Düzce University
Journal of Science & Technology

Research Article

Modeling of the Thermodynamic and Environmental Impact Assessment of a Geothermal Energy-Based Power and Hydrogen Generation Plant

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DOI: 10.29130/dubited.1070353

ABSTRACT

In this proposed study, hydrogen and power generation by low-temperature geothermal energy supported Kalina cycle is thermodynamically investigated with an energy and exergy efficiencies approaches. This combined plant includes a Kalina cycle and a PEM electrolysis for power and hydrogen generation. The key purpose of this paper is to generate power and hydrogen in an environmentally benign way. Furthermore, environmental impact analysis is discussed to investigate the carbon dioxide emission that will be released if the power and amount of hydrogen obtained are produced with natural gas. As coming to the examination results, the energy and exergy performance of the overall plant 7.94% and 37.64%, respectively. Also, the net power and hydrogen production rates are computed as 100.5 kW and 0.0001191 kgs^{-1}.

Keywords: *Energy, Exergy, Geothermal, Hydrogen, Kalina cycle*

Jeotermal Enerji Destekli Güç ve Hidrojen Üretim Tesisinin Termodinamik ve Çevresel Etki Değerlendirmesinin Modellenmesi

ÖZ

Önerilen bu çalışmada, düşük sıcaklıklı jeotermal enerji destekli Kalina çevrimi ile hidrojen ve güç üretimi termodinamik olarak enerji ve ekserji verimlikleri ile kapsamlı şekilde incelenmiştir. Bu birleşik tesis, güç ve hidrojen üretimi için bir Kalina çevrimi ve bir PEM elektrolizi içerir. Bu makalenin temel amacı, çevre dostu bir şekilde güç ve hidrojen üretmektir. Ayrıca elde edilen hidrojenin gücü ve miktarının doğal gaz ile üretilmesi durumunda ortaya çıkacak olan karbondioksit salınımını araştırmak için çevresel etki analizi tartışılmaktadır. Analiz sonuçlarına göre, tüm tesisin enerji ve ekserji verimliliği sırasıyla %7.94 ve %37.64'üir. Ayrıca net güç miktarı ve hidrojen oranı 100.5 kW ve 0.0001191 kgs^{-1}'dir.

Anahtar Kelime*: Enerji, Ekserji, Jeotermal, Hidrojen, Kalina çevrimi*

Received: 08/02/2022, Revised: 22/05/2022, Accepted: 27/05/2022

I. INTRODUCTION

Energy is an important subject for the development of humanity. As factors such as industrialization, urbanization, and globalization development, the need for energy and also the use of its have increased step by step. The light of these increments, the utilization of fossil-based fuels increased to fulfill the demand the energy. However, it is widely known that the usage of fossil-based fuels has great effects on our globe as environmental problems. Some of these problems are, for example, global warming, ozone depletion, melting of glaciers, floods, and acid rains. Moreover, a 2050 zero-emissions roadmap published by the IEA highlights the need to reduce the coal-fired energy generation by 6% to achieve the required emissions reduction [1]. On the other hand, in tackling these environmental problems, one of the most significant keywords is the addressed of renewable energy sources from energy generation to several areas.

On the other hand, in sustainable development, in addition to renewable energy sources, hydrogen, which is an energy carrier, will take its place in the future green renewable energy sources, as it has many advantages such as high energy density, high efficiency in production and consumption stages [2]. However, the generation the hydrogen from fossil-based fuels still continues which is accounts for almost %96 [3]. That is, it is mean that the environmental problems still remain. For this reason, the researchers should be mainly focused on the green hydrogen generation method that is the renewable energy-based hydrogen generation option. In particular, interest in renewable energy-supported hydrogen production methods such as solar, geothermal, biogas and wind are on the rise, which must be due to the above-mentioned situations. In this respect, it can be stated that geothermal energy has a very good potential for our country. Moreover, when looking at open literature studies, many researchers have carried out various studies on this subject. Zhang et al. [4] showed a review research of the Kalina cycle (KC). They compared that of the Rankine and KC based on energetic and energetic performances and then stated that the KC has a family of configurations used in different fields. Yilmaz[5] proposed a geothermal energy power plant that produces clean water and power. Comprehensive thermodynamic modeling is addressed by the author and then whole energetic and exergetic performances are determined as 10.18 % and 56.83 %. Th author [6] conducted a thermodynamic analysis of the geothermal energy based integrated cycle that generates power, hydrogen, hot water, heating, cooling and drying. The energy and exergy performance of the entire study are computed as 37.65 % and 39.26 %, respectively.

Thermodynamic and economic investigation of the geothermal energy supported various power plants is proposed and analyzed by Ambriz-Diaz et al. [7]. Their modeled plant uses low-grade geothermal water and produces cooling, power, and dehydrated crops. They employed and integrated the KC, organic Rankine cycles (ORC), and Goswami cycle, in this modeled system. Referring to their consequences, the overall energetic and exergetic efficiency of the polygeneration cycle is 30.68 % and 27.43 %, respectively. Zare and Palideh [8] examined a low-temperature geothermal energy-based power cycle that integrates the KC and thermoelectric generator. They investigated a thermodynamic and economic performance analysis to examine the modeled plant's performance. Looking at the results, they highlighted a 7.3 % increase in performance under a typical operating condition. Furthermore, Siddique and Dincer [9] to generate the power, fresh water, cooling, and hydrogen, a new solar and geothermal integrated multigeneration plant is proposed and analyzed. They resulted that the modeled plant has 42.3% energetic performance ratio. Moreover, the aim of the hydrogen generation, Yuksel et al. [10] modeled a multigeneration plant which is the integration of geothermal energy.

