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Energy Analysis and Exergy of the System of Simultaneous Production of Power and Hydrogen with the Excitatory Gasification of Municipal Solid Waste

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ABSTRACT: Nowadays, due to the extensive application of renewable-based cogeneration systems and also the economic and environmental necessities, their design and thermodynamic analysis have been conducted by many scientists. In this way, a novel, simple, and practical combined power and hydrogen cogeneration unit have been designed in the present study in which there are gas turbine, gasifier, transcritical Rankine cycle, and proton exchange membrane electrolyzer. This system has been analyzed from the first and second laws of thermodynamics by an engineering equation solver. The proposed system is able to generate power and hydrogen simultaneously for users. The power and hydrogen production capacities of the system are 3.92 MW and 608.8 cubic meters per hour, respectively, which consume biomass of about 1.155 kg/s. The energy utilization factor and exergy efficiency of the system is 34.71 % and 29.44 %, respectively. It can be seen that the overall exergy destruction of the system is 11854 kW, in which gasifier, gas turbine, and combustion chamber have the highest irreversibilities. In addition, it can be concluded that the exergy efficiency of condenser and heat exchanger 3 are the lowest ones among other types of equipment. According to the parametric studies, it was found that increasing the inlet temperature of the gas turbine has a positive effect, and increasing the maximum pressure of the transcritical carbon dioxide cycle has a negative effect on the energy utilization factor and the exergy efficiency of the system..

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1- Introduction

Energy is an essential ingredient of our developed life and is conceived as one of the main elements to achieve common economic, social, and environmental goals to accomplish sustainable development in global energy infrastructure. Several factors, including rapid growth in population and increasing demand for energy services, contribute to the uptake of energy production. To address this, many efforts have been made, among which employing new energy sources and cogeneration systems are perceived as viable alternatives to the use of fossil fuels as well as conventional energy systems [1].

In recent years, many studies have been conducted on cogeneration systems and the use of biomass as fuel. Fiaschi and Carta [2] analyzed the gas turbine power plant and concluded that when biomass combustion increases by 15 to 30% compared to the base state of the gas turbine, carbon dioxide production decreases by 30 to 50%. Zhao et al. [3] found that by gasifying municipal solid waste with air in a hot air furnace, the heating value of the product gas increases with increasing gasification for a constant equivalence ratio.

An important innovation of this system is receiving heat from the air cooler in the gas turbine cycle and using it for heating transcritical carbon dioxide, which improves the overall performance. Therefore, it can be concluded that the proposed system has not been designed and evaluated in similar works and has a good performance in terms of energy, exergy, economy, and environment. Furthermore, the proposed system contains two small compressors instead of the main compressor, and there is an intercooler of air between two compressors, which contributes to reducing the power consumption of compressors. Additionally, the transcritical carbon dioxide fluid is heated three times in first, second, and internal heat exchangers, so this kind of design in the transcritical Rankine cycle enhances the turbine inlet temperature and the electricity generation.

2- Methodology

The schematic of the proposed system of simultaneous generation of electricity and hydrogen is shown in Fig. 1. The system uses municipal solid waste as input fuel and consists of a gasifier, a Brayton cycle, a carbon dioxide Rankine cycle, and a proton exchange membrane electrolyzer.

To model the proposed system, each component of the system is considered as a control volume, and assuming the steady-state, the laws of conservation of mass and energy and the second law of thermodynamics are applied to it. The laws of conservation of mass and energy are expressed

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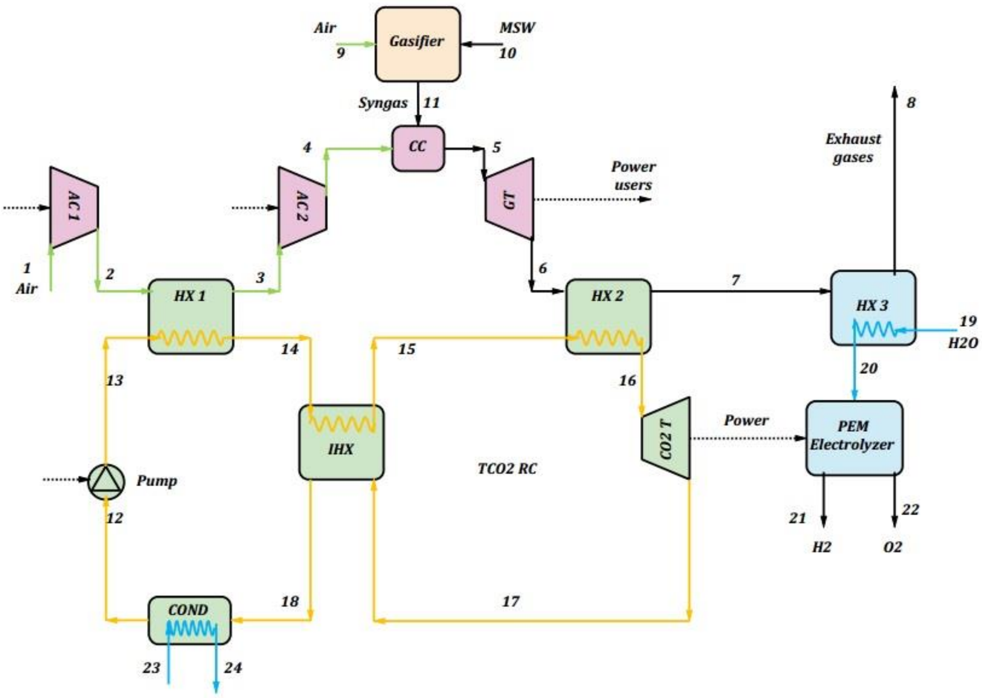

