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Research Paper

Evaluation of energy and exergy of hydrogen production process from glycerol steam reformation to improve performance

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1. ABSTRACT

In this study, hydrogen production from glycerol steam reforming (GSR) has been investigated as a renewable source of energy. Exergy-related balance was done for all simulation points, and carbon dioxide emission intensity and hydrogen production intensity were also calculated for the presented process. The simulation results showed that the hydrogen production intensity in the GSR process was equal to 3.92 kmole H2/kmole feed, which is in a good place compared to conventional processes. Exergy analysis showed that the total exergy destruction of the GSR process is equal to 24,755.871 kW, among which, the glycerol steam reformer has the highest exergy destruction rate with a share of 97.18%. Based on the environmental assessment, in total, the GSR process emits carbon dioxide equivalent to 24.45 tons/h, and the share of emissions for process flows, utility and feed is 96.59, 3.414 and 0.00 percent, respectively.

Keywords: Hydrogen Production, Glycerol Steam Reforming, Energy Analysis, Exergy, Process Performance Improvement.

2. INTRODUCTION

Due to the global economic growth and the rapid development of production, energy and resource efficiency will become an increasing competitive factor and scope for companies in the path of sustainability. This makes it extremely important to reduce the effects of energy waste on the environment and the need to reduce energy demand at the same time as providing sustainable energy sources. To achieve this, one of the solutions is to pay attention to alternative energy sources such as biomass as a renewable and carbon neutral candidate. In addition to paying attention to this, energy efficiency optimization approaches, including thermodynamic methods, help to improve energy efficiency in production processes. Moreever, exergy has recently been considered as a practical thermodynamic method to evaluate system energy [1].

The increasing trend of biofuel as a suitable option to replace fossil fuels has led to an increase in its production. Due to the availability and reduction of the price of glycerol, it is possible to increase the incentives to use this renewable energy substance, and this has led to extensive research in this field. On the other hand, the demand for hydrogen is growing due to technological advancements in various industries [2].

Currently, a lot of research is focused on providing sustainable and environmentally friendly energy from biomass to replace conventional fossil fuels. The validation of glycerol for the possibility of sustainable energy production using this cheap feed has made it an attractive subject for hydrogen production. Different processes for hydrogen production from glycerol are presented. Each of these methods has its own advantages and disadvantages and should be selected according to process and environmental conditions and needs [3].

The most common and economical method of hydrogen production in countries with natural gas reservoirs, including Iran, is natural gas reforming (SMR). In the best case, this method leads to the production of about

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4 moles of H_2 per mole of modified CH_4, while GSR allows the formation of 7 moles of H_2 per mole of glycerol. Considering the mentioned advantages of glycerol feed for the production of strategic and valuable hydrogen and also more hydrogen production than other methods, the GSR process was selected in the present research for the thermodynamic evaluation of the process. In this regard, process exergy evaluation and its environmental assessment are very important in order to improve process efficiency and reduce the consumption of energy resources.

Considering that until now, a comprehensive and accurate thermodynamic and environmental evaluation of the GSR process has not been done in the country of Iran, the present research is aimed to enhance the efficiency of the biofuel production process at an acceptable level and reduce the consumption of energy resources by performing exergy and environmental evaluation of this process.

3. Configuration of hydrogen production process from glycerol steam reforming (GSR)

The general schematic of the process for hydrogen production through glycerol steam reforming or GSR is presented in Figure 1. The production process consists of four process units, one process facilitity and tools unit. In the utility unit, part of the input glycerol is burned in the burner along with natural gas (methane) and the energy from this combustion is used to provide energy to the GSR reformer and steam generation.

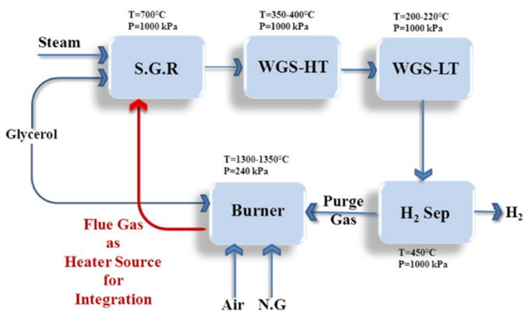

Figure 1. General structure of hydrogen production process through glycerol steam reforming.

The main reactions that occur in the process are as follows:

$$C_3H_8O_3 \leftrightarrow 3CO + 4H_2 \qquad \Delta H^0_{298} = 245\frac{kJ}{mol} \tag{1}$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \Delta H^0_{298} = -41\frac{kJ}{mol} \tag{2}$$

3.1. Simulation and thermodynamic information of the GSR process

In order to develop the simulation of the hydrogen production process from glycerol steam reforming as a renewable source, the Aspen Hysys software was used. The schematic of the simulation process of hydrogen production from glycerol steam reforming is shown in Figure 2.