Referring to the above-mentioned literature survey, there are many studies about the low-grade geothermal power to main of generating many useful crops e.g., power, heating, cooling, hydrogen and etc., However, in the studies examined, ORC systems working with hydrocarbon group fluids are widely used. In this proposed research study, an ammonia-water mixed KC is employed to power and hydrogen generation. The main importance and difference of this study is the investigation of hydrogen production by a low-temperature KC and thermodynamically investigated. In addition, the environmental impact analysis is studied to examine the carbon dioxide (CO_2) emissions that will occur if natural gas is used instead of geothermal to obtain beneficial outputs from the whole system. Furthermore, a parametric work is executed to examine the effects of the main limitations which are the changing of the geothermal water temperature, mass fraction rate of ammonia, and turbine inlet pressure on the modeled system's performance. Moreover, the innovative aspects of this proposed study can be expressed as follows;

- Design and analysis of a combined plant to generate green hydrogen
- Thermodynamic analysis of hydrogen production by PEM electrolysis
- To conduct the energy and exergy efficiency analysis of the total system
- Examination of performance change with parameter study

II. SYSTEM DESCRIPTION

This paper basically composed of a geothermal source, a KC to generate power, and a PEM electrolyzer which generates hydrogen that is as shown in Fig.1. KC systems are power generation system that works with ammonia-water mixture fluid, which is generally used in low-temperature applications. Firstly, it transfers the geothermal water heat, which comes out at 120 ºC at state 1, to the ammonia-water fluid in the heat exchanger 1 (HEX1) and then KC is working. Then, with the geothermal water goes in the HEX2 at state 2, hot water at 80 ºC required for PEM electrolysis is obtained. Hydrogen is produced in PEM electrolysis with some of the electrical power generated in KC. Subsequently, the ammonia-water solution at state 7 goes in the separator, where it is separated into rich solution and weak solution form at constant pressure and temperature. With the high mass fraction rate of this fluid enters the Turbine at state 9 and then where is expand and power generation occurs. On the contrary, the weak mass fraction rate fluid at a relatively high temperature enters HEX3 at state 8, where it preheats the ammonia-water mixture coming from state 5.

In conclusion, the geothermal fluid exiting at state 1 enters HEX1 and HEX2, respectively, and returns injection well at state 3, between approximately 50-70 °C, after KC and PEM provide the thermal energy required for electrolysis.

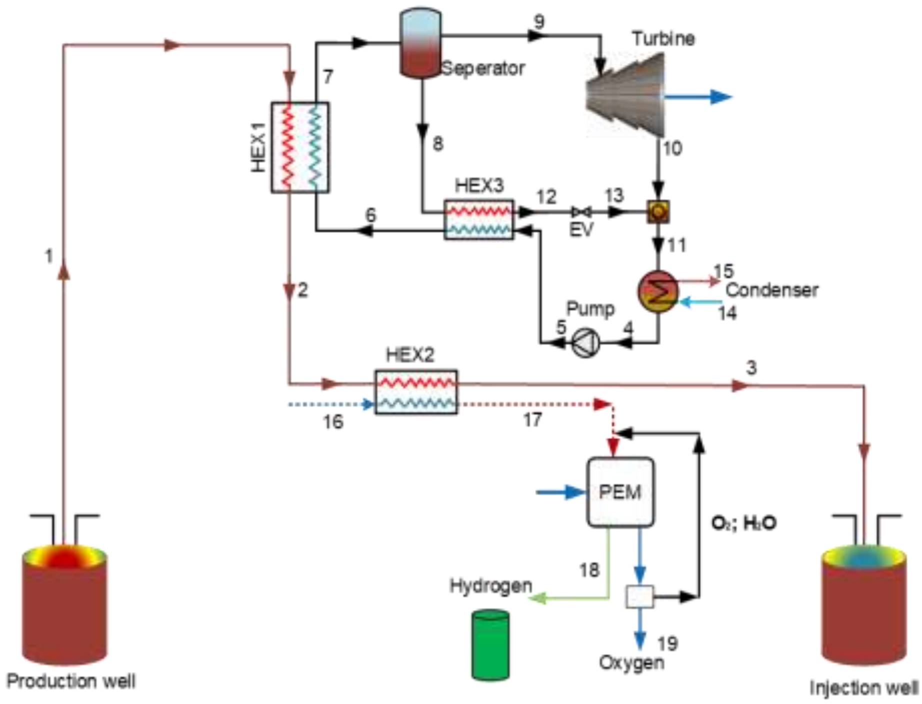

***Figure 1**. Schematic layout of the geothermal supported KC.*

III. ANALYSIS AND MODELING

The modeled system is integrated that to acquire the amount of power and hydrogen, in a sustainable way. In the light of this aim, the proposed study is comprehensively examined and modeled that is the thermodynamic performance and environmental impact evaluation approaches. moreover, the assumptions made to analyze this proposed geothermal-powered system are presented in Table 1.

Table 1. *Modeled system' assumed parameters.*

Parameter	Value	Unit
Inlet temperature of the geothermal fluid	120	℃
Mass flow rate of geothermal	10	kgs^{-1}
$\eta_{isen,Pump}$ [11]	80	%
$\eta_{isen,Turbine}$ [11]	85	%
Working fluid	$NH_3 - H_2O$	-
Pinch point temperature	20	℃
Pump compression rate	2.5	-
Pump inlet pressure	900	kPa
Effectiveness of HEXs [12]	80	%
PEM effectiveness	56	%
PEM power rate	$\dot{W}_T * (0.3)$	kW
Reference point temperature	25	℃
Reference point pressure	101.325	kPa

For the environmental impact assessment, the CO_2 emission rates that can be reduced as a result of using natural gas with different upper heating values in order to obtain the same capacity are examined. Therefore, the analysis part of this paper splitting the two parts.

