Comparison on Two Option Design of The RDE Cogeneration System

Sukmanto Dibyo, Ign. Djoko Irianto, Syaiful Bakhri

Center for Nuclear Reactor Technology and Safety – BATAN,
Kawasan PUPSPITEK, Gd. 80, Serpong, Tangerang Selatan 15310,
Tel. +62 (21) 756-0912, Fax. +62 (21) 756-0913, Indonesia.
sukdibyo@batan.go.id

Abstract. The Reaktor Daya Eksperimen (RDE) is the High Temperature Gas Cooled Reactor (HTGR) type that will be mainly used for research activities of nuclear energy utilization. The RDE thermal power is 10 MWt using Helium gas as a primary cooling system that applies indirect cycle and superheated steam resulted from the steam generator of secondary coolant system. In separate production of electricity, some energy is discarded as waste heat, but in the cogeneration, some of heat energy is removed to be used for heat applications. Regarding to safety aspect and to optimize the utilization of heat energy, the cogeneration system using the heat exchanger could be applied. There are two options to be studied in cogeneration system which is the heat exchanger that installed in the steam line. The option-1 is installed in outlet line from the Steam Generator, the option-2 is installed in outlet line from turbine. Purpose of this paper is to compare the cogeneration system between the two options. The comparison is carried out by the ChemCAD software. The feed water for cogeneration using mass flow rate from 0.6 kg/s until 2.0 kg/s at temperature of 28°C were studied.

The results show that the heat removal on the option-2 provides high power of turbine for generating the electricity more than the option-1. This study is expected provide possibilities of extended studies in the area of process heat applications.

Keywords: RDE, two option, cogeneration, comparison, heat exchanger

1. Introduction

The High Temperature Gas Cooled Reactor (HTGR) is one of the next generation reactor types. Currently, the HTGR design is considered one of the leading reactors for the future nuclear power plant which has attractive inherent safety features [1,2]. Although the results of study conducted in the past show that the HTGR type reactor would be most competitive when capital rates are low [3], however the application of nuclear heat have been widely studied [4]. It has been developed with various power capacities and can produce electricity and heat applications [5]. The HTR-10 with 10 MWt capacity is the small size of HTGR type reactor that was successfully operated in China [6].

The small modular reactor of Reaktor Daya Eksperimen (RDE) is the type of HTGR 10 MWt that will be mainly used for research activities in order to improve mastery of technology in Indonesia. The research is important to address under a shortage of electricity, and has many industries steam processes.

In the RDE of primary cooling system the helium gas is used, meanwhile the secondary coolant use the steam generator to produce the steam. RDE is designed with coolant outlet temperature of 700°C to produces the superheated steam. In separate production of electricity, some energy is discarded as waste heat, but in the cogeneration, some of thermal energy is used for various research purposes[7]. From the various types of the next-generation reactor, the high working temperature range of HTGR type makes them suitable to be implemented for various cogeneration concepts [8,9].
Combining the heat and electricity applications the power plant, can reach an overall efficiency up to 90%[10]. Therefore, the application of RDE for a cogeneration plant is clearly feasible, but a more detailed optimization extension of cogeneration utilization is required. To optimize the utilization of heat energy from the reactor, the cogeneration system can be applied. There are 2 options to be considered in developing the conceptual design for cogeneration of RDE. The first is cogeneration in the steam generator outlet of secondary coolant line, and the other is taken from outlet line from the turbine. Based on both option, the optimal power, efficiency and safety operation can be studied.

Therefore, purpose of this study is to compare the conceptual of cogeneration system between the two options. While the turbine power obtained should be considered to achieve a high electricity power generated. The option-1 is the heat removal installed in outlet line from the Steam Generator, the option-2 is heat removal installed in outlet line from the turbine.

2. Theory
The RDE reactor is a HTGR design with a thermal power of 10 MWt, which the pebble bed types nuclear reactor as a source of thermal energy. The reactor is cooled by Helium gas as primary coolant system in an indirect cycle of cooling system. It is designed to have an outlet temperature of 700°C at the pressure of 5 MPa. In the secondary line system, the steam outlet temperature and pressure of Steam Generator (SG) are respectively 530°C and 6 MPa[11]. Figure 1 shows the schematic flow of RDE block diagram.

![Figure 1. Schematic of RDE Block Diagram [12].](image)

3. Methodology
To optimize the utilization of heat energy from the reactor and considering the safety aspect of radioactive release from primary coolant system, the cogeneration system using the heat exchanger can be conducted.

