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Performance analysis of a heat engine driven combined vapor compression–absorption–ejector refrigerator

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Abstract

An endoreversible heat engine driven refrigeration cycle based on the combination of an absorption cycle with vapor and ejector compression cycles is described. This integration maximizes the performance of the conventional ejector and absorption cycles and provides high performance for refrigeration. The analysis shows that the combined cycle has a significant increase in system performance over the heat engine driven vapor compression refrigerators and heat engine driven combined vapor compression and absorption refrigerators. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

In order to raise the availability of energy sources, decrease the environmental pollution of high temperature waste heat and develop high performance systems, combined refrigeration cycles have been adopted by the HVAC and R industry. There are three main types of refrigeration systems: vapor compression, absorption and ejector compression. Investigations show that vapor compression cascading is useful where large temperature ranges are encountered [1]. Optimal performances of an endoreversible and irreversible two stage vapor compression refrigerator (VCR) cycles are investigated by many authors [2–5]. Absorption refrigerator (AR) and ejector refrigerator (ER) cycles are three heat source systems, and they exhibit continuous and stable operation under part load conditions from 0 to 100%. Compared with the VCR cycle, they have the advantage of using thermal energy from waste

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heat and other low grade heats. The theory and technology of AR and ER cycles have been developed in recent years [6–22]. While the coefficient of performance (COP) of a VCR cycle is typically 2–4, the COPs of AR and ER cycles are in the ranges 0.5–0.8 and 0.2–0.5, respectively. For enhancing the COP and cooling capacity of thermal energy powered systems, combined AR/ER, VCR/AR and VCR/ER cycles are suggested by many authors [23–28]. The heat engine (HE) driven VCR systems generally consume electric energy with the consequences of emission of large amounts of CO_2 and NO_x. Also, the COP values for HE driven VCR systems are relatively low compared with combined refrigeration cycles [29,30]. From the literature survey, it appears that none of the previous investigations concerned a HE driven combined VCR/AR/ER system for refrigeration to improve performance. In the present study, the optimum performance of an endoreversible HE driven combined VCR/AR/ER cycle is investigated. For this purpose, we define a cyclic model which includes the irreversibility resulting from the finite rate of heat conduction and use it for optimization of performance.

2. Theoretical model

A reversible HE driven combined VCR/AR/ER system consists of a Carnot HE, a Carnot VCR, a Carnot AR and a Carnot ER, with the condenser and absorber of the AR unit discharging their heat to the evaporator of the VCR and generator of the ER units, respectively. Fig. 1 shows the functional schematic of this device. The Carnot HE drives both the VCR and AR units and operates between the high temperature heat source at temperature T_H and the heat sink (generator of the AR unit) at temperature T_G. The Carnot VCR unit operates between the heat source (condenser of the AR unit) at temperature T_C and the heat sink at temperature T_0. The Carnot AR unit drives the Carnot ER unit and is composed of a generator, an absorber, a condenser and an evaporator at temperatures T_G, T_A, T_C and T_L, respectively. The Carnot ER unit is composed of a generator, a condenser and an evaporator at temperatures T_A, T_0 and T_L, respectively. According to Fig. 1, we obtain the overall COP of this reversible combined system as

$$\varepsilon_r = \left(\dot{Q}_7 + \dot{Q}_9\right)/\dot{Q}_1 = \eta_{1r}\left(1 - \eta_{2r}\right)\left(1 - \eta_{3r}\right)\beta_{1r} + \left(\beta_{2r}/\beta_{3r}\right)\beta_{4r}\eta_{3r} \quad (1)$$

where η_{1r} and η_{2r} are the thermal efficiencies of the power sub-cycles of the Carnot ER and AR units, respectively. η_{3r} is the thermal efficiency of the Carnot HE. β_{1r} and β_{2r} are respectively, the COPs of the refrigeration sub-cycle of the Carnot ER and AR units. β_{3r} is the COP of the heat pump sub-cycle of the Carnot AR unit and β_{4r} is the COP of the Carnot VCR unit. Fig. 1 yields

$$\eta_{1r} = (T_A - T_0)/T_A; \qquad \eta_{2r} = (T_G - T_A)/T_G \quad (2)$$

$$\eta_{3r} = (T_H - T_G)/T_H; \qquad \beta_{1r} = T_L/(T_0 - T_L) \quad (3)$$

$$\beta_{2r} = T_L/(T_C - T_L); \qquad \beta_{3r} = T_C/(T_C - T_L) \quad (4)$$