A.1. Thermodynamic analysis

Comprehensive thermodynamic modeling of the geothermal energy-based KC is addressed to generate power and hydrogen, in this subpart. For this aim, the mathematical formulation of the thermodynamic analysis is applied that is generally based on the general mass, energy, entropy, and exergy equivalence of any thermal systems. These formulations of the thermodynamic can be modeled as follows[13–15];

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$

In Equation 1, "in" and "out" subscripts are determined the inlet and outlet flow. Referring to thermodynamic laws, at steady-state flow conditions, the inlet mass flow rate is equal to the outlet mass flow rate. After that, the mathematical formulation of the energy balance can be specified as;

$$\sum \dot{m}_{in}\left(h_{in} + gZ_{in} + \frac{V_{in}^2}{2}\right) + \dot{W}_{in} + \dot{Q}_{in} = \sum \dot{m}_{out}\left(h_{out} + gZ_{out} + \frac{V_{out}^2}{2}\right) + \dot{W}_{out} + \dot{Q}_{out} \tag{2}$$

In the above-mentioned equation, $\dot{W}$, $\dot{Q}$ and h terms describe the heat rate, work rate, and specific enthalpy. General entropy equilibrium is also given as below;

$$\sum \dot{m}_{in}s_{in} + \dot{S}_{gen} = \sum \frac{\dot{Q}_c}{T_c} + \sum \dot{m}_{out}s_{out} \tag{3}$$

where, the terms s and $\dot{S}_{gen}$ define specific entropy and entropy generation concepts. As coming the finally, the exergy formulation of the general plant can be written as below;

$$\sum \dot{m}_{in}\, ex_{in} + \dot{Ex}_{in}^{\dot{W}} + \dot{Ex}_{in}^{\dot{Q}} = \sum \dot{m}_{out}\, ex_{out} + \dot{Ex}_{out}^{\dot{W}} + \dot{Ex}_{out}^{\dot{Q}} + \dot{Ex}_{des} \quad (4)$$

here, $\dot{Ex}_{in}^{\dot{W}}$ and $\dot{Ex}_{in}^{\dot{Q}}$ terms describe the work and heat exergy rates. Also, these terms can be formulated as below;

$$\dot{Ex}^{\dot{W}} = \dot{W} \quad (5)$$

$$\dot{Ex}^{\dot{Q}} = \dot{Q}(1 - \frac{T_0}{T_c}) \quad (6)$$

Additionally, $\dot{Ex}_{des}$ is the exergydestruction (irreversibility) rate and written as below;

$$\dot{Ex}_{des} = T_0 \dot{S}_{gen} \quad (7)$$

In the light of the above-mentioned mathematical formulation of thermodynamics, a detailed thermodynamic equation of the demonstrated plant's parts is tabulated in Table 2.

Table 2. *Thermodynamic balance equations of the examined plant's components.*

Components	Balance equation
HEX1	MB: $\dot{m}_1 = \dot{m}_2;\ \dot{m}_6 = \dot{m}_7$ EnB: $\dot{m}_1 h_1 + \dot{m}_6 h_6 = \dot{m}_2 h_2 + \dot{m}_7 h_7$ EntB: $\dot{m}_1 s_1 + \dot{m}_6 s_6 + \dot{S}_{gen} = \dot{m}_2 s_2 + \dot{m}_7 s_7$ ExB: $\dot{m}_1 ex_1 + \dot{m}_6 ex_6 = \dot{m}_2 ex_2 + \dot{m}_7 ex_7 + \dot{Ex}_{des,HEX1}$
HEX2	MB: $\dot{m}_{16} = \dot{m}_{17};\ \dot{m}_2 = \dot{m}_3$ EnB: $\dot{m}_{16} h_{16} + \dot{m}_2 h_2 = \dot{m}_{17} h_{17} + \dot{m}_3 h_3$ EntB: $\dot{m}_{16} s_{16} + \dot{m}_2 s_2 + \dot{S}_{gen} = \dot{m}_{17} s_{17} + \dot{m}_3 s_3$ ExB: $\dot{m}_{16} ex_{16} + \dot{m}_2 ex_2 = \dot{m}_{17} ex_{17} + \dot{m}_3 ex_3 + \dot{Ex}_{des,HEX2}$
HEX3	MB: $\dot{m}_5 = \dot{m}_6;\ \dot{m}_8 = \dot{m}_{12}$ EnB: $\dot{m}_5 h_5 + \dot{m}_8 h_8 = \dot{m}_6 h_6 + \dot{m}_{12} h_{12}$ EntB: $\dot{m}_5 s_5 + \dot{m}_8 s_8 + \dot{S}_{gen} = \dot{m}_6 s_6 + \dot{m}_{12} s_{12}$ ExB: $\dot{m}_5 ex_5 + \dot{m}_8 ex_8 = \dot{m}_6 ex_6 + \dot{m}_{12} ex_{12} + \dot{Ex}_{des,HEX3}$
Separator	MB: $\dot{m}_7 = \dot{m}_8 + \dot{m}_9$ EnB: $\dot{m}_7 h_7 = \dot{m}_8 h_8 + \dot{m}_9 h_9$ EntB: $\dot{m}_7 s_7 + \dot{S}_{gen} = \dot{m}_8 s_8 + \dot{m}_9 s_9$ ExB: $\dot{m}_7 ex_7 = \dot{m}_8 ex_8 + \dot{m}_9 ex_9 + \dot{Ex}_{des,Sep}$
Turbine	MB: $\dot{m}_9 = \dot{m}_{10}$ EnB: $\dot{m}_9 h_9 = \dot{m}_{10} h_{10} + \dot{W}_T$ EntB: $\dot{m}_9 s_9 + \dot{S}_{gen} = \dot{m}_{10} s_{10}$ ExB: $\dot{m}_9 ex_9 = \dot{m}_{10} ex_{10} + \dot{W}_T + \dot{Ex}_{des,T}$
Pump	MB: $\dot{m}_4 = \dot{m}_5$ EnB: $\dot{m}_4 h_4 + \dot{W}_P = \dot{m}_5 h_5$ EntB: $\dot{m}_4 s_4 + \dot{S}_{gen} = \dot{m}_5 s_5$ ExB: $\dot{m}_4 ex_4 + \dot{W}_P = \dot{m}_5 ex_5 + \dot{Ex}_{des,P}$
Expansion valve	MB: $\dot{m}_{12} = \dot{m}_{13}$ EnB: $\dot{m}_{12} h_{12} = \dot{m}_{13} h_{13}$ EntB: $\dot{m}_{12} s_{12} + \dot{S}_{gen} = \dot{m}_{13} s_{13}$ ExB: $\dot{m}_{12} ex_{12} = \dot{m}_{13} ex_{13} + \dot{Ex}_{des,P}$
Condenser	MB: $\dot{m}_{14} = \dot{m}_{15};\ \dot{m}_{11} = \dot{m}_4$

