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Energy and exergy investigation of a novel double effect hybrid absorption refrigeration system for solar cooling

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ABSTRACT

The objective of this work is to present an energy and exergy analysis of a novel configuration of absorption cooling system operating at low enthalpy sources. The double stage cycle developed in the present work is operating with water-ammonia. In this investigation, modeling and simulation of the proposed configuration is attempted. Also, a thermodynamic model based on the energy and exergy balances is developed. The obtained numerical results obtained have been compared with those corresponding to the conventional machine. Great emphasis is given to the estimation of the refrigeration systems' performance, the exergy efficiency, the global exergy destruction in the system and the exergy destruction in each of the main components. The analyzed parameters are the coefficient of performance (COP), the irreversibility and the exergetic efficiency. The results of the study reveal that the performance of the novel configuration is better than that of the two stage conventional configuration. Besides, it allows a lower operating temperature, about 60–120 °C instead of 100–160 °C for the conventional cycle.

Introduction

The cooling and refrigeration cycles are mostly based on mechanically driven vapor compression. The cooling demand in countries with a hot climate leads to a peak in electricity consumption; consequently, the use of alternative technologies should be encouraged. One possibility consists in the modification of absorption cycles [1]. Their principal advantages compared to mechanically driven compression cycles are summarized to the following: a) no contribution to the destruction of the ozone layer and to the global warming effect because of the natural refrigerants use, b) little energy consumption, because the compression cycles are thermally driven (Herold et al., 1996; Ziegler, 2002) [2,3] and c) absence of moving parts in, some circulating pumps. Absorption cycles use a working couple consisting of a refrigerant and an absorbent. In generally being water-lithium bromide, (LiBr), or ammonia-water. The basic absorption cycle structure is the single effect, having four basic components: absorber, generator, evaporator and condenser. Absorption refrigerators are commercially available and perform stable operation under part-load conditions, but their coefficient of performance (COP) values are relatively low compared to vapor

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compression refrigerators (Lee SF and Sherif SA, 2001) [4]. However, combined cycles of vapor compression–absorption refrigeration system can provide high COP. Several works on combined cooling system or absorption refrigerator (mainly on the cooling performance analysis and optimization) have been carried out (Lee SF and Sherif SA, 2001; Arora and S.C.Kaushik, 2009) [4,5]. In general, performance analysis of these systems is investigated using energy analysis method, based only on the first law of thermodynamics (energy balance) by means of the coefficient of performance (COP). Unfortunately, this approach is of limited use in view of the fact that it fails to make out the real energetic losses in a refrigerating system. For example, it does not identify any energetic losses occurring during the throttling process though there is a potential pressure drop and this can be predicted only through entropy or exergy analysis. Distinction between reversible and irreversible processes was first introduced in thermodynamics through the concept of 'entropy' (Dincer and Cengel, 2001) [6]. Thus, in contrast to energetic approach, the exergy analysis, which takes into account both the first and the second thermodynamics laws, assists the evaluation of the magnitude of the available energy losses in each component of the refrigeration system and the worth of energy from a thermodynamic point of view. In thermal design decisions, utilisation of the second law of thermodynamics is very well referenced (Bejan, 1994, 1995, 1996) [7–9]. In addition, the exergy analysis allows explicit presentation and improved comprehension of thermodynamic processes by quantifying the effect of irreversibility occurring in the system along with its location. Some studies have carried out exergy analysis (Lee SF and Sherif, 1999; .Ravikumar et al., 1998) [10,11] pertaining to single, double and multiple-effect absorption refrigerating systems that usie $LiBr/H_2O$ or NH_3/H_2O (Anand and Kumar, 1987) [12], in these three last references was carried out irreversibility analysis of single and double-effect systems under the following conditions: condenser and absorber temperatures 37.81 °C, evaporator temperature 7.21 °C and generator temperature 87.81 °C for the single-effect and 140.61 °C for the double-effect system. In these studies, there was neither computed the optimum generator temperature nor calculated the exergetic efficiency for the operation of series flow double-effect system. (Lee and Sherif, 1999) [10], have presented the second law analysis of various double-effect lithium bromide–water absorption chillers and computed the COP and the exergetic efficiency as well. It is obvious from literature that exergy investigation as regards compression–absorption heat pumps has not been carried out. This motivates the present investigation.

In the present study, energy and exergy analysis of a novel two stages hybrid heat pump based on NH3/H2O, has been carried out. All energetic and exergetic results are compared to those of the two stages absorption heat pump. The analysis also brings out the effects of generators, absorbers, evaporator, condenser, compressor and solution heat exchangers on the various performance parameters. The effects of the compressor discharge pressure and the generator temperature on system performances are examined. Exergy loss of each component of the heat pump was evaluated for several working conditions.

Heat pump cycle description

The heat pump, subject of this study, is a combination between the two conventional absorption stages (two absorbers, two generators, condenser and evaporator) and the compression one. A compressor is injected into the cycle, upstream the absorption part, in order to ameliorate the absorption process as was brought by Bouaziz et al. (Bouaziz et al., 2011) [13] (Fig. 1).

The system works above three pressure levels. The vapor refrigerant coming from the first generator (6) with intermediate pressure (P_1) is compressed by an isentropic transformation (6C) to an intermediate pressure (P_2) and then, it is reinserted into the second absorber. The rich solutions from absorbers (2) and (7) are heated by the poor solution originating from the generators (4) and (9) via heat exchangers inter-solution. The condenser and the second generator operate at the third pressure level (P_{CD}).

This installation has two generators operating at the same temperature (T_{GE}), two absorbers and a condenser working at the same temperature (T_{CD}) besides an evaporator and inter-solutions heat exchangers.

The evaporator and the first absorber (AB1) operate at the same pressure (P_{EV}), the first generator (GE1) operates at higher pressure (P1) which is increased by the compressor, so the second absorber operates at a second intermediate pressure (P2). Finally, the second generator and the condenser are operating at the highest pressure (P_{CD}).

Energy and mass balances

The mass balance for the two stages, governing the three present substances: weak solution, rich solution and refrigerant gas gives:

$$\dot{m}_{NH3} = \dot{m}_{NH3i} \tag{1}$$

The rich and poor solution flow rates are given by Equations (2) And (3):

$$\dot{m}_{SRi} = f_i \dot{m}_{NH3i} \tag{2}$$

$$\dot{m}_{SPi} = (f_i - 1)\dot{m}_{NH3i} \tag{3}$$

Energy balance for each installation component is presented by Equations (4)–(9):

$$\dot{Q}_{CD} = \dot{m}_{NH3}(h_{12} - h_{11}) \tag{4}$$

$$\dot{Q}_{EV} = \dot{m}_{NH3}(h_1 - h_{12}) \tag{5}$$

$$\dot{Q}_{GE1} = (f-1)\dot{m}_{NH3}h_4 + \dot{m}_{NH3}h_6 - fh_3 \tag{6}$$

$$\dot{Q}_{GE2} = (f-1)\dot{m}_{NH3}h_9 + \dot{m}_{NH3}h_{11} - fh_9 \tag{7}$$

$$\dot{Q}_{AB1} = fh_2 - (f-1)\dot{m}_{NH3}h_5 - \dot{m}_{NH3}h_1 \tag{8}$$