Conceptual Design of Indonesia Experimental Power Reactor Coupled with Desalination Unit

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Abstract. Several ways to overcome dependence on fossil fuels/ energy sources of petroleum for national energy procurement have been performed, such as replacing petroleum with liquid coal/ gas, and other renewable energy such as hydrogen. This has been stated in the Government Regulation no. 79 of 2014 on National Energy Policy and Law no. 17 of 2007 on the 2005-2025 National Long-Term Plan. To support national energy growth, the government has enacted the use of new and renewable energy contributing to more than 23% of total energy consumption and that the use of oil should be reduced to less than 25%. Experimental Power Reactor or called Reaktor Daya Eksperimental (RDE) is built to demonstrate for electricity generation or cogeneration purpose, which utilizes nuclear heat for producing electricity and for providing process heat for an industry, for example desalination. Cogeneration system can also improve the economical benefit of the RDE by thermal utilization. Seawater desalination is an attractive solution, of which the technologies have been well established over the past 50 years. The two most commonly used desalination technologies are multistage flash (MSF) and reverse osmosis (RO) systems. Basically, almost all PLTUs in Indonesia have applied desalination technology to supply the process water needs, but they still use fossil energy to supply heat. In order to overcome electricity deficiency and water scarcity in some areas of Indonesia, then to accommodate a government regulation on energy mix, it is necessary to study nuclear heat utilization for desalination (Nuclear Desalination) through cogeneration system. The Nuclear Desalination is conducted by coupling the RDE with desalination units, so it can simultaneously produce electricity and freshwater. An intermediate heat exchanger is incorporated between the nuclear reactor and the desalination unit to ensure no radioactive contamination in secondary system or to protect the desalinated water. The objective of study is to choose the most optimum options of the steam extraction points that will be used for desalination process. The result of this study showed that heat can be extracted in the heat application line before the steam turbine (coupling option 1) and the downstream of steam turbine (coupling option 2). For coupling option 1, the steam (0.94 kg/s) with the temperature of 520°C can be extracted to produce a 27 m³/h fresh water. Meanwhile, using the low-pressure steam rejected from turbine (coupling option 2), the fresh water of 16.5 m³/h (396 m³/d) flow rate can be produced from the desalination unit.

Keywords: desalination, coupling, RDE, seawater, heat, process, industry, energy
1. Introduction

Generally, population growth is always accompanied by increasing demand for electricity and water. In accordance to energy needs, Indonesia has energy resources which, if utilized appropriately, can ensure national energy security and independence. Now days, primary energy supply in Indonesia is still mainly based on fossil fuels like oil, gas and carbon. Furthermore, in almost region in Indonesia, the electrical energy needs is supplied from PLTU using fossil fuels (coal and petroleum) and it has an environmental impact because it emits \( \text{CO}_2, \text{SO}_x, \text{and NO}_x \) gases. The government has set the optimal primary energy mix target of 2025 which provides opportunities for new and renewable energy sources (biomass, nuclear, hydropower, solar power, wind power) to contribute more than 23% of total energy consumed and that the use of oil should be reduced to less than 25 per cent [1].

In order to accommodate a mandate in the national energy policy of energy mix target, it needs to introduce nuclear energy to contribute to the new and renewable portion for energy mix. Therefore based on the provisions of Law no. 10 of 1997[2] and PP 2 year 2014 that BATAN as the Implementing Body may undertake the development, operation and decommissioning of non-commercial or non-commercial power reactors (called \textit{Reaktor Daya Eksperimental} (RDE)). The RDE is built based on High Temperature Gas Cooled Reactor (HTGR) technology with very safe consideration, functions for cogeneration purpose, fuel flexibility, tested, competitive price, and multipurpose [3]. Furthermore, it can be developed throughout Indonesia as needed, and to meet the needs electricity supply. By this RDE project, Indonesia will have experience and ability to build and operate the reactors for demonstration of electricity generation and process heat applications for industries (cogeneration) systems such as coal gasification / liquefaction, desalination, etc. and research development of nuclear power plants in the country. To further enhance the role of nuclear energy, many developed countries develop a system that allows nuclear energy not only as a source of electricity, but also as a source of heat energy (cogeneration purpose) [4]. Therefore, it considers to utilizing nuclear heat for desalination process which is a water treatment process that removes salts from seawater to obtain fresh water adequate for irrigation, drinking and industrial use (nuclear desalination). There are two major types of desalination technologies used around the world can be broadly classified as either thermal desalination processes, in which feedwater is boiled and the vapour condensed as pure water (distillate), or membrane desalination processes. Both technologies need energy to operate [5,6]. In this 21\textsuperscript{st} century, about 78% of global production capacity comprised of multistage flash (MSF) plants and RO accounted for a modest 10%. With proven high operational reliability and the convenience of their integration, the MSF is a good choice as cogeneration system for the nuclear power plants.

