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Optimum design of ejector refrigeration systems with environmentally benign fluids

Abdelouahid Dahmani [a], Zine Aidoun [b], Nicolas Galanis [a,*]

[a] Génie Mécanique, Université de Sherbrooke, Sherbrooke, QC J1K2R1, Canada
[b] CanmetENERGY, Natural Ressources Canada, 1615 Lionel Boulet, C.P. 4800, Varennes, QC J3X 1S6, Canada

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ABSTRACT

A design methodology for simple ejector refrigeration systems of fixed cooling capacity operating with fixed temperatures of the external fluids entering the generator, the condenser and the evaporator is presented and applied for a particular combination of these four parameters. The results establish the existence of optimum values for the refrigerant pressure in the generator (P_G) and the temperature difference in the heat exchangers (ΔT) which minimize the total thermal conductance of the system. These optimum values of P_G and ΔT are particularly interesting since they yield high values for the coefficient of performance and the exergetic efficiency of the system. They have been determined for four refrigerants (R134a, R152a, R290, and R600a). An objective function, which to a first approximation is proportional to the product of the capital and operational costs, is defined and used to compare the performance of the system with these refrigerants.

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1. Introduction

Cooling in industrial processes, air-conditioning of buildings and refrigeration of perishable products are common practices throughout the world. In industrialized countries the energy consumption of such installations, used to create and maintain relatively low temperatures, represents an appreciable part of the corresponding total. In Canada, for example, approximately 10% of the total annual energy consumption is used for such operations.

The systems used to achieve heat removal from a low temperature reservoir are driven either mechanically (e.g. compression of vapor refrigerants) or thermally (e.g. absorption systems or ejector driven systems). The former constitute the vast majority of industrial, commercial and residential installations but the latter are attracting a lot of interest since they can be activated by low temperature renewable energy sources (e.g. solar) or industrial waste heat. Absorption systems use a combination of two fluids and have been commercially available for several decades but are quite complex due to the simultaneous heat and mass transfer processes in the absorber and desorber. Furthermore, the fluid combinations used in absorption systems are very limited in number. On the other hand, ejector systems use a single fluid and thus offer great flexibility and promise for the replacement of environmentally unacceptable refrigerants by benign ones. However, except for one very recent automotive application, ejector systems are not available commercially.

The father of ejector technology is Charles Parsons who used them to extract the air from the condensers of steam engines but their first application in refrigeration was introduced in 1910 by Maurice Leblanc as indicated by Chunnanond and Aphornratana [1] who compiled a review of studies on ejectors and their application in refrigeration. The first model of the transformations taking place in the ejector was published by Keenan et al. [2] who used the one-dimensional equations of mass, momentum and energy conservation assuming perfect gas behavior and isentropic expansion. This approach does not reflect the complexities due to real fluid properties. Thus, for example, the entrainment ratio of an ejector does not depend on the ratio of the primary to secondary total pressures, as predicted by perfect gas theory, but on the individual values of these pressures [3,4]. Therefore, recent numerical studies [5–8] use real fluid thermophysical properties for the design of ejectors and the prediction of the off-design performance of ejector refrigerators.

Aidoun and Ouzzane [5] used a one-dimensional, adiabatic, compressible fluid model and the NIST database and subroutines for the refrigerant properties to investigate operation at design and

* Corresponding author. Tel.: +1 819 821 7144; fax: +1 819 821 7163.
E-mail addresses: Abdelouahid.dahmani@USherbrooke.ca (A. Dahmani), zaidoun@nrcan.gc.ca (Z. Aidoun), Nicolas.galanis@usherbrooke.ca (N. Galanis).

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