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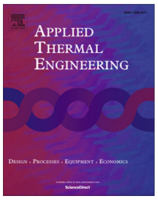

Research Paper

Thermodynamic investigation of a booster-assisted ejector refrigeration system

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HIGHLIGHTS

- COP based on thermal input increases with booster outlet pressure.
- Both entrainment ratio and area ratio increase with booster outlet pressure.
- COP based on work is larger than compressor-based refrigeration system.
- An optimum booster outlet pressure obtains maximum COP based on work.
- Exergy destruction occurs mainly in ejector, condenser, evaporator and generator.

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ABSTRACT

In order to improve performance of ejector refrigeration system, a booster is added before an ejector to enhance secondary flow pressure, which is called a booster assisted refrigeration system. Based on mass, momentum and energy conservation, a 1D model of ejector for optimal performance prediction was presented and validated with experimental data. A detailed study of working characteristics of the booster assisted ejector refrigeration system was carried out and compared against conventional ejector refrigeration system and compressor based refrigeration system, on the basis of first and second laws of thermodynamics. Effects of booster outlet pressure on COP_{th} based on thermal energy and COP_w based on work input, and also on entrainment ratio and area ratio of ejector were studied. The exergy destruction rates were also computed and analyzed for components of the booster-assisted ejector refrigeration system. Ways to reduce exergy destruction were discussed.

1. Introduction

Compressor based Refrigeration System (CRS) is most widely used in air conditioning and refrigeration. Conventional Ejector Refrigeration System (ERS) is similar to CRS except that the compressor is replaced by an ejector and a generator is used to provide driving force through heat input, as shown in Fig. 1.

Ejector Refrigeration System (ERS) is a promising way to utilize sustainable energy like solar energy, geothermal energy, and low grade heat energies, which are easily available from sources such as automobiles and industrial processes [1–4]. However, the low Coefficient of Performance (COP) of ejector systems in comparison to mechanical compression systems is considered a barrier, but a gradual increase was seen with the development of ejector refrigeration technology (COP up to 0.689) [1–3].

Since the early 50 s, numerous studies have been carried out to improve the understanding of ejector processes and performance. Keenan and Neumann [5] introduced a constant-pressure mixing model and a constant-area mixing model. Munday and Bagster [6] further developed the constant-pressure mixing model by assuming that the primary fluid fans out without mixing with the secondary fluid immediately after discharging through the nozzle exit, which forms a “hypothetical -throat” for the entrained fluid. Later, Eames et al. [7] studied a small-scale steam jet refrigerator and built a model capable to predict 85% of the experimental data. Huang et al. [8] performed a 1D analysis of ejector performance by assuming double-choking before mixing for both primary flow and secondary flow. They also pointed out that 1D analysis could be treated as semi-empirical because all the ejector efficiencies were based on experience. Zhu et al. [9] proposed a 2D exponential expression for velocity distribution to approximate the

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Nomenclature

A_t	cross section area of ejector nozzle throat
A_m	cross section area of ejector mixing chamber
Ar	area ratio
COP	coefficient of performance
c	speed of sound (m s^{-1})
h	specific enthalpy (kJ kg^{-1})
M	Mach number
P	pressure (kPa)
Q	quantity of heat (kW)
R	gas constant (kJ kg^{-1} K^{-1})
s	specific entropy (kJ kg^{-1} K^{-1})
T	temperature (°C)
u	velocity (m s^{-1})
W	power (kW)

Greek letters

η	coefficient of isentropic efficiency
κ	gas specific heat ratio
ρ	refrigerant density
φ_m	mixing loss factor
ω	entrainment ratio

Subscripts

b	booster
c	condensation
e	evaporation
g	generator
p	pump
sat	saturation
s	isentropic
t	throat
th	thermal
W	work
1–11	state points

viscosity flow near the ejector inner wall, by introducing a "shock circle" at the entrance of the constant area chamber. An ejector model for evaluating the optimum performance of an ejector refrigeration system was proposed by Chen et al. [10] by taking into consideration the mixing pressure and the shock process. Chen et al. [11] also carried out a detailed investigation of ejector working characteristics by using R141b, R245fa and R600a. A global state-space modeling approach was adopted by Xue et al. [12] for dynamic response and real time control of ejector refrigeration system in a simpler form.