The RDE reactor has excellent characteristics such as a passive, modular, and passive safety system that has the potential for a hot / steam cogeneration system. Related to the condition in Indonesia which is currently seeking to increase the supply of electricity and to accommodate the government's goals related to energy mix and efforts to improve the supply of clean water, the reactor system with the purpose of double application (cogeneration) is more suitable for the purpose of coupling between nuclear reactors with desalination plant [7]. Related to the condition in Indonesia which is currently seeking to increase the supply of electricity, efforts to improve the supply of clean water, and to accommodate the government's goals related to energy mix and the reactor system with the purpose of double application (cogeneration) is more suitable for the purpose of coupling between nuclear reactors with desalination plant [8]. In this paper, a conceptual design of RDE coupled with desalination plant is studied. The objective is to choose the most optimum options of the steam extraction points that will be used for desalination process, so RDE heat can be efficiently extracted and use for desalination process.
2. Methodology
Technological and literature review of Indonesia Experimental Reactor and desalination equipment was carried out. To specifically evaluate the heat recovery from the coupling system, heat and mass balance evaluation was conducted by using ASPEN Plus software.

3. Results and Discussion

3.1 Process Design of Indonesia Experimental Power Reactor
Nuclear Energy Agency of Indonesia (BATAN) has been given the task to build and operate an Nuclear Experimental Power Reactor or Reaktor Daya Eksperimental (RDE). The reactor is expected to have many uses that to generate electricity and cogeneration research for the development of new and renewable energy so that this reactor will become a multi-purpose power reactors. RDE will be utilized to generate the electricity and steam for research. Figure 1 describes the process flow diagram of RDE system which comprises two big parts of nuclear reactor and electricity generation [9].

![Figure 1. Process diagram of experimental power reactor consisted of nuclear reactor and electricity generation systems.](image)

The heat generated by RDE is 10MWth. The heat generated will be used for electricity generation maximum of 3 MWe and/or heat application unit maximum 10 MWth. The electricity is generated by steam turbine and electric generator. The steam discharged from steam turbine will be condensed and recycled in to the steam generation system.

Steamp is created by heating water in a steam generator. The energy for heating the water is come from nuclear reaction of nuclear fuel in the reactor, carried out by reactor primary coolant, in this case is gas Helium, to the steam generator.[10] Steam generator of RDE is designed to generate superheated steam. Superheated steam is steam at a temperature higher than its boiling point for the specific pressure. The important steam information in the steam generation for electricity system is shown in Table 1.
Table 1. Stream information containing process condition and flow rate in the electricity system generated by steam.

| Stream No. | 1 | 2 | 3 | 4 | 5 |
|------------|---|---|---|---|---|
| **Stream Name** | Inlet Steam Turbin | Steam Extraction | Outlet Steam Turbin | Outlet Condenser | Inlet Steam Gen |
| Temperature, °C | 520.00 | 256.46 | 41.45 | 41.45 | 147.80 |
| Pressure, bar | 60.00 | 4.20 | 0.08 | 0.08 | 70.00 |
| Enthalpy, MW | 12.38 | 1.70 | 7.53 | 0.52 | 2.23 |
| Vapor mass frac. | 1.00 | 1.00 | 0.97 | 0.00 | 0.00 |
| Total, kmol/s | 0.20 | 0.03 | 0.17 | 0.17 | 0.20 |
| Total, kg/s | 3.57 | 0.57 | 3.00 | 3.00 | 3.57 |
| Total std, L m³/h | 12.85 | 2.05 | 10.80 | 10.80 | 12.85 |
| Component | H₂O | H₂O | H₂O | H₂O | H₂O |

3.2 Cogeneration of Indonesia Experimental Power Reactor with Desalination Unit

The safe option for cogeneration requirement in the RDE system is to utilize steam produced in the steam generator as heat application units. The line provided for heat application is shown Figure 2. Extracting heat from the steam line is a better choice than the option implied extracting energy from the helium cycle. The drawbacks of the helium utilization are that the primary radioactive helium has to be transported over a considerable distance and heat transport system and heat application unit equipment have to be designed and operated in compliance with standards and regulations adopted in nuclear industry.

