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Research paper

Performance comparison between a conventional vapor compression and compression-absorption single-stage and double-stage systems used for refrigeration

D. Colorado [a, *], W. Rivera [b, *]

[a] Centro de Investigación en Recursos Energéticos y Sustentables (CIRES), Universidad Veracruzana (UV), Av. Universidad km 7.5, Col. Santa Isabel, C.P. 96535 Coatzacoalcos, Veracruz, Mexico
[b] Instituto de Energías Renovables, Universidad Nacional Autónoma de México (UNAM), 62580 Temixco, Morelos, Mexico

HIGHLIGHTS

- A compression-absorption double-stage (CADS) system is by the first time proposed.
- The compression power in cascade cycles was 45% lower than in compression cycles.
- The COP for proposed system was up to 45.2% higher than those with other systems.
- The systems operating with R134a achieved higher COP than those obtained using CO_2.
- The irreversibilities for the CADS using R134a were 17% lower than using CO_2.

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ABSTRACT

This study reports a comparison from the first and second law of thermodynamics of a conventional vapor compression cooling system, a compression-absorption single-stage (CASS) system, and a compression-absorption double-stage (CADS) system operating with CO_2 and R134a in the compression cycle and H_2O/LiBr in the absorption cycles. The CADS system is being by the first time proposed in the literature. The performance of the systems were analyzed as function of diverse operating parameters. It was found that the electrical energy consumption in the refrigeration cycles was about 45% lower than in the classical compression refrigeration cycles using CO_2 and R134a as refrigerants under the same operating conditions. The results showed that the COP for the CADS could be 50% higher than those obtained with the CASS system. The systems operating with R134a always achieved higher COP than those obtained using CO_2. From the exergy analysis it was clear that the highest irreversibilities occurs in the absorber and the evaporator for both mixtures. It was also found that the irreversibilities of the proposed system using R134a in the compression cycle were 17% lower than those obtained with the system using CO_2

1. Introduction

Cascade refrigeration cycles have been proposed for low temperature applications ranging from food conservation and ice production to cryogenics. A two-stage cascade compression refrigeration system was presented as an option to meet those applications. Lee et al. [1] studied the optimal condensing temperature and maximum coefficient of performance for carbon dioxide-ammonia cascade refrigeration cycle by means of a thermodynamic analysis. Bhattacharyya et al. [2] presented a cascade cycle operating with propane in the low cycle and carbon dioxide in the transcritical cycle. They demonstrated that the carbon dioxide–propane cascade system offers a wider operating range for simultaneous heating and cooling applications compared with that provided by the carbon dioxide–ammonium cascade system. This cascade system can operate simultaneously with a refrigerating space temperature of 233 K and a heating output temperature of about 393 K. Colorado et al. [3] compared the performance of NH_3, CO_2, butane and propane as a working fluids in the two-stage

* Corresponding authors.
E-mail addresses: dcolorado@uv.mx (D. Colorado), wrgf@ier.unam.mx (W. Rivera).

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cascade compression system for simultaneous cooling and heating. According to the authors, R134a refrigerant at low temperature cycle and carbon dioxide at high temperature cycle configuration seems to be a better alternative for industrial applications in comparison with the other cycles evaluated.

A compression-absorption cascade cycle was proposed to reduce electrical energy consumption for refrigeration applications. Fernández-Seara et al. [4] presented a study to analize a compression-absortion cascade system from the view point of the first law of thermodynamics and cogeneration with exhaust gasses up to 873 K. Cimsit and Ozturk [5] compared the performance of the compression-absorption cascade system using ammonia, R134a and R410A as refrigerants in the low temperature cycle, while LiBr/H_2O and NH_3/H_2O were used as working fluids in the high temperature cycle. The numerical results showed a reduction of the compressor work up to 52% if R134a and LiBr/H_2O were used in the compression-absorption cascade system compared with a classical vapor compression system using R134a. Garimella et al. [6] developed a computational model of a cascade absorption–vapor compression system with a high temperature lift in order to provide different levels of temperature: low temperature refrigeration, space conditioning and water-heating applications in a naval ship. Jain et al. [7] studied a thermodynamic model for cascade vapor compression–absorption system (CVCAS) has been developed which consists of a vapor compression refrigeration system (VCRS) coupled with single effect vapor absorption refrigeration system (VARS) based on first and second laws. The results showed that the electric power consumption in CVCAS is reduced by 61% and COP of compression section is improved by 155% with respect to the corresponding values pertaining to a conventional VCRS. Also, Jain et al. [8] thermodynamically analyzed VCAS (vapor compression-absorption system) with carbon dioxide (compression section) and ammonia-water (absorption section) as refrigerants and determined the optimal condensing temperature of cascade condenser using modified Gouy-Stodola equation. The optimum cascade condenser temperature maximises the overall COP, rational efficiency and minimises the total irreversibility rate of the VCAS system. Cimsit et al. [9] presented the thermoeconomic optimization of LiBr/H2O-R134a compression-absorption cascade refrigeration cycle. The analysis pointed out that the evaporator and solution heat exchanger should be designed carefully according to the exergoeconomic factor values. Xu et al. [10] developed a novel absorption-compression cascade refrigeration system, which can reach an evaporating temperature of −170 °C. In the cascade system, the refrigerant of compression subsystem (CS) is subcooled by the refrigerant of low-grade heat driven absorption subsystem (AS) to reduce the electric power consumption. Theoretical and experimental investigations were carried out over the CS evaporating temperature ranging from −100 to −170 °C. Jain et al. [11] addressed the size and cost estimation of vapor compression–absorption cascaded refrigeration system (VCACRS) for water chilling application taking R410a and water–LiBr as refrigerants in compression and absorption section respectively. The results showed that the cascading of compression-absorption systems becomes attractive for lower rate of interest and increase life span and operational period.