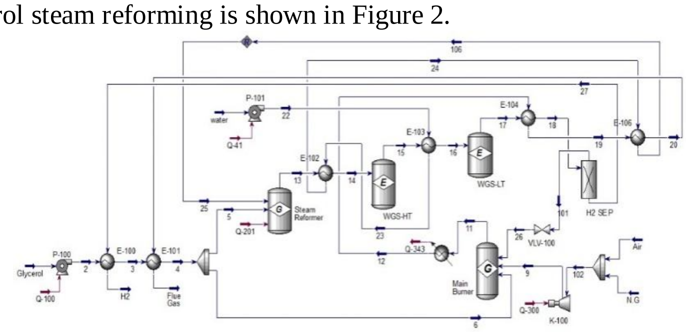

Figure 2. Simulation of hydrogen production process through glycerol steam reforming (GSR).

3.2. Exergy analysis

Some variables that are important in evaluating exergy are: (1) Exergy efficiency of components, both product and fuel identification are necessary for component analysis, (2) the overall exergy efficiency of the equipment, and (3) Exergy destruction percentage of each component of the system, which allows identifying the maximum irreversibility in the system.

3.3. Environmental analysis

The intensity of carbon dioxide emission is an important parameter for the environmental assessment of the process. In order to calculate the intensity of carbon dioxide emission, it is necessary to measure the parameter of carbon dioxide emission.

4. RESULTS AND DISCUSSION

4.1. Exergy analysis

The percentage of exergy destruction is shown in Figure 3. According to the exergy analysis, the highest share of exergy destruction (97.18%) is related to the reformer. As a result, it is necessary to use optimization methods such as increasing the inlet glycerol temperature to reduce exergy destruction in the reformer. After the reformer, the burner, which has the task of providing the necessary heat for the conversion reaction of glycerol to synthesis gas, has a share of 43.83% with 10850.84 kilowatts of exergy destruction and ranks second. Besides, the contribution of exergy destruction in the high temperature WGS reactor is more than that of the low temperature reactor.

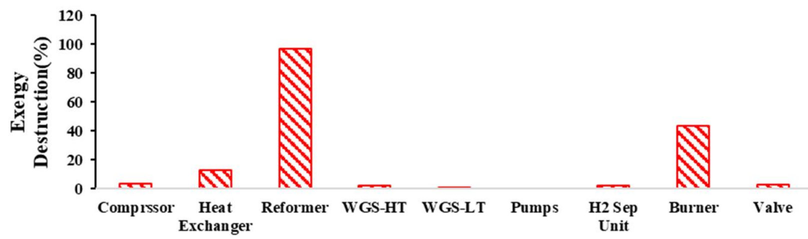

Figure 3. Comparison of exergy destruction percentage for hydrogen production process equipment from GSR.

4.2. Exergy analysis

Figure 4 compares the share of carbon dioxide emissions for streams, process facilities and tools, and feed. Based on the calculations, equivalent to 24.45 tons of carbon dioxide is emitted per hour. The share of emissions for process flows, facilities, process tools and feed are 96.59, 3.414 and zero percent, respectively. Also, the intensity of carbon dioxide emission in the hydrogen production process through glycerol vapor reforming is equal to 34.08 $\frac{t_{CO_2}}{t_{H_2}}$.

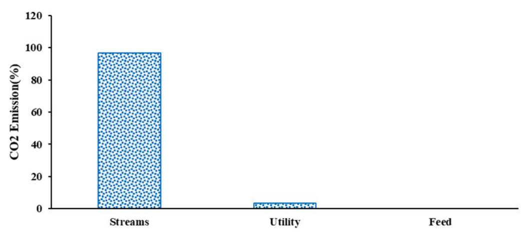

Figure 4. Comparison of carbon dioxide emission percentage in hydrogen production process from GSR.

4.3. Comparison and validation of results

The results of this study have been compared and validated according to the most important parameter of this technology, i.e., the intensity of hydrogen production, with previous works. It should be noted that the experimental works done on this issue confirm the obtained results well, but since these works were done under different operational conditions, the results obtained may be somewhat different from each other and with the present work [4]. It also demonstrated that the method of producing hydrogen from glycerol has a high efficiency potential compared to other methods.

5. CONCLUSION

The most important findings of the present study can be summarized as: (1) the highest exergy destruction is related to the glycerol reformer (2) the temperature of the glycerol stream should be higher than 400 ºC (3) the exergy efficiency of the hydrogen production process through glycerol steam reforming is 95.4% and the lowest amount of destruction belongs to the pumps (4) the intensity of hydrogen production through steam reforming of glycerol is equal to 3.92 kmole H_2/kmole feed (5) the highest share of carbon dioxide emission was related to the flow of flue gas, and the percentage of emission was 96.59%.

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