![Figure 2. Diagram showing points of steam extraction for heat application unit](image)

When utilizing a steam for cogeneration, there are two options can be made. Figure 3 displays the system coupling of RDE and desalination unit when the heat is extracted in the heat application line before the steam turbine (Coupling option 1) and the downstream of steam turbine (Coupling option 2). For Coupling Option 1, the steam has the temperature of 520°C at the turbine inlet. At the conceptual stage, pipe branches with stop valves and plugs will be provided to ensure connection of heat application unit. Superheated steam is extracted at the temperature of 520°C and pressure of 6.0 MPa. Steam extraction points on superheated steam pipeline are located downstream of isolating valves which isolate steam generator from power conversion system. For the assumption that, under normal operation conditions, the main portion of steam is supplied to the
turbine, and the heat application unit uses less than 2 MW of thermal power (heat application unit power is approximately 1 MW(th)). In order to extended research activities in the area of process heat application, it is possible to use a heat application unit with the power of no less than 2 MW(th). At the same time the generator power shall not be less than nuclear station in-house power needs, including safety systems. From energy balance, when the total heat utilized in the desalination unit is 2 MW, it means that about 0.94 kg/s steam can be employed from the heat application unit. Using 0.94 kg/s steam, approx. 7.5 kg/s fresh (27 m³/h) water can be produced (using steam economy of 8 [11].

![Diagram](image)

**Figure 3.** RDE system coupled with desalination unit

For Coupling Option 2, the steam employed to generate fresh water in the desalination plant is low pressure steam of 4.2 bar and temperature of 256 °C (see Figure 1 and Table 1). The flow rate of steam is 0.57 kg/s and by simple heat balance it is approximated that a 1.2 MW thermal energy can be utilized. The heat is less than that of extracted in Coupling Option 1, but with this system there is no reduction of the electricity system (net energy for electricity preserved at 3 MWe). Using the low-pressure steam rejected from turbine, the fresh water of 16.5 m³/h flow can be produced from the desalination unit.

3.3 Process Design of Desalination Unit

To extract heat from steam, the multistage-flash distillation (MSF) is chosen. Compared to the conventional system of multiple-effect distillation (MED), MSF can work at higher temperature, is less scaling and fouling problem, and also can be employed at high concentration of salt.[12,13] The basis mechanism of MSF is the saltwater evaporation by flashing mechanism. The vapor produced then condense in the tube bundles where the salt water is flowing. MSF plants normally has 20 stages, where fresh water is separated from brine through evaporation. The schematic diagram of MSF (the first stage) is shown in Figure 4 [14].
Figure 4. Schematic system of first MSF stage where coupling between steam from power plant and desalination unit takes place

The first stage consists of flash column equipped with external heat exchanger. Before the heat exchanger, the salt water is heated by vapor produced in the flash column. Since the condensation occurs in the same stage, it means the vaporization enthalpy of distillate is transferred to the salt water in the tube bundles located in the top of flash column. The vapor condenses and the fresh water is collected in the distillate tray. The heat exchanger is employed to heated up the salt water to the boiling point temperature of the first inlet temperature to the first stage. Normally, the higher the inlet temperature produces higher rate of distillate product since a larger amount of vapor can be generated in the flash column. The brine from brine pool then move to the next stage of flash column. In each flash chamber, the pressure is set hence specifying the flash evaporation conditions.

Multi-stage flash equipment can be designed according to two different configurations i.e. once through (the basic one) and brine circulation (complex, with heat recovery). Once through means that the brine flows through each stage once time as shown in Figure 5. The second configuration is the brine circulation which provides to recover heat from the brine leaving the last stage by recycling process. The brine circulation features the better enthalpy recycle thus increasing the plant thermal efficiency, but it employs more complex system.

Figure 5. One through system of MSF configuration

4. Conclusions
Indonesia Experimental Power Reactor was assessed for cogeneration purpose. The Nuclear Desalination is conducted by coupling the RDE with desalination units, so it can simultaneously
produce electricity and freshwater. The study showed that cogeneration can be made by extraction
heat in the heat application line before the steam turbine and the downstream of steam turbine. The
first option allows the production of fresh water with capacity of 27 m$^3$/h (650 m$^3$/d) employing the
superheated steam at 520°C temperature and 6 MPa (0.94 kg/s). Meanwhile, the second option which
employs the low-pressure steam rejected from turbine, can produce 16.5 m$^3$/h (396 m$^3$/d) fresh water.
For the desalination system, the multistage flash (MSF) is used which extracts heat from cogeneration
steam with steam economy up to 8.

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