Analysis on Operating Parameter Design to Steam Methane Reforming in Heat Application RDE

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Abstract. The high temperature reactor has been developed with various power capacities and can produce electricity and heat application. One of heat application is used for hydrogen production. Most hydrogen production occurs by steam reforming that operated at high temperature. This study aims to analyze the feasibility of heat application design of RDE reactor in the steam methane reforming for hydrogen production using the ChemCAD software. The outlet temperature of cogeneration heat exchanger is analyzed to be applied as a feed of steam reformer. Furthermore, the additional heater and calculating amount of fuel usage are described. Results show that at a low mass flow rate of feed, its can produce a temperature up to 480°C. To achieve the temperature of steam methane reforming of 850°C the additional fired heater was required. By the fired heater, an amount of fuel usage is required depending on the Reformer feed temperature produced from the heat exchanger of the cogeneration system.

Keywords: RDE, heat application, hydrogen production, steam methane reformer, additional heater.

1. Introduction

The 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]. Application of nuclear heat for the high temperature of HTGR have been widely studied [2]. The reactor has been developed with various power capacities and can produce electricity and heat applications [3]. The HTR-10 with 10 MWt capacity is the small size of HTGR type reactor that was successfully operated in China [4].

Currently, Indonesia will plan to build a small size HTGR called RDE (Reaktor Daya Eksperimen) that have a thermal power of 10 MWt. High coolant temperature from the RDE is very potential for cogeneration purpose [5]. Therefore, the RDE can be applied for electricity generation, heat generation and for hydrogen production. Utilization of hydrogen is one of the scenarios of Indonesian government for the renewable energy application [6]. Hydrogen is an important raw material for the chemical, the refinery industry, and it may play a future role in the energy sector. Among the existing technologies, most hydrogen production occurs by steam reforming i.e. converting a hydrocarbon-steam mixture into a mixture of mainly hydrogen and carbon dioxide [7]. The steam reforming process is operated at high temperature [8]. Although, an assessment of the steam reforming process utilizing low-temperature nuclear reactor as heat sources have been done [9]. Principally, the products in steam reforming are synthesis gas of carbon monoxide (CO), carbon dioxide (CO₂) and Hydrogen (H₂). This reaction is highly endothermic [10], therefore to achieve such chemical reaction the high temperature with an additional heat is required.
Since the reaction is highly endothermic and is performed in the presence of a catalyst such as nickel or rhodium, in order to achieve near equilibrium conversion, steam reforming in the conventional technology is conducted in a multi-tubular reformer operated at a temperature of 850°C [11, 12]. Meanwhile, the temperature at the reformer inlet is between 450°C and 600°C [13].

The steam methane reformer is one of the facilities for the nuclear process heat application system. In the cogeneration system, the steam can be used for rotate the turbine as well as for the heat application. Furthermore, heat removal on the cooling system can be applied with a cogeneration of heat exchanger (HEx), although the efficiency of direct cycle cogeneration system is higher than indirect cycle [14].

This study would analyze the feasibility of heat application design of RDE reactor in the steam methane reforming for hydrogen production using the ChemCAD software.

2. Theory
In the RDE during normal operation, the Steam Generator (SG) at the power of 10 MWt transfers the heat of the high temperature of helium gas flowing as primary coolant system to the secondary coolant system. This secondary coolant at the pressure of 4 MPa leaving from the SG [4], the superheated steam produced has no moisture. Therefore, the steam production is higher temperature than saturation temperature. At steam pressure of 4 MPa, the saturation temperature is about of 276 °C [15].

![Diagram design of heat application in RDE](image)

**Figure 1.** Diagram design of heat application in RDE

The principle in the cogeneration system is the dry steam can be used for rotate the turbine as well as for the heat application. As shown in Figure 1, the analysis on diagram design for heat application in RDE, the HEx is used for heat removal from the steam outlet line of SG. Heat transfer occurs from a hot fluid (steam) to a cooler fluid through a solid wall separating the two. The heat transfers are sensible heat, latent heat, involving a phase change of vaporization.

In accordance with the previous studies [4, 16], the steam outlet temperature produced from the SG was estimated in the range of 440°C-570°C. On the other hand, the steam comes out from the HEx into the fired heater. This heater is used to rise the temperature from the HEx. Furthermore, steam at high temperature reacts with methane gas in the steam methane reformer. Additional heat occurs in the heater so does this heater a fuel gas is required.