Fig. 1. Schematic of the combined power and hydrogen generation system.s

according to Eqs. (1) and (2):

$$\sum \dot{m}_i = \sum \dot{m}_e \tag{1}$$

$$\dot{Q}_{C.V} + \sum_{in} \dot{m}_i h_i = \dot{W}_{C.V} + \sum_{out} \dot{m}_e h_e \tag{2}$$

Where $\dot{m}$ and h represent the mass flow rate and specific enthalpy, respectively, $\dot{W}_{C.V}$, and $\dot{Q}_{C.V}$ represent the output power and the input heat to the control volume.

The maximum ability to do work when the system from a specific state (temperature T and pressure P) reaches a restricted dead state (temperature T_0 and pressure P_0) is called physical exergy.

$$e = \overbrace{(h-h_0)-T_0(s-s_0)}^{e_{ph}} + e_{ch} \tag{3}$$

The electrical efficiency of the second law electrical efficiency, Energy Utilization Factor (EUF), and exergy efficiency of the entire system are the criteria that we consider to evaluate the studied system, and they are defined as follows:

$$\eta_{Elec,Sys} = \frac{\dot{W}_{net}}{\dot{m}_{Biomass} LHV_{Biomass}} \tag{4}$$

$$EUF_{Sys} = \frac{\dot{W}_{net} + \dot{m}_{H_2} LHV_{H_2}}{\dot{m}_{Biomass} LHV_{Biomass}} \tag{5}$$

$$\eta_{II,Elec,Sys} = \frac{\dot{W}_{net}}{\dot{E}_1 + \dot{E}_9 + \dot{E}_{10} + \dot{E}_{19}} \tag{6}$$

$$\eta_{II,Sys} = \frac{\dot{W}_{net} + \dot{E}_{P,PEME}}{\dot{E}_1 + \dot{E}_9 + \dot{E}_{10} + \dot{E}_{19}} \tag{7}$$

It should be noted that the net output power of the cycle and exergy of the Proton Exchange Membrane Electrolyzer (PEME) cycle product is calculated according to Eqs. (45) and (46), respectively:

$$\dot{W}_{net} = \dot{W}_{GT} - \dot{W}_{AC1} - \dot{W}_{AC2} - \dot{W}_{Pump} \tag{8}$$

$$\dot{E}_{PEME} = \dot{E}_{21} + \dot{E}_{22} \tag{9}$$

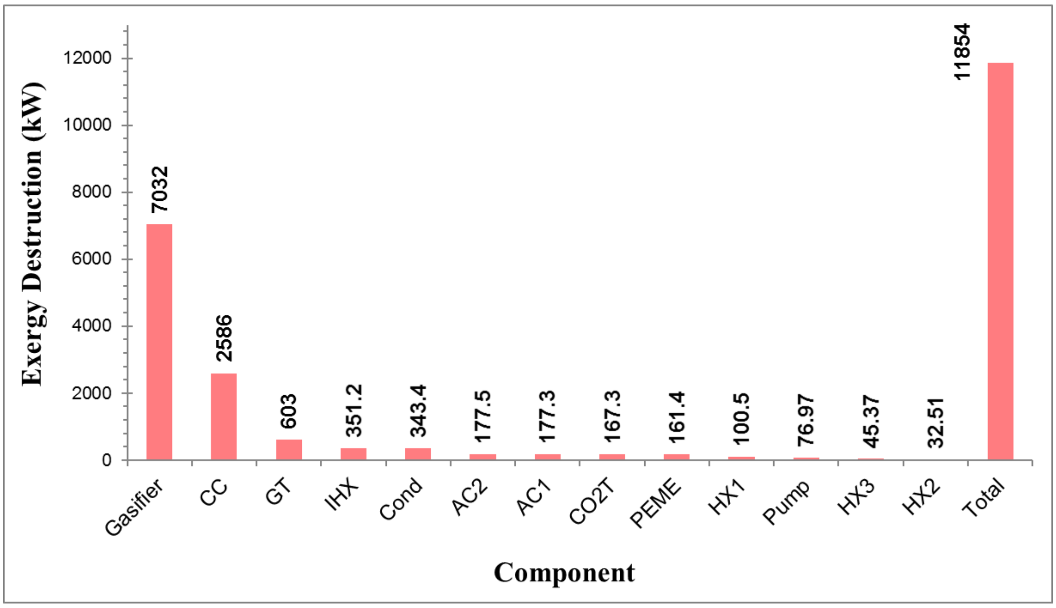

Fig. 2. Exergy destruction within components.