The cogeneration system conceptual of RDE 10 MWt is started with preparing the design of the process flow (PFD) diagram using ChemCAD 6.1.4[13], based on the block diagram (Figure 1). The principle in the cogeneration system and power plant is the dry steam that can be used to rotate the
turbine as well as for the heat applications, therefore two options in this study were compared for the placement of cogeneration heat removal, namely is;

- Heat removal using the heat exchanger with adiabatic operation that installed in outlet steam line from the Steam Generator (option-1).
- The heat application of cogeneration mounted in an outlet line from the turbine (option-2)

The systematics of procedure as shown in the schematic diagram of Figure 2 below;

**Figure 2.** Schematic of Methodology

Main parameters for references are shown in Table 1. The showing the parameters including temperature, pressure and mass flow rate.

**Table 1.** Main Parameter of RDE [11,14]

| Parameter, unit                                      | Value  |
|-----------------------------------------------------|--------|
| inlet temperature of helium gas, °C                 | 700.0  |
| outlet temperature of helium gas, °C                | 245.0  |
| pressure of helium gas, MPa                         | 3.4    |
| mass flow rate of helium gas, kg/s                  | 4.27   |
| outlet temperature of steam generator, °C           | 520.0  |
| mass flow rate of steam, kg/s                       | 3.54   |
| heat generated from the steam generator, MJ/s       | 10.0   |

Beside the above input data, some assumptions and determinations used in the heat application of cogeneration system i.e;

- the thermal design is under adiabatic steady-state conditions.
- feed water temperature for cogeneration system is 28°C.
- cooling temperature for condenser is 32°C.
- mass flow rate is 0.6 kg/s - 2.0 kg/s to produce saturated steam at 2.5 bar.
- turbine efficiency of 90% [14, 15].
- the optimum pressure ratio of turbine is 0.24 [16]

### 4. Result And Discussion

Figure 3 shows the diagram design of PFD (Process Flow Diagram) for heat application of RDE using the heat exchanger for heat removal from the steam outlet line of Steam Generator based on the option-1. The heat exchanger transfer the heat from hot fluid (steam) to the water becoming the saturated steam. In this case the sensible heat, latent heat, involving a phase change of vaporization are required. Further in the heat exchanger application, the operating parameter of pinch temperature for both hot and cold fluid is not expected. The pinch temperature is the smallest temperature difference occurs between the hot fluids and cold fluids or the temperature between the cold curve and the hot curve is at a minimum.

As shown in Figure 3 the result i.e. mass, energy balance and pressure flow of each streams shown in the diagram. The heat generated from the steam generator is 10.00 MJ/s. In this option-1 as well as option-2, the steam pressure resulted from the cogeneration is determined about of 2.500 bar (saturation temperature of 127.33°C). Due to effect the heat application, the hot stream from the steam generator decreases from 520°C to 277.60°C. After that the steam with quality of 100% goes into the turbine.

![Diagram of Cogeneration of option-1](image)

**Figure 3. Cogeneration of option-1**

Furthermore, Figure 4 shows the result of PFD cogeneration based on the option-2. In this option, the heat recovery in the cogeneration-system uses steam at the outlet flow of the turbine. In this case the steam from Steam Generator directly drives the turbine-A while the steam outlet is still capable of rotating the turbine-B. The steam at pressure of 14.99 bar flows to the turbine-B while a part of steam flow is used to raise the feed water temperature to Steam Generator.
Figure 5 and Figure 6 depict the differences between option-1 and option-2, the curve shows the mass flow rate used for heat removal against the power of turbine that can be generated. The discussion presented here is that the power of turbine-A on option-1 changes depending on the mass flow rate used for the heat application. This is because before entering into the turbine-A, the significant energy has been absorbed by the cogeneration system. Meanwhile in the option-2, the power of turbine-A is not affected by the cogeneration system, which heat removal is installed after turbine-A. Although the power of turbine-B in option-1 is slightly higher than option-2, however the total power turbine to generate electricity in the option-2 is higher than option-1. Finally, based on two options studied in the RDE cogeneration, the results show that the heat removal in the option-2 provides higher power of turbine to generate the electricity more than the option-1. As seen in both figures that at a mass flow rate of 0.6 kg/s the total power of turbine is 3.8 MJ/s in the option-2 or 31% higher than option-1.
5. Conclusion
The process flow diagram of coolant system has been created. It is include the operating parameters and thermal design for the component units of RDE cogeneration system. According to the comparison of two options studied for the heat application, its show that the heat removal on the option-2 provides high power of turbine for generating the electricity more than the option-1. The option-2 power of turbine is 31% higher than option-1. This study is expected useful to provide possibilities of extended studies in the area of process heat application.

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