials Science and Engineering. Institute of Physics Publishing; 2020.
9. Irianto ID, Dibyo S, Sriyono, Salimy DH, Kusumastuti R, Pujiastuti E, et al. Performance analysis on the design of the energy conversion system of the Indonesia experimental power reactor. In: AIP Conference Proceedings. American Institute of Physics Inc.; 2019.
10. Sun J, Li Z, Li C, Sui Z, Yan H, Qi W, et al. Progress of Establishing the China-Indonesia Joint Laboratory on HTGR. Nuclear Engineering and Design. 2022 Oct 1;397.
11. Fallah Vostakola M, Ozcan H, El-Emam RS, Amini Horri B. Recent Advances in High-Temperature Steam Electrolysis with Solid Oxide Electrolysers for Green Hydrogen Production. Vol. 16, Energies. MDPI; 2023.
12. Norouzi N, Fani M, Talebi S. Exergetic design and analysis of a nuclear SMR reactor tetra generation (combined water, heat, power, and chemicals) with designed PCM energy storage and a CO2 gas turbine inner cycle. Nuclear Engineering and Technology. 2021 Feb 1;53(2):677–87.
13. Bartnik R, Kowalczyk T. Thermodynamic and economic analysis of a hierarchical gas–gas nuclear power plant with a high-temperature reactor and helium as a circulating medium. Nuclear Engineering and Design. 2021 Oct 1;382.
14. Dong Z. Dynamical modelling and coordinated control design of a multi modular nuclear power-hydrogen cogeneration plant. Energy Convers Manag. 2022 Nov 15;272.
15. Donald Q. Kern. Process Heat Transfer. International Student Edition. 1983;