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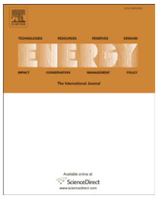

Exergy analysis and parametric optimization of three power and fresh water cogeneration systems using refrigeration chillers

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ABSTRACT

Three power and fresh water cogeneration systems that combine a GT (gas turbine) power plant and a RO (reverse osmosis) desalination system were compared based on the exergy viewpoint. In the first system, the GT and RO systems were coupled mechanically to form a base system. In the second and third systems, a VCR (vapor-compression refrigeration) cycle and a single-effect $AC_{Water-LiBr}$ (water/lithium bromide absorption chiller) were used, respectively, to cool the compressor inlet air and preheat the RO intake seawater via waste heat recovery in the VCR condenser and $AC_{Water-LiBr}$ absorber. A parametric analysis-based exergy was conducted to evaluate the effects of the key thermodynamic parameters including the compressor inlet air temperature and the fuel-mass flow rate on the system exergy efficiency. Parameter optimization was achieved using a GA (genetic algorithm) to reach the maximum exergy efficiency, where the thermodynamic improvement potentials of the systems were identified. The optimum values of performance for the three cogeneration systems were compared under the same conditions. The results showed that the cogeneration system with the AC is the best system among the three systems, since it can increase exergy and energy efficiencies as well as net power generation by 3.79%, 4.21%, and 38%, respectively, compared to the base system.

1. Introduction

Power and fresh water are two important requirements that are simultaneously needed in many regions, climates, and industries. Water is available in large quantities on earth, but only a small amount is low enough in salinity for drinking and irrigation. Desalination of sea and brackish water is the main source of fresh water in regions suffering from scarcities of natural fresh water supplies [1,2]. The two most widely used desalination techniques are RO (reverse osmosis) membrane separation and thermal desalination systems, such as MED (multi-effect distillation) and MSF (multi-stage flash) [3,4]. The energy consumption of the RO desalination systems is less than thermal desalination systems which is only in the form of shaft work (electric power). GT (Gas turbine) and steam turbine power plants are widely utilized throughout the world for electricity generation. Design and construction of the GT power plants are simpler than those of the steam turbine and more useful in regions facing water scarcity. Therefore, coupling the GT power plants and the RO systems is known to be the simplest way to generate the power and fresh water, simultaneously [5,6].

In hot climates, the efficiency and power output of GTs can be enhanced by reducing the compressor inlet air temperature [7]. Different methods are used to cool the intake air of the GT compressor. These include evaporative coolers, spray inlet coolers or fogging systems, and mechanical vapor compression or ACs (absorption chillers) [8]. Evaporative coolers require a dematerialized water supply while compression and ACs use shaft work and heat as the energy input, respectively [7]. Therefore, compression chillers can be mechanically coupled to the GT by shaft and ACs can be thermally coupled to the GT power plant via waste heat recovery from the GT exhaust gases using a HRSG (heat recovery steam generator).

Recently, several studies [7–16] have been performed on utilizing evaporative cooling, mechanical vapor compression, and ACs to cool the compressor inlet air in the GT power plants. Popli et al. [7] investigated using the single-effect $AC_{Water-LiBr}$ (water/lithium bromide AC) for cooling the inlet air of the GT compressor, with particular applicability to Middle East countries. Khaliq and Dincer [12] applied exergy method to analyze the GT cycle cogeneration

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with inlet air cooling and evaporative aftercooling of compressor discharge. They reported that the inlet air cooling along with evaporative aftercooling has an obvious increase in the energy and exergy efficiency.

In compression and ACs, to continue the refrigeration cycle, the heat should be transferred to the environment, which can be recovered for many purposes. In the RO desalination systems, for constant fresh water production, the power consumption decreases with increase in feed water temperature. Because, increase in feed water temperature decreases both the osmotic pressure differential across the membrane and water viscosity [17]. Therefore, the waste heat of the refrigeration chillers can be recovered to preheat the RO feed water which lead to improve the RO performance.

A few studies [5,8] has recently been performed on preheating the RO feed water via waste heat recovery from other processes. Ataei et al. [5] investigated the effect of the preheating the seawater through the waste heat recovery from the VCR (vapor-compression refrigeration) cycle on the RO power consumption. Janghorban Esfahani et al. [8] proposed a new combined GT and RO desalination systems which uses a VCR system to cool the compressor inlet air and to preheat the RO feed water by waste heat recovery from the refrigeration system condenser.

According to the literature review, only the use of compression refrigeration chillers has been investigated in combined GT power plant and RO desalination systems. However, the use of ACs in combined GT and RO systems is scare.

