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A highly efficient combined multi-effect evaporation-absorption heat pump and vapor-compression refrigeration part 2: Thermoeconomic and flexibility analysis

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ABSTRACT

This paper continues Part 1 of our study and develops a thermoeconomic model of the system with low and high pressure compressors. The thermoeconomic model was used to assess the unit cost of the fresh water and cooling and to evaluate the flexibility of the system for fuel allocation from different electricity and heat energy sources. A parametric analysis was carried out to investigate the effects of the RR (refrigerant flow-rate ratio) from the high pressure compressor to the low pressure compressor of the VCR (vapor compression refrigeration) system, the price of steam, and the price of electricity on the product cost rate and the exergy efficiency of the system. The results showed that the system with two compressors had high flexibility to allocate the different energy sources when the availability of the sources was limited for a given value of fresh water and cooling production.

1. Introduction

Fresh water and refrigeration are two important products that are usually required simultaneously in many regions with hot and dry climates such as Middle Eastern countries. In order to decrease the product cost rate of fresh water and refrigeration production and to increase the performance of the fresh water and refrigeration production processes, a new configuration of a combined system has been introduced in Part 1 of this paper. This system combines the MEE-ABHP (multiple effects evaporation-absorption heath pump) desalination system with the VCR (vapor compression refrigeration) cycle. In Part 1 of this two-part paper, the energy and cost performances of the proposed combined systems with the refrigeration ratio values of 0, 0.5, and 1 were investigated and compared to the stand-alone MEE-ABHP, and VCR systems by developing model-based energy and cost. In Part 2 of this paper, since the combined system produces two products including fresh water and refrigeration the thermoeconomic model was developed in order to calculate the product cost rates to investigate the thermoeconomic performance and the flexibility of the system, which cannot be achieved by model-based energy and economics.

Thermoeconomics combines the principle of thermodynamics and economics in order to provide useful information on cost effective energy conversion systems that is not usually available through conventional energy and economic modeling [1]. The thermoeconomic approach is used to distribute the cost of the entire process onto the internal process streams based on exergy not energy. The monetary cost of the process streams, specifically the cost of product streams, in thermoeconomic analysis were calculated by the stream-cost equations that are arranged in a matrix form [2,3].

Recently, several researchers have studied thermoeconomic modeling of seawater desalination, refrigeration, and combined systems [1–11]. Farshi et al. [1] performed exergoeconomic analysis for the series flow double effect and combined ejector double effect systems in order to investigate and compare the influences of various operating parameters on the investment costs of the overall systems and the product cost flow rates. Hosseini et al. [2] considered the effects of equipment reliability in their thermoeconomic analysis of a combined power and multi stage flash water desalination plant. They developed an economic model according to the total revenue requirement method. Zare et al. [4] investigated and optimized the performance of an ammonia-water/cooling cogeneration cycle and they focused on the economic point of view. Their results showed that the sum of the unit costs of the cycle products obtained through thermoeconomic optimization

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was approximately 18.6% and 25.9% less than that in the cases when the cycle was optimized from the viewpoints of the first and second laws of thermodynamics, respectively. Wang and Lior [5] analyzed the thermal and economic performance of a LT-MEE (low temperature-MEE) water desalination system coupled with a LiBr–H_2O absorption heat pump. Their results showed that a 67–78% increase in water production over a stand-alone LT-MEE run in the same heat source conditions can be obtained due to the coupling. As noted in the literature, thermoeconomic analysis should be carried out to analyze the proposed system for better understanding of the system, because exergy reflects the measures of the processes.

This part of our two-part paper contributes to the thermoeconomic analysis of the combined MEE-ABHP-VCR system with low and high pressure compressors in order to investigate the thermo-economic performance and flexibility of the proposed system in fuel allocation from different energy sources. Part 2 of this paper consists of four major parts. First, the thermodynamic properties of the system were specified using the thermodynamic model developed in the first part of this paper. Second, exergy analysis was conducted in order to determine the exergy destruction, exergy loss, exergetic efficiency, and exergy destruction ratio as the energy performance criterion. Third, thermoeconomic analysis was conducted in order to calculate the thermoeconomic variables and to present the suggested design guidelines for potential cost-effective improvements for the system. Forth, the effects of the refrigerant flow-rate ratio from the low pressure compressor to the high pressure compressor (RR) and the price of the energy sources, including electric power and heat energy, on the product cost rates of the system were investigated in order to investigate the flexibility of the system for the allocation of the different energy sources.

