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Exergy Analysis of an Alkaline Water Electrolysis System †

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Abstract: Life on Earth is being affected daily by the enormous amounts of greenhouse gas emissions, due to the utilization of fossil fuels to produce energy for almost everything. Many researchers have been working for the development of new clean and sustainable energy sources such as solar and wind energies. Hydrogen, being a clean fuel having very high calorific value, can be used as a storage medium for these renewable energy sources and can be used efficiently in fuel cells, as well as in combustion engines. This research is focused on the investigation of hydrogen production through the electrolysis of water. An Aspen Plus-based model for the electrolysis process has been designed and validated and its exergy analysis has been conducted. Also, the improvement potential of all the equipment has been reported.

Keywords: hydrogen; electrolysis; exergy analysis; exergy efficiency

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1. Introduction

The dependence of global energy on renewable resources is increasing day-by-day to cope with the problem of climate change and global warming. These renewable resources, despite having a number of advantages over fossil fuels, have a drawback, which is their unpredict able nature. Hydrogen is considered to be one of the most promising energy carriers to fulfil all of the energy demands [1], but it is not present in nature in its elemental form, it needs to be separated from other elements through different energy-intensive methods [2]. Currently, most of the research is focused on reducing the cost of hydrogen production and, for this, different methods of hydrogen production are under consideration, namely electrolysis, thermolysis, thermochemical cycles, and biological processes [2].

Renewable energy-based electrolysis is the cleanest method of hydrogen production. There are generally three types of electrolysis processes, alkaline electrolysis, which is the most mature among them; proton exchange membrane electrolysis (PEM); and solid oxide electrolysis cells (SOECs) [2]. Many researchers have published their work on alkaline electrolyzers and the electrochemical behavior of cells. Sánchez et al. [3] developed an Aspen Plus model of an overall alkaline electrolysis plant including the cell stack as well as the balance of the plant. Zhang et al. [4] analyzed the performance of an alkaline water electrolyzer system and structured new configurations to utilize the redundant heat in the electrolyzer. Hammoudi et al. [5] developed a multi-physics model for the design and diagnosis of alkaline water electrolyzers, which allows the characterization of the electrolyzers in a relatively small amount of time. Ulleberg [6] developed a mathematical model for an advanced alkaline electrolyzer.

In this study, an Aspen Plus model of an alkaline electrolyzer is developed and its exergy analysis was conducted using Excel. The following section, materials and methods, presents the process description and exergy analysis followed by results and discussion and, finally, the conclusion.

2. Materials and Methods

2.1. Process Description

The flowsheet in Figure 1 represents a model of an alkaline electrolysis system for hydrogen production. The main part of the flowsheet is the cell stack, which is composed of an R-Stoic reactor and a separator. Water and electrolyte feed enter the cell stack from stream 4. Feed water enters the system through the oxygen separator. Water is decomposed into H_2 and O_2 in the cell stack, after being supplied with electricity and heat. In the H_2 separator and O_2 separator, the electrolyte KOH is separated from both the gases, respectively. In H_2O traps, condensate water is eliminated from H_2 and O_2, respectively.

