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Optimization of a novel carbon dioxide cogeneration system using artificial neural network and multi-objective genetic algorithm

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HIGHLIGHTS

- Energy and exergy analysis of a novel CHP system are reported.
- A comprehensive parametric study is conducted to enhance the understanding of the system performance.
- Apply a multi-objective optimization technique based on a code developed in the Matlab software program using an evolutionary algorithm.

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ABSTRACT

In this research study, a combined cycle based on the Brayton power cycle and the ejector expansion refrigeration cycle is proposed. The proposed cycle can provide heating, cooling and power simultaneously. One of the benefits of such a system is to be driven by low temperature heat sources and using CO_2 as working fluid. In order to enhance the understanding of the current work, a comprehensive parametric study and exergy analysis are conducted to determine the effects of the thermodynamic parameters on the system performance and the exergy destruction rate in the components. The suggested cycle can save the energy around 46% in comparison with a system producing cooling, power and hot water separately. On the other hand, to optimize a system to meet the load requirement, the surface area of the heat exchangers is determined and optimized. The results of this section can be used when a compact system is also an objective function. Along with a comprehensive parametric study and exergy analysis, a complete optimization study is carried out using a multi-objective evolutionary based genetic algorithm considering two different objective functions, heat exchangers size (to be minimized) and exergy efficiency (to be maximized). The Pareto front of the optimization problem and a correlation between exergy efficiency and total heat exchangers length is presented in order to predict the trend of optimized points. The suggested system can be a promising combined system for buildings and outland regions.

1. Introduction

Combined cycle technologies are one of the good options that has been considered to be a solution to mitigate global warming as they can produce two or three useful commodities using a single source as energy input. Using a single source and utilize the waste energy to produce heating or cooling leads to increase the efficiency of the system and reduce the purchase and maintenance cost of the system. In recent years, combined cycles have become more popular as higher thermal efficiency, fewer equipment's, and lower operating cost per energy output. Besides, the cycles which can operate based on low temperature heat source and external combustion unit are more promising. These cycles have the advantages of utilizing waste heat, various fuels (e.g. biofuels and natural gas), renewable energy sources (e.g. solar energy, geothermal energy) and having enough time for combustion. Meanwhile, a working fluid such as CO_2, which is cheap, nontoxic, environmentally benign, and has good heat transfer properties will be an appropriate working fluid in combined cycles. In addition,

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thermal systems using CO_2 as refrigerant or working fluid are more compact, and work in pressures above the atmospheric pressure [1,2].

After reintroducing CO_2 as a refrigerant in refrigeration cycles by Lorentzen [3], many researchers have tried to use the advantages of CO_2 and have suggested solutions for its drawbacks. One of the important drawbacks of CO_2 in the conventional refrigeration cycle is the large irreversibility in expansion valve and compressor, respectively [4]. Li and Groll [5] proposed a two phase ejector instead of the expansion valve in the conventional CO_2 refrigeration cycle to recover the losses in expansion process and also suggested a feed-back way from vapor part of separator to inlet of evaporator to improve the control of the cycle. Cavallini et al. [6] also proposed two stage compression with intercooling to reduce the losses in the compressor. Moreover, other researchers have suggested a vortex tube or a working recovery turbine instead of the expansion valve in the conventional CO_2 refrigeration cycle [7,8] in order to reduce the losses and improve the cycle performance.

Due to the low critical temperature, CO_2 also is suitable in power cycles using low temperature heat source. This is due to the fact that the process of heating occurs in the transcritical region, pinching which limits the heat transfer in heat exchangers does not occur in CO_2 power cycle. Cayer et al. [9] analyzed the CO_2 transcritical power cycle using low temperature heat source, and Baik et al. [10] compared the CO_2 with R125 in the transcritical power cycle. Some of the research conducted suggests combined heating, cooling and power cycles in literature are based on the Rankine cycle and absorption cycle using a mixture of ammonia-water as a working fluid [11–14]. Despite of the weakness of ammonia-water thermo physical properties mentioned by Zheng et al. [13], it is used for its environmental benign property meaning that in general the heat transfer characteristics of the mixtures fluid are always lower than the pure working fluid [15]. Dai et al. [16] studied the exergy and parametric analyses on a novel combined power and ejector refrigeration cycle. The appropriate working fluid in their suggested cycle was R123. Chen et al. [17] proposed a combined cooling and power cycle using carbon dioxide as working fluid for a truck based on the Brayton cycle and the conventional refrigeration cycle.