	EnB: $\dot{m}_{14}h_{14} + \dot{m}_{11}h_{11} = \dot{m}_{15}h_{15} + \dot{m}_4h_4$ EntB: $\dot{m}_{14}s_{14} + \dot{m}_{11}s_{11} + \dot{S}_{gen} = \dot{m}_{15}s_{15} + \dot{m}_4s_4$ ExB: $\dot{m}_{14}ex_{14} + \dot{m}_{11}ex_{11} = \dot{m}_{15}ex_{15} + \dot{m}_4ex_4 + \dot{E}x_{des,Con}$
PEM	MB: $\dot{m}_{17} = \dot{m}_{18} + \dot{m}_{19}$ EnB: $\dot{m}_{17}h_{17} + \dot{W}_{PEM} = \dot{m}_{18}h_{18} + \dot{m}_{19}h_{19}$ EntB: $\dot{m}_{17}s_{17} + \dot{S}_{gen} = \dot{m}_{18}s_{18} + \dot{m}_{18}s_{18}$ ExB: $\dot{m}_{17}ex_{17} + \dot{W}_{PEM} = \dot{m}_{18}ex_{18} + \dot{m}_{19}ex_{19} + \dot{E}x_{des,Con}$

In conclusion, the total energy and exergy efficiencies of the investigated plant can be formulated as below;

$$\eta_{sys} = \frac{\dot{W}_{net}+(\dot{m}_{H_2}LHV_{H_2})}{\dot{m}_{geo}(h_1-h_3)} \quad (8)$$

$$\psi_{sys} = \frac{\dot{W}_{net}+(\dot{m}_{H_2}ex_{H_2})}{\dot{m}_{geo}(ex_1-ex_3)} \quad (9)$$

A.2. Environmental impact assessment

There are many harmful emissions that occur as a result of burning fossil fuels. In this study, environmental impact analysis is addressed in order to calculate the CO_2 emission that may be released as a result of the combustion of natural gas, which has different upper calorific values, given in Table 3. In our country, namely Turkiye, natural gas has been preferred because it is widely used for both heating and electricity generation purposes. The amount of CO_2 released per kWh as a result of the combustion of natural gas is presented in Table 3.

Table 3. *CO_2 emission factors of the natural gas [16-17].*

Fuel types	HHV (Btu/scf)	CO_2 emission (kg/kWh)
Natural gas	975-1000	0.184
	1025-1050	0.181
	1075-1100	0.183

IV.RESULTS AND DISCUSSION

A.1. Model Validation and comparison

In this study, the KC cycle is preferred for power generation, and model validation is carried out with a study that is carried out in the literature by Zare and Palideh [8], in 2018. Zare and Palideh determined the energy efficiency of the system as 6.504 % when the turbine inlet pressure is fixed at 2000 kPa and the ammonia concentration at the inlet of the separator is fixed at 0.85. Under the same conditions, they stated that the energy efficiency of the traditional KCS 11 cycle is calculated as 6.063. On the other hand, in this study, which is designed under the same conditions for model validation, the electrical energy going to PEM electrolysis is neglected and the energetic efficiency of the KC, is computed as 6.559 %. As a result, the relative error rate between the energy efficiencies of this KC system proposed by the study of Zare and Palideh is 0.83%, and this value can be expressed quite consistently and logically.

Table 4. *KC model validation [8].*

Studies	Separator input pressure (kPa)	Separator input ammonia mass fraction	Energy Efficiency (%)	Exergy Efficiency (%)
Zare and Palideh	2000	0.85	6.504	52.91
Convectional KCS11	2000	0.85	6.063	49.32
Proposed KC system	2000	0.85	6.559	45.6

From another point of view, the energy and exergy efficiencies of different design KC systems are examined and their comparison is presented in Table 5. KCs are very suitable and widely preferred systems for low-temperature applications. As realized in Table 5 below, the efficiencies of these systems vary depending on many factors such as system design, working pressure and etc., It is possible to increase their efficiency by modifying simple KC systems.

Table 5. *Performance comparison of different design KC systems.*

Different studies	System	Energy efficiency (%)	Exergy efficiency (%)
Ref. [11]	Basic KC	7.22	32.20
Ref. [11]	Modified KC	26.96	39.14
Ref.[18]	KC	10.6	59.3
Re. [19]	Basic KC	9.71	33.39
Ref. [19]	Modified KC	8.314	31.262
Ref. [20]	KC system	8.31	31.26
Proposed study	KC+PEM	7.94	37.64

A.2. Analysis results

This planned geothermal energy-based plant is thoroughly examined which is integrated the KC and PEM unit to generate power and hydrogen. To conducted these analysis method, Engineering Equation Solver (EES)[21] program is employed. In this context, energetic efficiency, exergetic efficiency, and irreversibility are researched extensively, and moreover, CO_2 emission decrease rate is calculated based on the natural gas use. Referring to the assumptions mentioned in Table 1, the thermodynamic analysis consequences are presented in Table 6. It is realized that the quantity of the net power and hydrogen rate of this examined plant are 100.5 kW and 0.0001191 kgs^{-1}. Furthermore, energy and exergy efficiency of the entire cycle is determined as 7.94 % and 37.64 %, respectively.

Table 6. *Analysis outcomes of the studied plant.*

	Values	Unit
Net power generation rate	100.5	kW
Hydrogen generation rate	0.0001191	kgs^{-1}
Total exergy destruction rate	301.7	kW
Calculated electrical power of PEM	30.14	kW
Energy efficiency	7.94	%
Energy efficiency	37.64	%

A parametric work is also executed to examine how the influence of the geothermal reservoir outlet temperature on the system efficiency and the obtained power and hydrogen amounts, and these behaviors are presented in Figures 2 and 3. Looking at Figure 2, the whole energetic and exergetic performance of the advised plant increased by rising the geothermal reservoir temperature from 120 °C to 145 °C. While the ammonia-water mixture at the separator inlet is constant at 0.8, both energy and exergy performances increased linearly for the overall cycle with a temperature of 25 °C source increase. Figure 3 illustrates the hydrogen and power production rate of the total cycle increasing with rising the geothermal reservoir temperature. The produced hydrogen rate goes from 0.0001 to 0.00022 kgs^{-1} with the rise of the geothermal water temperature by 25°C. As a result of the rise in beneficial outputs, the performance of the model increases positively.