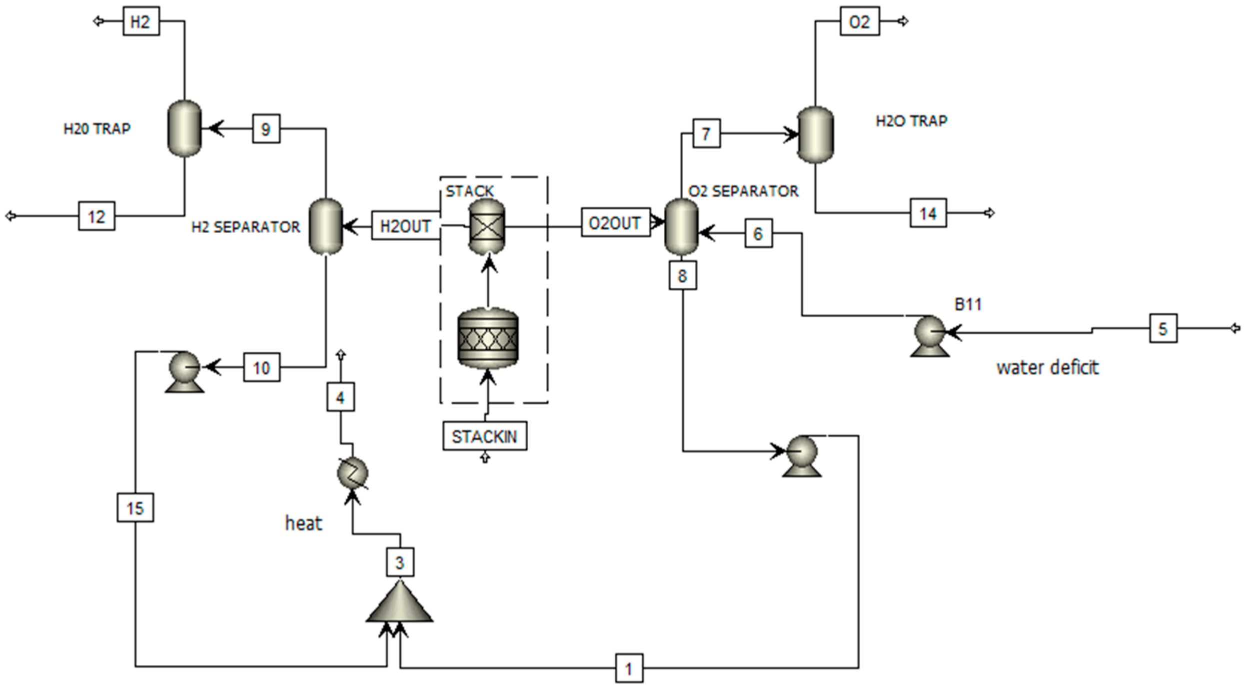

Figure 1. Process flowsheet of alkaline water electrolysis plant [3].

2.2. Exergy Analysis

Exergy analysis is the assessment of the usefulness of energy obtained from a system being in equilibrium with its surroundings. This technique incorporates the first and second laws of thermodynamics [6]. Generally, the exergy analysis of a system focuses on its physical and chemical exergies. Physical exergy is a system's maximum useful work when it is brought to an equilibrium state with the surroundings, where the chemical exergy is a system's maximum useful work when it is brought from environmental condition to dead condition [7]. Exergy destruction or irreversibility is the process' lost exergy or the difference between the process' inlet and outlet exergies [8]. The equations used to perform the exergy analysis in this study are as follows:

$$Ex_s = Ex_{Ph} + Ex_{ch} \tag{1}$$

$$Ex_{heat} = Q\left(1 - \frac{T_0}{T}\right) \tag{2}$$

$$Ex_W = W \tag{3}$$

$$I = \sum\left(Ex_{feed} + Q_r\left(1 - \frac{T_0}{T_r}\right)\right) - \sum\left(Ex_{product} + Q_c\left(1 - \frac{T_0}{T_c}\right)\right) \tag{4}$$

$$\eta = \frac{Ex_{out}}{Ex_{in}} \times 100 \tag{5}$$

$$Improvement\ Potential = (1-\eta)(Ex_{in} - Ex_{out}) \tag{6}$$

3. Results and Discussion

This section tabulates the equipment exergy efficiency, exergy destruction, and improvement potential of an alkaline water electrolysis plant. The pressure and temperature values chosen are 101.325 kPa and 25 °C, respectively. In the results presented in Table 1, physical exergy has been considered. It is shown that the H_2 separator has the highest exergy efficiency and the lowest improvement potential, whereas the stack has the lowest exergy efficiency among all other equipment and, therefore, has the highest improvement potential. The exergy losses in the reactors are due to the endothermic nature of the reactions, which decreases the physical exergy, resulting in entropy generation [7]. The exergy efficiency of the stack may be increased by designing a custom model of an electrolyzer, based on empirical equations using an Aspen custom modeler [3]. The H_2O trap separates condensate water from H_2; the mass flow rate of the condensate water stream increases as the pressure increases from 2 bar to 7 bar, resulting in a decrease in the flow rates of H_2. The overall improvement potential of the plant is 7.071158559 KW. The heat from the recycled electrolyte KOH can be recovered by integrating a heat exchanging network, which would increase the overall plant efficiency [3]. Pump 2 has the minimum exergy efficiency among all three pumps. The exit stream of the heat exchanger, stream 4, is not considered as the stack inlet, because the Aspen model uses a sequential solver and, therefore, it is necessary to model a break in closed cycles to give inputs to the model.