On the other hand, double-stage absorption systems have been studied by several authors. Arun et al. [12] presented the performance analysis of a double-effect in series LiBr/H_2O absortion system in which all the vapor generated at the high pressure generator is fully condensed at the low pressure generator. Garousi et al. [13] carried out first and second law analyses for series, parallel and reverse parallel double-effect absorption refrigeration

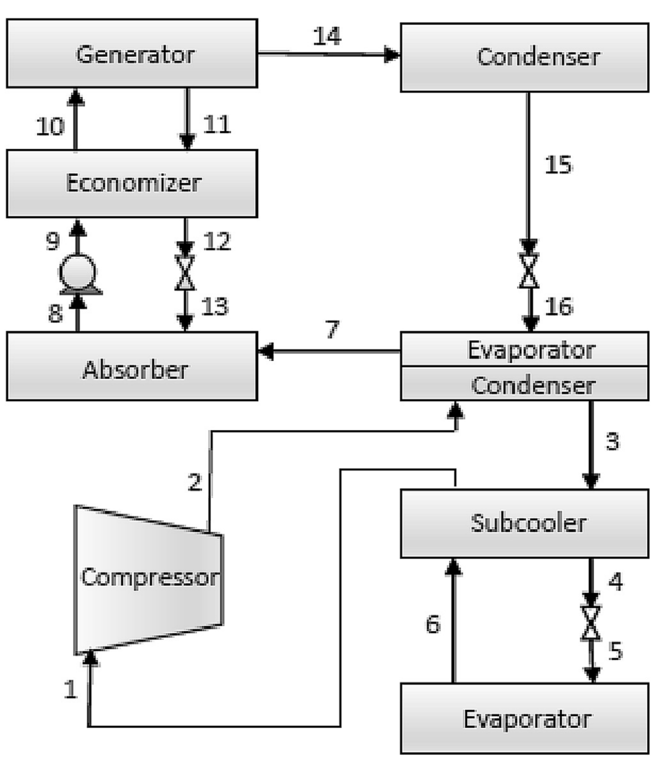

Fig. 1. Schematic diagram of the compression-absorption single-stage cascade system.

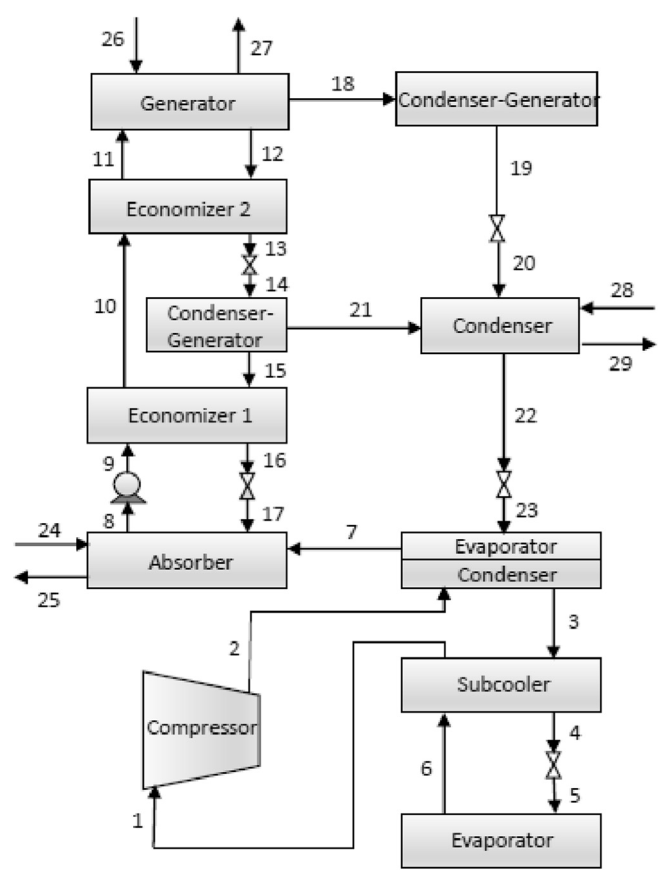

Fig. 2. Schematic diagram of the compression-absorption double-stage cascade system.