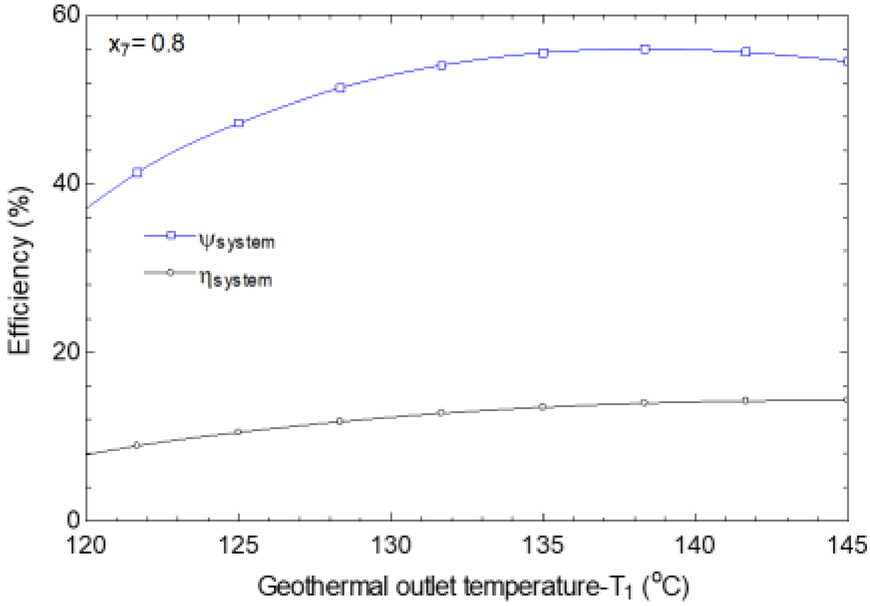

Figure 2. *Performance ratios of the examined plant vs geothermal reservoir temperature*.

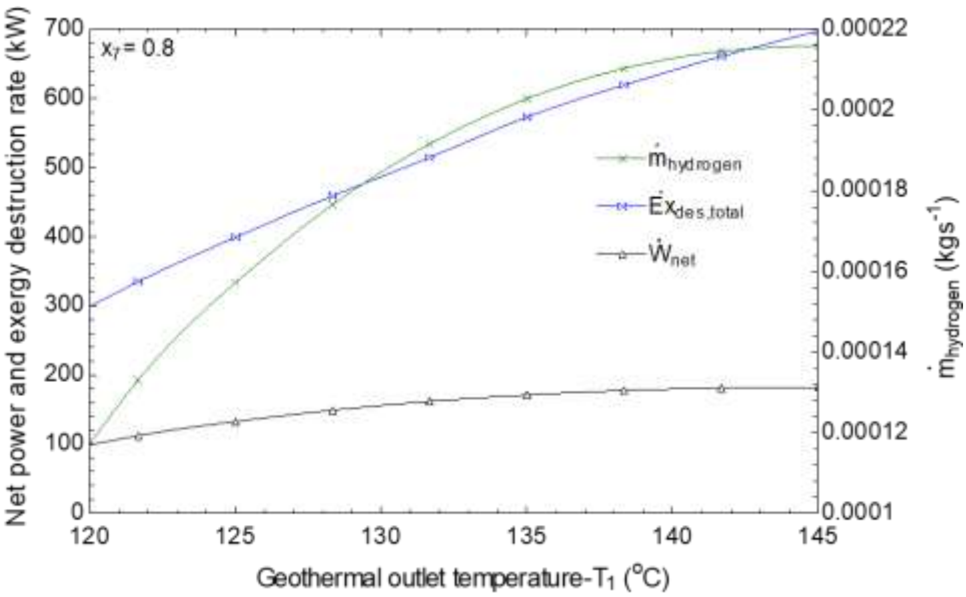

Figure 3. *Useful products and exergy destruction rate of the overall plant vs geothermal reservoir temperature*.

Another factor is the impact of changing the ammonia mass fraction rate at state 7 (x_7) on the system performance and produced power and hydrogen from the cycle. Figure 4 shows the how the influence of the different x_7 rates on the modeled cycle's performance. Increment in the x_7 rate from 0.7 to 0.9, the mass flow rate of ammonia-water at point 7 reductions, and the mass rate of the rich mixture indirectly going to the turbine at point 9 decreases in parallel. Accordingly, the performance value of the cycle, which is energy and exergy performance, decreases as the power generation obtained in the turbine decreases. The decreasing behavior seen in this graph is compatible with the study in the literature [8].

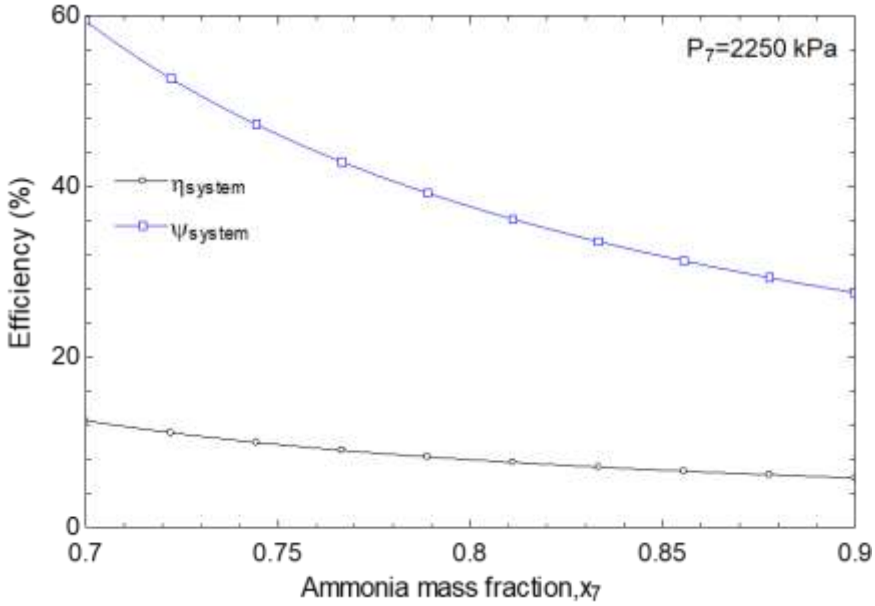

Figure 4. *Performance ratios of the examined plant with different ammonia mass fraction*.