Since GT power plants, refrigeration cycles, and RO desalination systems are energy-intensive industries, energy analysis is used to assess and improve their performance. In addition, exergy analysis needs to be used because energy analysis gives no information on how, where, and how much the system performance is degraded [18]. Exergy analysis usually aims to determine the maximum performance of the system and identify the equipment in which exergy loss occurs, and indicate the possibilities for thermodynamic improvement of the system [19].

Several studies have conducted exergy analysis for GTs, refrigeration, and RO desalination systems [18–37]. Dai et al. [22] performed an exergy analysis to guide thermodynamic improvement for a new combined power and refrigeration cycle. Gebreslassie et al. [23] performed an exergy analysis for single-, double-, triple-, and half-effect Water/Lithium bromide absorption cycles. They also determined the exergy efficiencies and exergy destruction rates for each system. As were investigated in the literature, recent research efforts have been focused on an exergy analysis of cogeneration systems but few studies on the exergy analysis of the combined power and fresh water systems integrated with refrigeration systems are scarce.

This study contributes to propose a new combined GT and RO desalination system which couples the GT and RO systems mechanically via the shaft of the GT and thermally via the AC. In the proposed structure the waste heat of the GT exhaust gases is recovered to generate steam as an energy source for the single-effect H_2O/LiBr absorption chiller ($AC_{H_2O-LiBr}$) system. The inlet air of the GT compressor is cooled using the evaporator, and the waste heat of the absorber is utilized to preheat the feed water of the RO system to decrease the power consumption of the combined system as a contribution of research. Also it is compared to two other combined GT and RO systems from the viewpoint of exergy to evaluate the capability value of the suggested system to increase the exergy efficiency than those of the two other systems.

This paper consists of three major parts. First, a thermodynamic model is developed to simulate and specify the thermodynamic properties of the systems. Second, exergy analysis is conducted to determine the exergy destruction in the components and exergy efficiencies of the systems. Also the effects of the two key parameters of the compressor inlet air temperature and the fuel-mass flow rate on the exergy efficiencies are investigated. Third, the optimal operating values of the parameters for maximizing exergy efficiency are obtained by using a GA (genetic algorithm), which can identify the thermodynamic improvement potentials of the systems.

2. Materials and methods

2.1. System configurations

The three systems under consideration are shown in Figs. 1–3. The base system (GT–RO system, Fig. 1) comprises two subsystems:

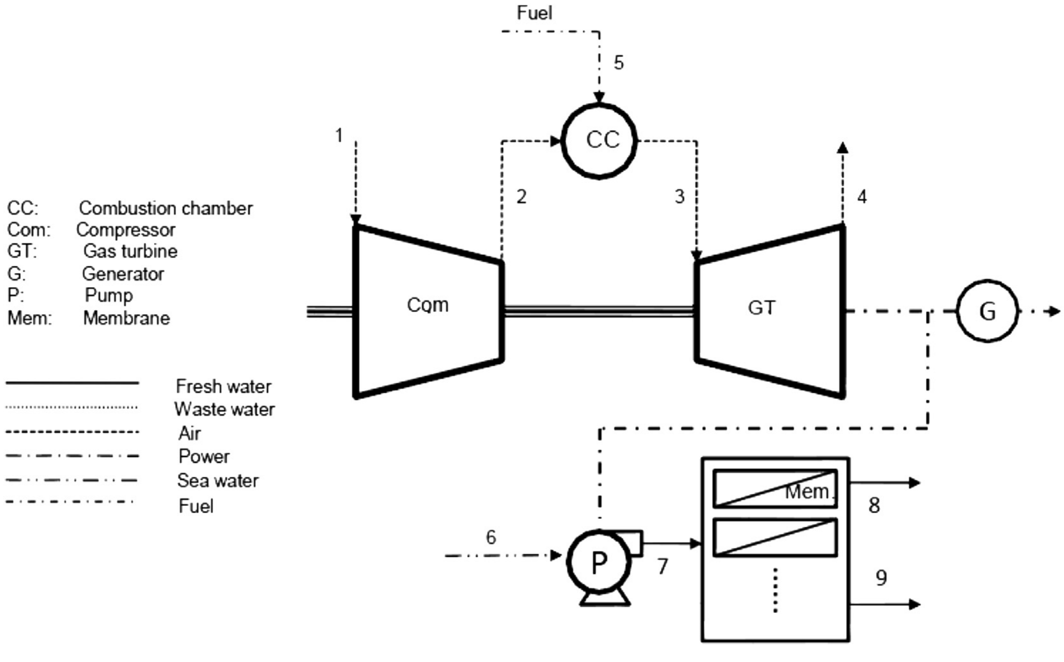

Fig. 1. Schematic of GT–RO system (first system) [6].

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