The analysis design parameter on heat application uses the CC-Therm heat exchanger module of ChemCAD.6.1.4 code. The ChemCAD.6.1.4 is thermal-hydraulic calculation code that has been very popular and widely used for various applications of heat transfer design, including design operations, the evaluation process equipment manufacturing, systems analysis of unit operation installation process, includes a calculation for the cooling system design. In the code, an equation of state i.e.
mathematical relationship between temperature, pressure and volume or internal energy uses the Redlich-Kwong equation as follows,

$$p = \frac{RT}{Vm-b} - \frac{a}{\sqrt{Vm(Vm+b)}}$$  \hspace{1cm} (1)

$$a = 0.4278 R^2 T_c^{5/2}$$  \hspace{1cm} (2)

$$b = \frac{0.0876 R T_c}{P_c}$$  \hspace{1cm} (3)

where,

- \( p \): pressure (absolute), Pa
- \( V_m \): molar volume, the volume of 1 mole of gas or liquid
- \( T \): absolute temperature, K
- \( R \): ideal gas constant :8.31446 J/(mol·K)
- \( P_c \): pressure at the critical point, Pa
- \( T_c \): absolute temperature at the critical point, K

3. Methodology

The analysis step of schematic diagram is described in Figure 2. The diagram are consist of design of flow chart, modeling, input data and Output (results).

![Figure 2. The analysis step of schematic diagram](image)

Following are input data and assumptions used in the analysis,

- steam outlet temperature produced from the SG is determined of 540°C,
- demineralized feed water temperature for HEx (shell-tube type) is 26°C,
- outlet superheated steam from SG at pressure of 4.0 bar,
- input for Steam Methane Reformer feed mass flow rate in the range of 0.8 – 20 kg/s.
- the thermal analysis has been made under steady-state conditions.
- the heat losses in pipelines are negligible.
- natural gas of gross heating value is 1143 (BTU/SCF) [17].

Futhermore the preparation of model for analysis is shown in Figure 3, determination of boundary condition, assumption and input data option were carried out. The output is including the reformer feed temperature \((T_{out})\) from HEx, heat absorbed from the additional fired heater and fuel usage required.
4. Results and Discussion
The analysis of operating parameter design for heat application of Steam Methane Reformer feed has been obtained. The use of a higher temperature of steam superheated is an advantage for application of cogeneration system. Figure 4 shows the relation between mass flow rate against temperature used for feed of Steam Methane Reformer resulted from the HEx. The heat is taken from the hot temperature of outlet pipe line SG. This curve shows that with increasing of feed mass flow rate, so the lower temperature results in accordance with the first law of thermodynamics. Therefore, to achieve the perfect reaction between steam and methane gas, its require an additional heat using the fired heater (component no.2 as shown in figure 3). In this case, an additional heat requires an amount of fuel. Figure 4 shows also the curve of the power of the fired heater (in MJ/s) to achieve the temperature of steam methane reforming process i.e. 850°C [11]. For the low outlet temperatures from HEx, the number of fuel usage is required. Figure 5 shows the fuel usage (in SCF) used in a fired heater. In this case, the natural gas with the heating value of 1143 SCF was used.

![Diagram](image)

Figure 3. The model of ChemCAD6.1.4

![Graph](image)

Figure 4. Curve of high reformer feed mass flow rates versus temperature and fired heater power
Figure 5. Curve of reformer feed mass flow rates versus fuel usage

Based on the descriptions in Figure 4 and 5, the reformer feed at the low mass flow rate, a small amount of fuel for fired heater was required. Therefore, figure 6 shows the variation of reformer feed at low mass flow rates resulted from the HEx as a function of temperature. It is expected that the reformer feed from HEx into the fired heater is vapor phase (steam). In this analysis, a low mass flow rate can be produced at the temperature up to 480°C. Meanwhile, the outlet temperature of steam from the SG was determined as an input of 540°C. As a notation, that in this heat application using HEx, the pinch temperature causes the HEx can not produce the steam at a temperature above 480°C (pinch zone). The pinch temperature is where 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.

Figure 6. Curve of low reformer feed mass flow rates versus temperature and power of fired heater

5. Conclusion

Analysis on heat application design for feed into the steam methane reformer was carried out. To achieve the temperature of steam methane reforming of 850°C, an additional heat should be required. By the fired heater, an amount of fuel usage is required depending on the steam methane reformer feed temperature produced from the heat exchanger of the cogeneration system. If the steam methane reformer feed in low mass flow rate, therefore the vapor phase (steam) of feed from HEx can
be produced. This work is useful to assess the design of heat application of RDE especially for the process of steam methane reforming.

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