Performance Analysis Of The Helium Purification System In
The Indonesia Experimental Power Reactor

Ign. Djoko Irianto1, Sriyono1, Syaiful Bakhri1, Sukmanto Dibyo, Rahayu
Kusumastuti1, Purwo Kadarno3

1Center for Nuclear Reactor Technology and Safety, BATAN,
Puspiptek Area, Building 80, Serpong, Tangerang 15310
2Department of Mechanical Engineering, Universitas Pertamina,
Jalan Teuku Nyak Arief, Kebayoran Lama, Jakarta 12220

igndjoko@batan.go.id

Abstract. Indonesia's experimental power reactor (RDE) is a reactor design based on the high-
temperature gas-cooled reactor (HTGR) technology with the power of 10 MWe. According to
the reactor safety, helium gas as the primary coolant has to be purified to assure the thermal
characteristic. There are several stages of the purification process in the helium purification
system (HPS). One stage in the train of HPS for removing N₂ and O₂ gas from the primary
coolant system is the cryogenic unit. The cryogenic unit operates in the temperature about -196
°C. The objective of the research is to analyze the cryogenic unit performance in the helium
purification system for removing N₂ and O₂ gas from the primary coolant system in the design
of RDE. The performance analysis has been done by simulation using ChemCAD with variations
in mass flowrate in the helium purification system and variations in the concentration of N₂ and
O₂ gas in the helium coolant. The pressure in the cryogenic unit and all units of HPS is set in the
same pressure of the primary coolant system is 3 MPa. The result showed that helium can be
purified from the impurities N₂ and O₂ gas about 99 % at the mass flow rate of 0.45 kg/s. This
result is important to support the design of HPS for RDE.

Keywords: Performance, cryogenic unit, helium purification system, primary coolant system,
RDE.

1. Introduction
The design of an experimental power reactor in Indonesia with the reactor power of 10 MW thermal is
called Reaktor daya eksperimental (RDE). The design of this reactor is based on the high-temperature
gas-cooled reactor (HTGR) technology [1]. This reactor system was designed to generate electricity for
supplying to the BATAN Serpong area and to generate heat energy for supplying the experimental [2].
Some researches have been done for supporting the design of the RDE system. The operating parameter
of the void fraction and the temperature in the outlet stream from the RDE steam generator has been
investigated by Dibyo [3]. The result of the investigation shows that the superheated steam temperature
in the outlet stream from the steam generator is between of 275.5 °C – 600 °C. The other research has
done by Sudadiyo [4] to investigate the performance of the RDE feedwater pump. The investigation
result shows that the optimum characteristics performance was obtained when the fluid flow capacity of
the feedwater pump was 4.8 kg/s and the head of fluid was 29.1 m. The other research that has been
done for supporting the RDE designed is the performance of the system, in the normal operation and in the start-up condition [5].

As an HTGR technology, the design for the primary cooling media in the RDE reactor also uses helium gas. The helium gas is employed for the primary cooling media in HTGR due to some advantages such as the thermal properties and the radiochemical inertness [6]. The purity of helium must always be maintained in the primary coolant of RDE according to its design of the safety system. There are two kinds of impurities in the cooling media in the primary cooling system such as particulates impurities and gaseous impurities in the helium gas[7]. The impurities of helium gas are released from fission products in the reactor core [7], from graphite dust [8], and from the gaseous impurities which contain \( \text{H}_2, \text{N}_2, \text{O}_2, \text{CO}, \text{H}_2\text{O}, \text{CH}_4 \) [6]. These gaseous impurities originated from various sources such as reactions of the ingressed water and ingressed oil with graphite in the reactor core and degassing reactor equipment [9]. Helium gas impurities can enter the cooling media from the surrounding environment through the desorption process of structural or can be formed through chemical reactions. The impurities of helium gas can damage the construction materials which consist of graphite by oxidation of the steels, carbonization or decarbonization.

The helium gas purification system in the design of the RDE reactor consists of several stages. The initial stage consists of a filter to remove carbon dust particles. Next is a cartridge filter consisting of three fixed beds, first, copper oxide beds to remove the oxygen traces and convert hydrogen into vapor of water and carbon monoxide into carbon dioxide, second, the molecular adsorber filter to remove carbon dioxide and vapor of carbon, and the third, cryogenic adsorber of activated carbon to remove remaining impurity such as methane and nitrogen gas as well as radioactive components from xenon and krypton. [10]. Various studies related to the purification of helium gas have been carried out for supporting the design of the helium purification system in the RDE reactor, one of them is research on the effect of the temperature on the oxidation process of CO. In the report, Sumijanto [11] explained an explanation of the CO oxidation reaction process. According to this report, increasing temperature will cause the increased reaction rate, this is due to the average kinetic energy of the reactants and the number of molecules that have a minimum increase in activation energy. In the Mourgues report, contaminating helium (0.1 - 5.5 vpm) with several gas impurities (\( \text{H}_2, \text{N}_2, \text{H}_2\text{O}, \text{CO}_2, \text{CO}, \text{CH}_4, \text{Kr}, \text{and Xe} \)) can be eliminated using inorganic membranes constantly during the cooling process [12].