The influence of varying the x_7 rate on the total irreversibility of the total plant as well as on the generated hydrogen and net power rate from the system is examined and displayed in Figure 5. It is clear shown that all three parameters that are mentioned are reduced linearly by raising the x_7 rate. That is, as a final, it can be emphasized that the rise in the x_7 ratio has a negative impact on the whole plant, especially between 0.7 and 0.9. The main reason for this decline can be defined as a reduction in mass flow entering the separator at state 7 and then entering the turbine as a result of the growth in ammonia mass fraction between 0.7 and 0.9.

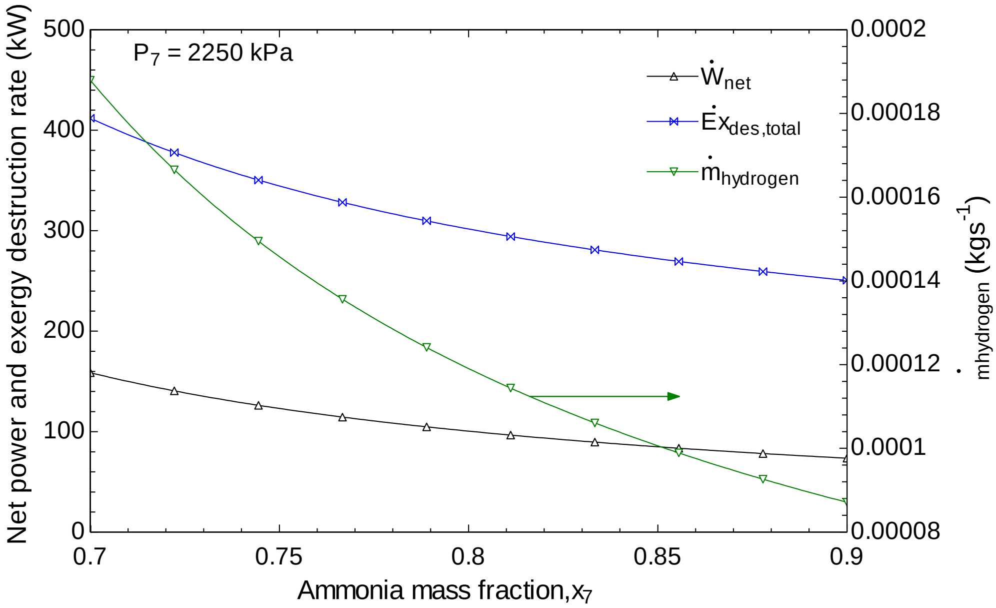

Figure 5. *Useful products and irreversibility of the overall cycle with different ammonia mass fraction*.

In the turbine section where power generation occurs in thermal systems such as KC, it is one of the important points to examine how the turbine inlet pressure change affects the whole system's performance. Therefore, Figures 6 and 7 indicate the performance, irreversibility, and acquired beneficial products of the modeled total cycle versus different turbine inlet pressure. Increasing the turbine inlet pressure from 1500 kPa to 2500 kPa leads to the energy and exergy efficiency of the overall cycle increase, as mentioned in Figure 6. Contrary to this situation, as realized in Figure 7, the irreversibility of the whole plant decreased, as expected. Moreover, the increase of turbine inlet pressure has an optimistic impact on the of hydrogen and power rates. Referring to both these figures, the power generation increases as the system operates in higher pressure ranges with the increase of turbine input, and thus an increase in performance. As a result, for Figures 6 and 7, as the system operates at higher pressure (enthalpy) with the growth of the turbine inlet pressure, the net power generation increases, and accordingly, the system performance is also increased.

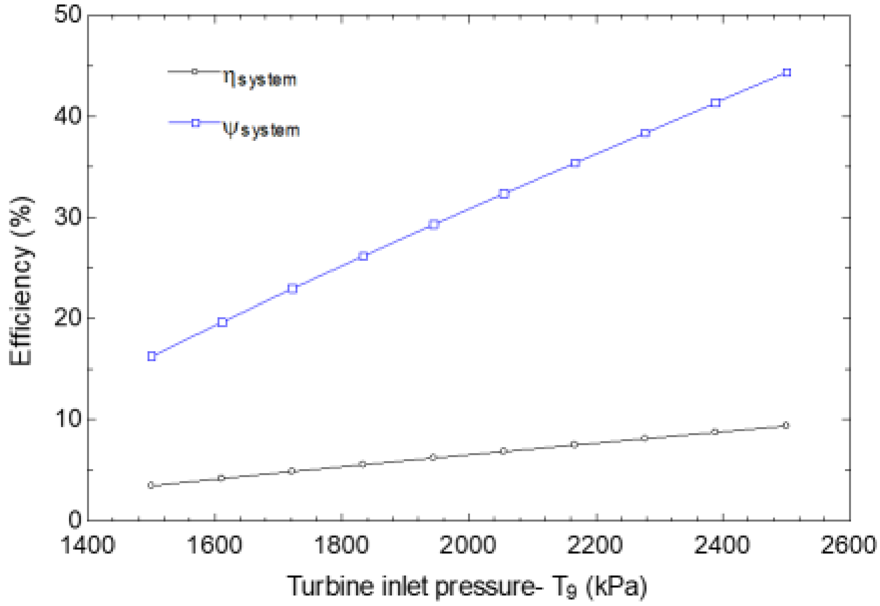

Figure 6*. Impact of the turbine input pressure on the modeled plant' performance*.