All the aforementioned research are mainly about ejector modeling, and many investigations of enhanced ejector refrigeration cycles and their combination with other thermodynamic cycles were also carried out to improve system performance. Sokolov and Hearshgal [13] proposed three compression enhanced ejector refrigeration cycles: (1) booster assisted ejector cycle; (2) hybrid compressor and ejector cycle; (3) combined booster, compressor and ejector cycle. Yu et al. [14] proposed a new ejector refrigeration system with an additional liquid–vapor jet pump added between ejector and condenser to reduce back pressure of ejector. Later on Yu and Li [15] proposed another ejector refrigeration system by applying mechanical-subcooling with an additional liquid–gas ejector in the system to improve system performance. Yu et al. [16] also proposed a regenerative ejector refrigeration cycle with COP improvement from 9.3% to 12.1%. Zhu and Jiang [17] proposed a hybrid vapor compression refrigeration system with an ejector cooling cycle driven by waste heat from condense to improve system COP by 9.1%. Yan et al. [18] conducted an experimental study on a combined ejector-vapor compression cycle connected via a subcooler with relatively high COP improvements (15.9–21.0%). A hybrid A/C system composed of an ejector refrigeration cycle and a compressor based refrigeration cycle driven by automobile exhaust waste heat was conceived by Wang et al. [19]. Results showed that the hybrid system can significantly enhance the performance of the automobile A/C systems (35.2–40%). Habibzadeh et al. [20] proposed a thermal system which combines an organic Rankine cycle and an ejector refrigeration cycle using different working fluids. The above studies prove that ejector refrigeration cycle combined with other thermo-cycles will be a good way to achieve performance improvement.

Originally proposed by Sokolov and Hearshgal [13], a schematic diagram of the Booster-assisted Ejector Refrigeration System (BERS) is shown in Fig. 2. Compared with ERS in Fig. 1, a booster is added before the ejector to enhance the pressure of secondary flow. In Fig. 3, *P–H* diagrams for both ERS and BERS are sketched.

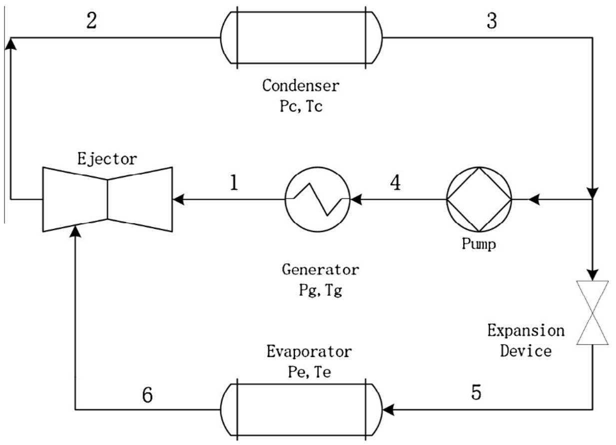

Fig. 1. Conventional ejector refrigeration system (ERS).

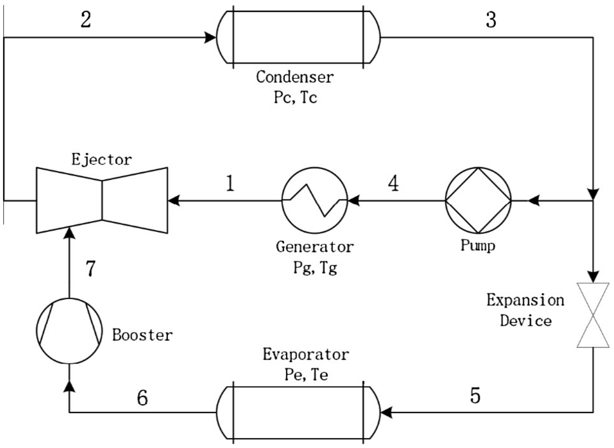

Fig. 2. A booster-assisted ejector refrigeration system (BERS).