This research was carried out with the aim of analyzing the performance of cryogenic units in the helium purification system to remove \( \text{N}_2 \) and \( \text{O}_2 \) gases from the cooling media in the primary cooling system of the RDE design. The performance analysis has been carried out with simulation calculations using the ChemCAD computer code with variations in mass flowrate in the helium purification system and variations in the concentration of \( \text{N}_2 \) and \( \text{O}_2 \) gas in the helium coolant. The pressure in the cryogenic unit and all units of helium purification system (HPS) is set in the same pressure of the primary cooling system is 3 MPa.

2. The Designed of RDE Helium Purification System
The RDE helium purification system (HPS) is a supporting system in the primary coolant system that is used to remove particulate and chemical contaminants in helium from the primary coolant to maintain the specified level of the purified helium in the primary coolant system. The HPS design for the RDE reactor was designed in a train that has two purification stages and one additional purification unit to remove moisture at the start-up condition and the accident anticipation conditions as shown in Figure 1 [13]. The first purification stage of HPS consists of a filter; a copper oxide filter (oxidizer or catalytic converter); heater; a helium recuperator; a cooler with moisture separator; and a molecular sieve filter. The second purification stage of HPS is a cryogenic adsorber unit consisting of an active carbon adsorber and a cold trap with a nitrogen filling system at the temperature of -196 °C. Additional units on HPS that are installed in parallel are units that are designed to regulate start-up conditions and to handle accident conditions.

In the normal operation, some helium gas flows from the primary coolant system to the carbon-dust removal filter for removing the carbon or graphite dust. And then, some helium gas flows through an
electric heater, then flows through oxidizing or CuO beds, continues to the helium recuperator, then flows through coolers that use a moisture separator, and then flows to the zeolitic adsorber filter (molecular sieve), and then flows to the cryogenic unit. The first filter on the HPS train is used for removing mechanical impurities of helium such as graphite or carbon dust. After the carbon dust filter, helium flows through the electric heater is used to heat helium gas so that the temperature of the helium raises to be around 250 °C. The helium temperature of 250 °C is the optimal operating temperature for copper oxide beds.

In the copper oxide bed, some tritium (HT), hydrogen, and carbon oxide are converted to be water (HTO and H₂O) and carbon dioxide. Carbon dioxide and water are deposited by the process of adsorption in a molecular sieve after the helium gas flow is cooled to be around 40 °C through the helium recuperator and cooling water. After deposited water and carbon dioxide, helium gas leaves the molecular sieve and flows to the next stage of the purification line. At the second stage of the helium purification process, the inert fission gases Xe, Kr, and other volatile gases i.e. N₂, O₂, Ar and CH₄, are adsorbed by activated carbon at the temperature around –196 °C. In the next stage is reheating of the helium gas. After recuperative reheating, the purified helium is flowed into the primary cooling system and/or the helium storage system.

A cryogenic unit is a unit that contains a series of heat exchangers. This unit is also called a cold trap and adsorber columns which is immersed in a vessel that contains liquid nitrogen. A series of heat exchangers in the vessel are helium-helium recuperator with the type tube in the tube. These exchangers serve to cool the helium and make the helium temperature decreases up to -196 °C. The column of the adsorber is a U-shaped pipe that contains activated carbon and molecular sieve at the top. Around the column for regeneration are provided an electric heater. The vessel of the cryogenic unit is shown in Figure 2 and the cryogenic vessel specification in the line of HPS is shown in Table 1.
Figure 2. Cryogenic Unit [13]

Table 1. The Cryogenic Vessel specification [15]

| No | Parameter                        | Value                                      |
|----|----------------------------------|--------------------------------------------|
| 1  | Type                             | Vessel with double walls                   |
| 2  | **The Inner Vessel**             |                                            |
|    | Outer diameter                   | 600 mm                                     |
|    | Depth                            | 1600 mm                                    |
|    | The thickness of the shell       | 5 mm                                       |
|    | Material                         | SS304L                                      |
| 3  | **The Outer Vessel**             |                                            |
|    | Outer diameter                   | 700 mm                                     |
|    | The thickness of the shell       | 4 mm                                       |
|    | The thickness of the dish end    | 5 mm                                       |
|    | Material                         | SS304L                                      |
| 4  | The thickness of the flange      | 22 mm                                      |
| 5  | Superinsulation material         | 20 layers of double aluminized mylar, or   |
|    |                                  | employs other insulation with fine pores of |
|    |                                  | trapped air                                |

3. Methodology

Simulations for cryogenic units in the design of HPS for the RDE reactor have been carried out using the ChemCAD computer code. This computer code has been commonly used in simulations, modeling, and calculations related to cooling system simulations [16,17] as well as for energy conversion systems [18]. In the first step of the simulation, the cryogenic unit of the design of HPS for the RDE reactor that will be analyzed is modeled by using ChemCAD computer code as shown in Figure 3. Stream 1 is the line of helium with the impurities flows from the molecular sieve unit. Stream 2 is the line to remove...
the impurities of helium, and stream 3 is the purity of helium. The pressure in the cryogenic unit and all units of HPS is set in the same pressure of the primary coolant system is 3 MPa.