In these studies [16,17], heat source temperature is assumed to be around 120 °C–250 °C. This temperature could be provided by evacuated solar collectors, low concentration solar collectors, geothermal sources, waste heat from other cycles [11], or hybrid solar/gas [18]. The main objective of the present work is to conduct a comprehensive thermodynamic and exergy analyses, and multi-objective optimization of a new CO_2 combined cycle which can provide power, heating (hot water) and cooling simultaneously. Two objective functions considered here are combined cycle exergy efficiency and heat exchangers size. The new objective function, heat exchangers size is introduced as a small system is also attractive for energy systems designer. The design parameters selected in this study are the mass flow rate ratio χ (m_{15}/m_1), the first compressor discharge pressure P_5, the second compressor discharge pressure P_7, the cooler outlet temperature T_6, the turbine inlet temperature T_9, the inlet and outlet temperature of the water side of cooler T_{wi}, T_{wo}, the heat exchangers inner and annular diameter d_i, d_o and the entrainment ratio of ejector ω. This proposed cycle is based on the Brayton power cycle and the ejector expansion refrigeration cycle as shown in Fig. 1. In addition, the P–h diagram of the cycle is also illustrated in Fig. 2.

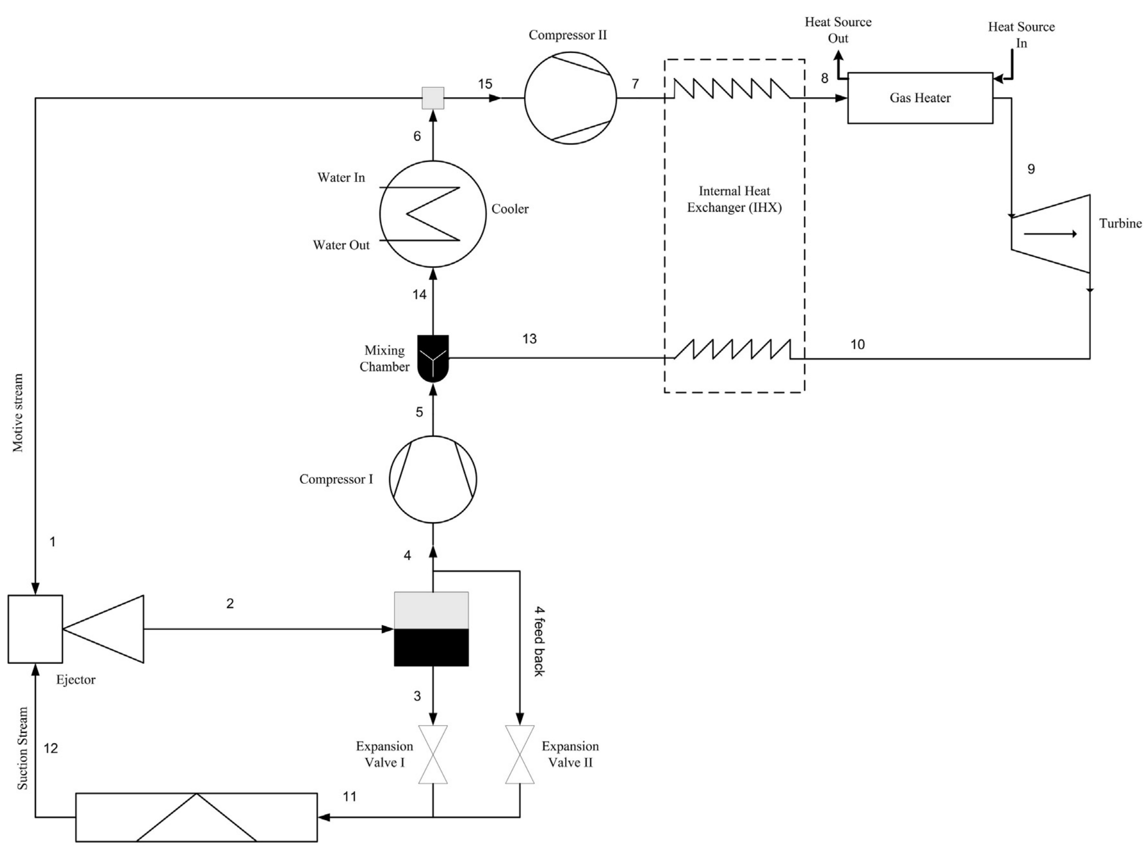

Fig. 1. Schematic diagram of the proposed cycle.