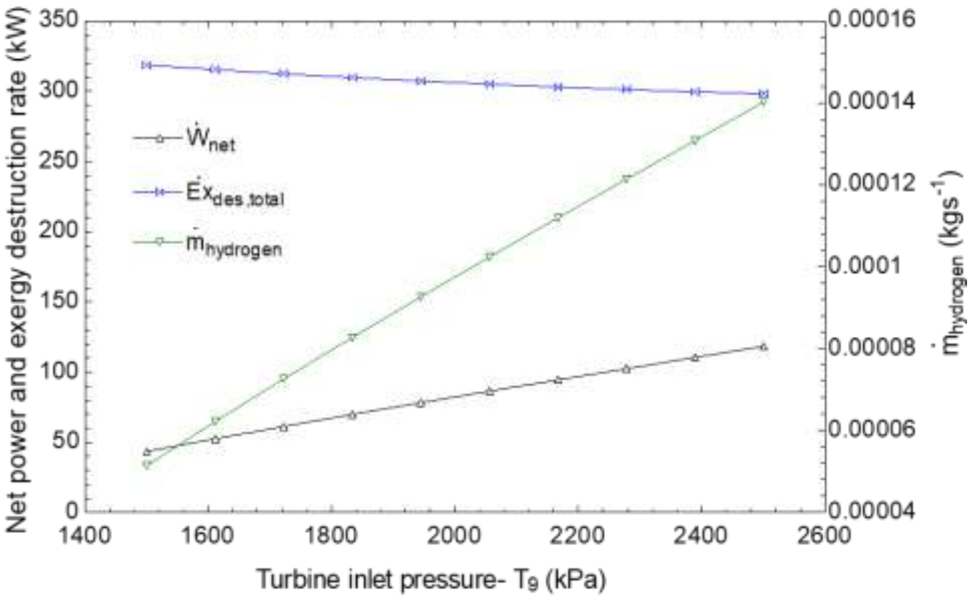

Figure 7. *Impact of the turbine inlet pressure on the power, hydrogen and exergy destruction rates.*

The pinch point temperature (PPT) is one of the significant factors that is must be examined in the system design. Especially since HEX1 is thermally interconnected with geothermal water and KC working fluid, the effects of PPT_{HEX-1} temperature change on system performance were investigated in this study. With the increase of PPT_{HEX-1} from 5 to 20 °C, the energetic and exergetic performance of the suggested system decreased in the expected direction, as revealed in Figure 8. The key reason for this reduces is the rise in the temperature difference between the two fluids with the rise of PPT_{HEX-1}, and the KC system operates in a lower temperature range.

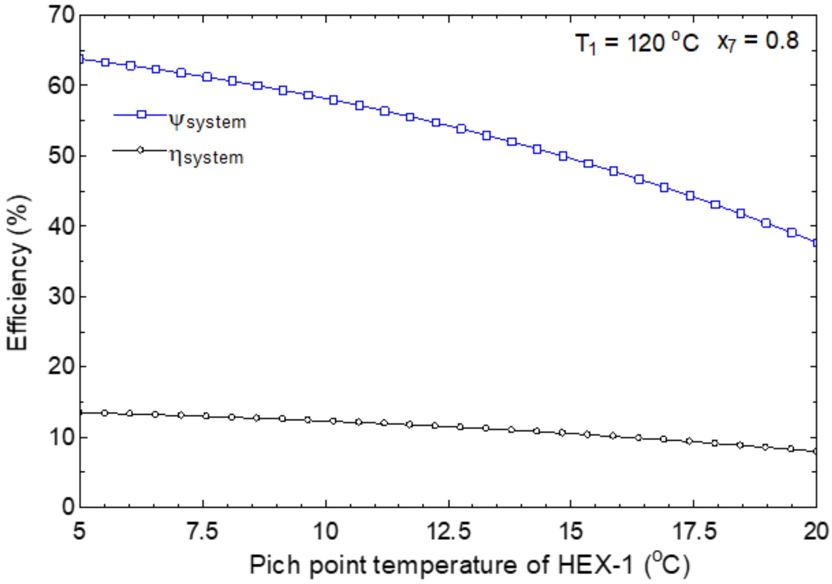

Figure 8. *Effect of the PPT_{HEX-1} on the modeled plant' performance.*

In the continuation, Figure 9 presents the effect of the $\mathrm{PPT_{HEX-1}}$ on the irreversibility and generated power and hydrogen rate of the overall systems. Again, it should be noted the power, hydrogen, and irreversibility rates of the modeled plant decrease with increasing the $\mathrm{PPT_{HEX-1}}$. As a result of these two figures that are Figures 8 and 9, the selection of the ideal temperature of PPT is most important, in order to higher performance acquired.

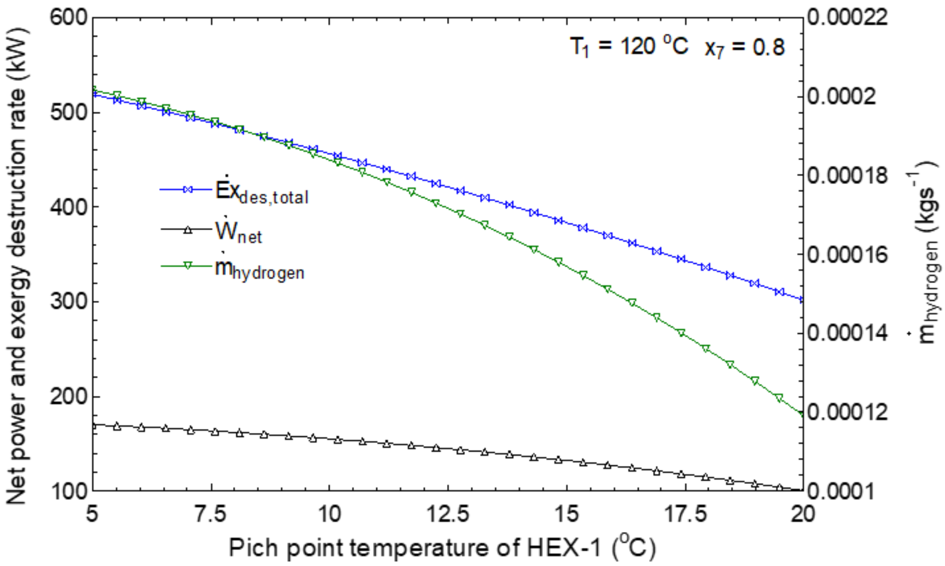

Figure 9. *Effect of the PPT_{HEX-1} on the power, hydrogen and irreversibility.*

The thermodynamic second law presents a detailed investigation the any modeled thermal system in terms of entropy and exergy balances. For this aim, the irreversibility of the suggested system's components is investigated and presented in Figure. 10. The irreversibility rate of the overall system is figured as 301.6 kW and the highest irreversibility is observed in HEX1 among the subcomponents. And then, the second-highest irreversibility is also observed in the condenser. The main reason for this situation is that more irreversibilities are seen in these components due to the high-temperature change.

