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1D Computational model of a two-phase R744 ejector for expansion work recovery

Krzysztof Banasiak [a,*], Armin Hafner [b]

[a] Institute of Thermal Technology, Silesian University of Technology, Konarskiego 22, Gliwice 44-100, Poland
[b] SINTEF Energi, Kolbjørn Hejes v. 1D, Trondheim 7465, Norway

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ABSTRACT

A one-dimensional mathematical model of the R744 two-phase ejector for expansion work recovery is presented in this paper. Governing equations were formulated for all passages of the ejector based on the differential equations for mass, momentum, and energy balance as well as a differential representation for the equation of state. For two-flow sections (mixer and diffuser) closing equations for mass, momentum and energy transfer between the primary and secondary flow were introduced. This model utilises the Delayed Equilibrium Model along with the Homogeneous Nucleation Theory for the purpose of the metastable state analysis for a transcritical flow with delayed flashing over the motive nozzle. The thermal properties model was based on a real fluid approach, where the REFPROP 8.0 database was used. Based on the results of experimental tests performed at SINTEF Energi Laboratory, the model was validated for a typical range of operating conditions. The range of available simulation output allowed for the creation of 1D profiles of local values for the flow variables and the computation of the overall indicators, such as pressure lift and expansion work recovery efficiency.

1. Introduction

Two-phase ejectors have constituted an attractive alternative for classic expansion devices for several decades. The main advantage of the ejector may be found in the recovery of the expansion work normally wasted in throttling processes at a typical expansion valve. Nevertheless, proper design of a two-phase ejector for the expansion work recovery requires a detailed analysis in terms of both the numerical simulations and the experimental work. Over the last 20 years, significant effort was invested in the development of computational codes capable of assessing the key features of the two-phase ejector performance, i.e., entrainment and pressure ratios along with the profiles of pressure, velocity and density. However, the capabilities of commercially available computational tools for the mathematical modelling of two-phase ejectors are still quite limited.

The vast part of the scientific outcome reported in journal papers concerned steady state, zero-dimensional (0D) or pseudo one-dimensional (1D) models of the ejection cycle. Balamurugan et al. [1] provided and validated a 0D semi-empirical model of a gas-water ejector, taking into account the compressibility of air and the overall pressure losses of a two-phase mixture. Selvaraju and Mani [2] and Nehdi et al. [3] showed a design mode, pseudo 1D (inlet-outlet conditions) theoretical analysis of a two-phase ejector cycle for several chlorofluorocarbons and hydrofluorocarbons. In their work, the real fluid properties were calculated based on data from the REFPROP database. Cizungu et al. [4] performed a pseudo 1D design and off-design numerical analysis for ammonia and ammonia–water two-phase ejectors. In addition, the authors optimised the ejector geometry to achieve maximum values for either the entrainment ratio or the pressure ratio. Lear et al. [5] simulated choking conditions in a two-phase R134a ejector using pseudo 1D equations of the conservation for mass, momentum and energy, and equations of thermodynamic processes for characteristic cross sections of the passage. A brief review of those and other influential articles may be found in the paper of Hemidi et al. [6].

The authors of the aforementioned papers took into account all of the required geometrical parameters of the ejector along with assumed values of the integral coefficients, such as isentropic efficiencies, for all of the passages. As a result, they were able to perform the off-design analysis and to determine the operating characteristics of the ejector in this mode, e.g., Cizungu et al. in [4]. However, the governing algebraic equations for velocity, pressure, density, enthalpy and cross-section area of the duct did not allow for the evaluation of local field quantities.

* Corresponding author. Tel.: +48 32 237 10 19; fax: +48 32 237 28 72.
E-mail address: krzysztof.banasiak@polsl.pl (K. Banasiak).

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