2. Materials and methods

2.1. System configuration

The system presented in Fig. 1 was suggested as a replacement of a portion of the required energy for the MEE system with electric power. In the proposed system, the condenser of the VCR system was replaced with the MEE-ABHP desalination system in order to recover the waste heat from the VCR condenser as a heat energy source for the MEE system. For this purpose, a portion of the fresh water produced in the last stage of the MEE-ABHP system (which has lower pressure than the other stages) was used as a refrigerant for the VCR system. The refrigerant was expanded through the expansion valve (EV_2) and passed through the evaporator. The refrigerant coming from the evaporator was divided into two parts: one part was compressed by the low pressure compressor and sent to the absorber, and the other part was compressed by the high pressure compressor and sent to the tube side of the first stage of the MEE subsystem as an energy source. The high pressure compressor operated as a mechanical heat pump for the MEE subsystem, which could reduce the heat energy consumption of the MEE system and consume electric power instead of the motive steam flow rate in order to produce fresh water. Therefore, the combined system with two compressors had the flexibility to allocate heat energy and electric power energy as energy sources. The initial circumstances for operating and the thermodynamic parameters for the MEE-ABHP-VCR system presented in Fig. 1 are presented in Table 1.

2.2. Exergy analysis of the system

Exergy analysis is essential to identify the location, source, and magnitude of the true thermodynamic inefficiencies and to assess the thermoeconomic behavior of the energy converting systems [1,2]. Exergy can be divided into kinetic, potential, physical, and chemical exergies. Chemical exergy is an important part of exergy in combustion processes. Neglecting the kinetic and potential exergies, the physical exergy is defined as the theoretical maximum of the useful work obtained as a system interacts in the equilibrium state that is given by the following Eq. (1) [12]:

$$\dot{E}x_{ph} = \dot{m}\cdot((h-h_0)-T_0(s-s_0)), \quad (1)$$

where m is the mass flow rate, h is the specific enthalpy, s is the specific entropy, T is the absolute temperature (K), and (0) refers to

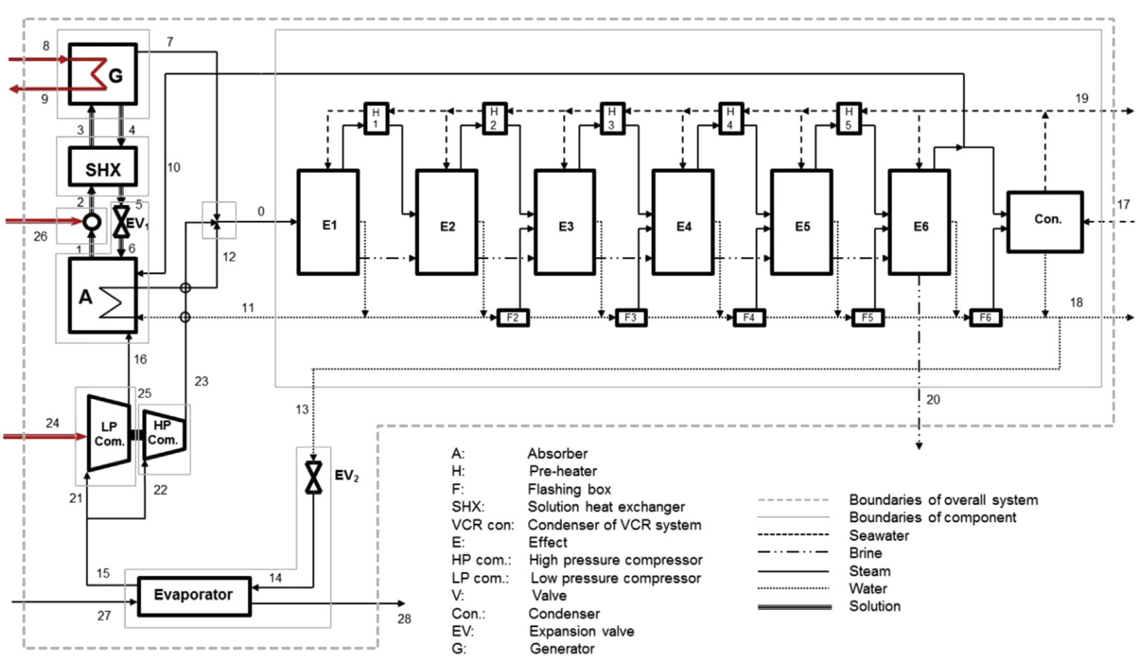

Fig. 1. Schematic of the proposed combined MEE-ABHP system with a VCR system with two compressors.

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