![Image](image.png)

**Figure 3.** Cryogenic unit modeled by using ChemCAD

Simulation parameters such as the range impurity level in RDE and the operating parameter for RDE including the HPS are shown in Table 2 and in Table 3. Simulation proses are done with the variation of mass flow rate in the helium purification system and variations in the concentration of N\textsubscript{2} and O\textsubscript{2} gas in the helium coolant.

**Table 2.** The range impurity level in HTGR.[19]

| Impurity   | Concentration (ppm) |
|------------|----------------------|
| H\textsubscript{2} | 20 - 50              |
| H\textsubscript{2}O | Up to 1               |
| CO          | 1 - 300              |
| CH\textsubscript{4} | 2 - 40               |
| CO\textsubscript{2} | 0.1 - 10             |
| N\textsubscript{2} | Up to 1.5            |
| O\textsubscript{2} | < 0.1                |
| Dust       | -                    |

**Table 3.** The Parameter of RDE for HPS Simulation [14]

| No. | Parameter                                      | Unit | Value |
|-----|-----------------------------------------------|------|-------|
| 1   | The power of the reactor                      | MWth | 10    |
| 2   | The pressure of primary coolant (helium)      | MPa  | 3     |
| 3   | The temperature of the reactor core inlet     | °C   | 250   |
| 4   | The temperature of the reactor core outlet    | °C   | 700   |
| 5   | The mass flow rate of primary coolant         | kg/s | 4.27  |
| 6   | Feed water temperature (secondary coolant)    | °C   | 104   |
| 7   | Steam temperature (secondary coolant)         | °C   | 530   |
| 8   | Primary blower pressure                       | bar  | 30    |
| 9   | Primary blower/compressor temperature         | °C   | 250   |
| 10  | Flow to HPS from the primary coolant          | %    | 5     |
| 11  | The impurities of helium                      |      | CO, H\textsubscript{2}O, CO\textsubscript{2}, N\textsubscript{2}, CH\textsubscript{4}, H\textsubscript{2}, HTO, O\textsubscript{2}, and noble gas (Xe, Kr, Ar, etc.) |
| 12  | Helium particle impurities                    |      | Carbon Dust |
4. Result And Discussion

Simulation results for analyzing HPS performance, especially cryogenic units are shown in Figure 4 and Figure 5. The simulation was investigated in a mixture of helium gas, N₂, and O₂. The mass flow rate of a mixture of helium, N₂, and O₂ gases is increased by an increase of 0.02 kg/s. The pressure in the cryogenic unit and all units of HPS is set in the same pressure as the primary cooling system is 3 MPa. As shown in Figure 4, the concentration of N₂ and O₂ in stream 2 are ascending. Stream 2 is a helium gas impurity disposal path. Therefore in this stream, the content of helium gas is very small, while the impurity gas content increases. Stream 3 is the purified gas pathway for helium. Therefore the impurity gas content in helium gas is very small, almost 99% pure helium gas.

In Figure 4 it is also shown that at the outlet of the cryogenic unit or at stream 2, the rate of increase in O₂ levels is not as high as the increase in N₂ levels. This is because O₂ gas disposal is not only in cryogenic units but also in the previous unit. Whereas in stream 3 helium gas is passed which has been purified or released from O₂ and N₂ impurities. In Figure 4 it is also shown that the regeneration process or the process to produce pure helium gas in a cryogenic unit takes about 4 hours. Figure 5 is a graph of N₂ concentration with the time of simulation results with various mass flow rates of a mixture of helium, O₂, and N₂ gases. As shown in Figure 5, N₂ gas will be wasted faster if the mass flow rate is lower. For O₂ gas disposal has the same tendency as N₂ gas disposal. The result showed that helium can be purified from the impurities N₂ and O₂ gas about 99% at the mass flow rate of around 0.45 kg/s.

![Outlet Concentration (ppm) vs Time (hours) graph](image)

**Figure 4.** The outlet concentration of N₂ and O₂.
5. Conclusion

Simulations using ChemCAD have been carried out to analyze the level of purity of helium gas used as an RDE coolant. Simulation calculations are performed to measure the effectiveness of cryogenic units in HPS. Cryogenic units are more effective at purifying helium gas from N2 impurities and from O2 impurities. The purification of helium gas from N2 and O2 gas impurities will be more effective at the lower mass flow rates. The result showed that helium can be purified from the impurities N2 and O2 gas about 99% at the mass flow rate of 0.45 kg/s.

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