Table 1. Exergy analysis.

Equipment	Exergy Destruction (KW)	Exergy Efficiency (%)	Improvement Potential (KW)
Stack	9.20532	24.64893	6.936305322
H_2 Separator	0.00031	99.98000	0.000000061
H_2O Trap 1	0.07978	34.72741	0.052073033
Pump 1	0.00123	99.91311	0.000001071
Mixer 1	0.20000	92.93972	0.014120266
Heater	0.16570	90.00552	0.016560510
O_2 Separator	0.00151	99.89795	0.000001536
H_2O Trap 2	0.07978	34.72741	0.052073033
Pump 2	0.00009	76.14504	0.000022647
Pump 3	0.00124	99.91272	0.000001080

4. Conclusions

The exergy analysis of an alkaline water electrolysis plant provides valuable insights into the plant's thermodynamic performance. It is observed that the H_2O traps and cell stack have the lowest exergy efficiencies of 34.72741% and 24.64893%, respectively under standard pressure and temperature conditions of 101.325 kPa and 25 °C, respectively. This implies that there is a significant potential for the improvement in the performance of the cell stack, which is the heart of this process and will, eventually, have an impact on the whole process. The exergy analysis was purely based on the physical exergy and the chemical exergy was ignored in this study. Chemical exergy will be studied in our future research work.

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References

1. Charvin, P.; Stéphane, A.; Florent, L.; Gilles, F. Analysis of solar chemical processes for hydrogen production from water splitting thermochemical cycles. *Energy Convers. Manag.* **2008**, *49*, 1547–1556. [CrossRef]
2. Nikolaidis, P.; Poullikkas, A. A comparative overview of hydrogen production processes. *Renew. Sustain. Energy Rev.* **2017**, *67*, 597–611. [CrossRef]
3. Sanchez, M.; Amores, E.; Abad, D.; Rodriguez, L.; Clemente-Jul, C. Aspen Plus model of an alkaline electrolysis system for hydrogen production. *Int. J. Hydrogen Energy* **2020**, *45*, 3916–3929. [CrossRef]
4. Zhang, H.; Su, S.; Lin, G.; Chen, J. Configuration designs and parametric optimum criteria of an alkaline water electrolyzer system for hydrogen production. *Int. J. Electrochem. Sci* **2011**, *6*, 2566–2580. [CrossRef]
5. Hammoudi, M.; Henao, C.; Agbossou, K.; Dubé, Y.; Doumbia, M.L. New multi-physics approach for modelling and design of alkaline electrolyzers. *Int. J. Hydrogen Energy* **2012**, *37*, 13895–13913. [CrossRef]
6. Mustafa, J.; Ahmad, I.; Ahsan, M.; Kano, M. Computational fluid dynamics based model development and exergy analysis of naphtha reforming reactors. *Int. J. Exergy* **2017**, *24*, 344–363. [CrossRef]
7. Samad, A.; Ahmad, I.; Kano, M.; Caliskan, H. Prediction and optimization of exergetic efficiency of reactive units of a petroleum refinery under uncertainty through artificial neural network-based surrogate modeling. *Process Saf. Environ. Prot.* **2023**, *177*, 1403–1414. [CrossRef]
8. Samad, A.; Saghir, H.; Ahmad, I.; Ahmad, F.; Caliskan, H. Thermodynamic analysis of cumene production plant for identification of energy recovery potentials. *Energy* **2023**, *270*, 126840. [CrossRef]