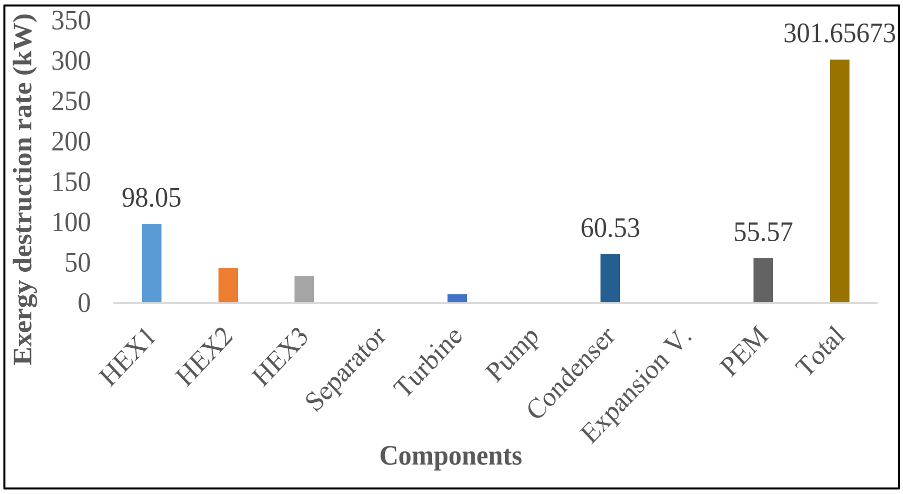

Figure 10. *Exergy destruction rate of the modeled system' components.*

CO_2 emission reduction graph, which is the last chart of the analysis results, that is, the environmental impact evaluation figure. Considering the CO_2 emission values in Table 3, the amount of CO_2 emission analyzed if natural gas in different HHVs, is used for the power and hydrogen production, and it is presented in Figure 11. Referring to different HHV values, geothermal energy is preferred in this study, reducing the average CO_2 emission of 21.43 kg per hour. As finally, this figure shows the CO_2 emission to the atmosphere if natural gas is used to obtain the useful outputs obtained in this system.

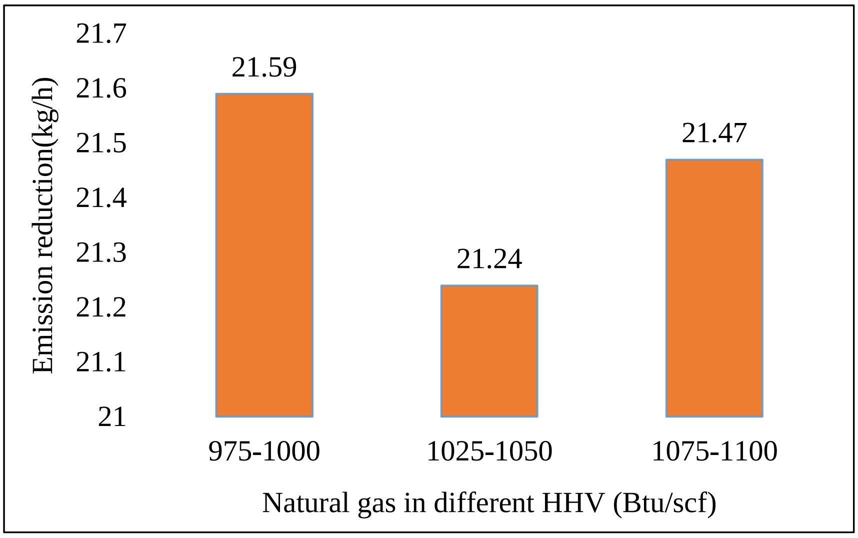

Figure.11. *CO_2 emission reduction rate of the examined plant.*

V.CONCLUSION

The main objective of the examined geothermal energy-based KC, which is generating power and hydrogen, is to examine the thermodynamic analysis and CO_2 emission reduction rate. Another of the main objectives is to observe in detail the hydrogen production from a low-grade geothermal energy source with a clean and sustainable method. Furthermore, to study the performance ratio, irreversibility, and power and hydrogen rate of the designed plant, a detailed parametric study is conducted. Finally, the CO_2 emission assumption that may occur if natural gas is used to achieve the same outputs has been investigated. Briefly, looking at the outcomes of the analysis, the prominent points can be highlighted as below;

- This system has the capacity to produce 100.5 kW of electricity and 0.0001191 kgs-1 of hydrogen in total.
- The total irreversibility rate is determined as 301.7 kW and the highest exergy destruction is determined in HEX1.
- The whole system has an energy efficiency of 7.94 % and an exergy performance of 37.64 %.
- It is concluded that it is possible to obtain higher system performance with the rise in geothermal reservoir temperature and turbine inlet pressure.

Looking at the coming years, it is a fact that many environmental problems are increasing step by step. For this purpose, with the integration of low-grade systems such as KC systems, it will be indispensable to be preferred for different purposes for instance heating, electricity, hydrogen, cooling.

Nomenclature

$\dot{E}x$	Exergy, kW
$\dot{m}$	Mass flow rate, kg/s
h	Specific enthalpy, kJ/kg
s	Specific entropy
T	Temperature, ºC-K
$\dot{Q}$	Heat transfer rate, kW
$\dot{W}$	Work rate, kW

Subscripts

c	Component
des	destruction
gen	generation
geo	geothermal
in	input
out	output

Acronyms

EnB	Energy balance
EntB	Entropy balance
ExB	Exergy balance
HEX	Heat exchanger
KC	Kalina cycle
MB	Mass balance

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