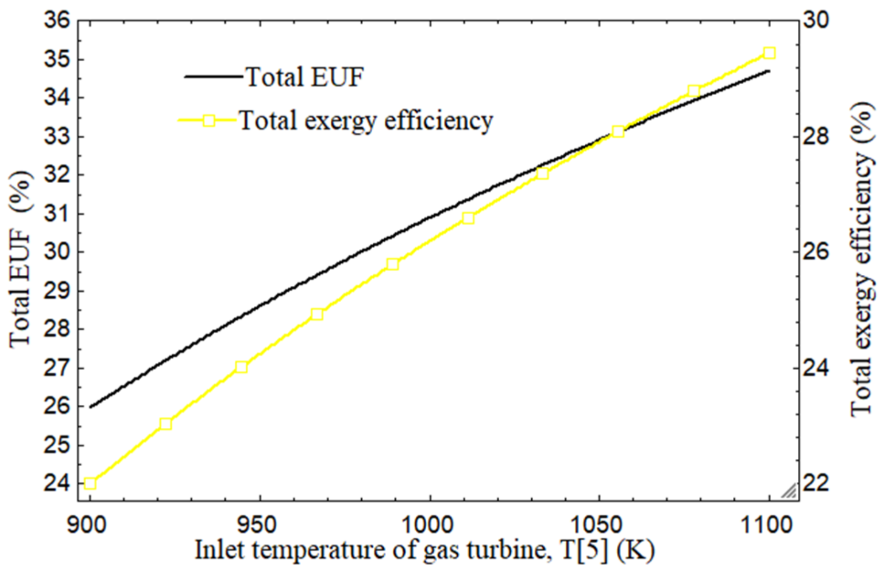

Fig. 3. The effects of the inlet temperature of the gas turbine on EUF and exergy efficiency.

3- Results and Discussion

In this section, the results obtained for the system with a power generation capacity of 3.92 MW are given. The amount of exergy destruction in each component of the system under basic operating conditions is shown in Fig. 2. It can be seen from the figure that the amount of exergy destruction of the whole system is equal to 11854 kW, and the gasifier and the combustion chamber have the highest rate of exergy destruction, which is due to the chemical reactions in these two components.

One of the most important effects is the effect of the inlet temperature of the gas turbine on the EUF and exergy efficiency of the system. As the temperature of the exhaust gases from the combustion chamber increase, the temperature of these gases at the turbine outlet also increases. As a result, the amount of heat transfer in heat exchangers 2 and 3 increases, and consequently, the capacity of the CO2 cycle and the electrolyzer increases. This increases the EUF and the exergy efficiency of the whole system.

4- Conclusion

In this study, to prevent energy wastage and increase efficiency, a system of dual production of power and hydrogen with a new, simple, and at the same time, practical design is presented, which includes a gasifier, a Brayton cycle, a transcritical carbon dioxide cycle, and a proton exchange membrane electrolyzer. This system, while generating power, recovers waste heat to provide the hydrogen needed by the consumer.

The system is capable of producing 3.92 MW of electricity and 608.8 m3/h hydrogen gas. The fuel consumption of the cycle is 1.155 kg/s. The EUF and exergy efficiency of the system is 34.71% and 29.44%, respectively. The amount of exergy destruction of the whole system is 11854 kW. The combustion chamber and gasifier have the highest rate of exergy destruction. This is due to the high chemical reactions in the combustion chamber and gasifier. The exergy efficiency of the condenser and heat exchanger 3 has the lowest values because the temperature difference between the working fluid of these components and the cold inlet water is higher than the other components, and as expected, the high-temperature difference causes these components to be inefficient.

In conclusion, the dual generation system proposed in this paper can produce clean electricity and hydrogen due to the consumption of biomass. The strengths of this system are consumption of municipal waste as the main fuel, simplicity in design, as well as good productivity of hydrogen gas. The weaknesses of this system are also examined from the perspective of the second law of thermodynamics so that other researchers can conduct new studies on them. Also, in future works, the economic and environmental performance of the current system can be examined in order to obtain more reliable results and conclusions.

References

[1] H. Ghiasirad, N. Asgari, R.K. Saray, S. Mirmasoumi, Thermoeconomic assessment of a geothermal based combined cooling, heating, and power system, integrated with a humidification-dehumidification desalination unit and an absorption heat transformer, Energy Conversion and Management, 235 (2021) 113969.

[2] D. Fiaschi, R. Carta, CO2 abatement by co-firing of natural gas and biomass-derived gas in a gas turbine, Energy, 32(4) (2007) 549-567.

[3] L. Zhao, H. Wang, S. Qing, H. Liu, Characteristics of gaseous product from municipal solid waste gasification with hot blast furnace slag, Journal of Natural Gas Chemistry, 19(4) (2010) 403-408.

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