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Research Paper

# Assessment and prediction of component efficiencies in supersonic ejector with friction losses

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## HIGHLIGHTS

- Efficiencies of each part in ejector are investigated by considering friction losses.
- Friction in different components represent diverse impacts on ejector efficiency.
- An efficiency assessment correlation is established.
- Proposed correlation benefits for ejector refrigerant system design.

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## ABSTRACT

In this paper, the influences of friction losses on ejector efficiencies are investigated by the computational fluid dynamics (CFD) technique. Roughness values factor is introduced to analyze ejector performance by considering the components efficiencies. Efficiencies of each component are assessed with different levels of roughness. Validation is given through comparisons between the calculated and experimental values obtained from the ejector refrigerant platform with diverse levels of surface roughness. Results indicate that the efficiency of the ejector decreases with the increase of roughness values and friction losses in constant-area section and diffuser have the most significant impact on ejector performance. By analyzing the relationship between efficiencies and roughness values, an efficiency correlation is built with a coefficient of determination over 0.9654. It is shown that proposed correlations for ejector component efficiencies can be utilized more accurately in system design of ejector based refrigerant system considering the friction losses.

## 1. Introduction

With the ongoing increase of refrigeration demands and environmental deterioration, novel and energy efficient technologies are attracting more attention. The ejector refrigeration system (ERS) is currently considered as one of the most innovative and promising technologies in the area of refrigeration, due to its simple structure, low energy consumption, and reliability.

Since it was first realized that the major weak point of an ERS is its relatively low COP (coefficient of performance), when compared with conventional refrigeration systems. An enormous amount of numerical, experimental and theoretical studies were performed to enhance ejector performance and to establish the ERS as being more economically attractive.

In recent years, the computational fluid dynamics (CFD) method has been widely employed to numerically investigate complex transonic flow inside the ejector. Rusly et al. [1] discovered that the maximum entrainment ratio (Er, the ratio between the secondary and primary mass flow rates.) occurs just before a shock-wave; thus, the nozzle position is an important design parameter for the ejector. Ariafar et al. [2,3] presented a simulation method to research the mixing layer effects on the Er under different conditions. Above researches demonstrate that the CFD is a reliable method to study and simulate the fluid flow in ejector. However, there can be certain errors between the simulation results and experimental data. Hemidi et al. [4,5] compared the classical K-ε model with the K-ε-sst model with an air ejector and the overall deviation of the Er was below 10%, as compared with experimental data. Comparisons were also made between results from experiments, such as the CFD model and a theoretical 1-D model by Ouzzane and Aidoun [6]. The results confirmed that the CFD model provided a more acceptable agreement (difference of less than 16%) than the 1-D model. Nevertheless, one important factor, the roughness of the ejector, has been ignored by most ejector simulations which may have caused aforementioned errors.

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## Nomenclature

| | |
|---|---|
| P | pressure, Pa |
| E,Q | total energy, J |
| T | static temperature, K |
| R | determination coefficient |
| S | entropy |
| d | diameter |
| $\dot{m}$ | mass flow rate |
| h | specific enthalpy |
| $\rho$ | density, kg m$^{-3}$ |
| $\alpha$ | thermal conductivity, W m$^{-1}$ k$^{-1}$ |
| $\delta_{ij}$ | growth rate of mixing layer |
| u | dynamic viscosity, N s m$^{-2}$ |
| $\varepsilon$ | entrainment ratio |
| $\mu$ | roughness value, mm |
| $\eta$ | efficiency |
| $\Gamma$ | mass generation rate, kg m$^{-3}$ s$^{-1}$ |

*Abbreviations*

| | |
|---|---|
| Er | pressure, Pa |
| Rv | roughness value, $\mu$ |
| RE | static temperature, K |
| R | determination coefficient |

*Subscripts*

| | |
|---|---|
| eff | effective |
| is | isentropic |
| CSA | constant-area section |

A similar situation occurs in the field of enhancing system performance through experimentally optimizing ejector geometry. For example, Jia et al. [7,8] presented an experimental investigation regarding the effects of six key geometric dimensions on the performance of an ejector refrigeration system and designed a high efficiency ejector based on their simulations and experiments. Yapici et al. [9] also studied the performance of R123, using six configurations of the ejector, covering a range of the ejector area ratio from 6.5 to 11.5. Based on these Refs. [7–13] it can be concluded that fractional changes of the geometry parameters will certainly result in a remarkable impact on ejector performance.

Many researches have been described as the theoretical basis for ejector designing, subsequent to the first ejector model that was proposed by Keenan et al. [14]. However, the friction losses in the model were based on an empirical methodology. The classical model based on the 1-D constant pressure theory was proposed by Huang et al. [15], which assumed that the mixing of two streams occurs inside a constant area section with uniform pressure under double choking conditions. The model was experimentally verified with 11 different ejectors using R141b as the working fluid. Zhu et al. [16] proposed an ejector for real-time control and the optimization of an ERS based on a 1-D analysis. Moreover, some recent innovations on ejector modeling have also been reported in [17]. In all these various modeling methods, numerous assumptions were made, which include, for example, ideal gas conditions, a static mixing process, downstream velocity, etc. Especially, for most of the researches, it was also assumed that the flow relations are isentropic and losses were expressed by a molecular collision and friction coefficient, which were selected empirically or arbitrarily [18]. As the coefficient evaluation is widely discussed in more recent relevant researches, the typical values of isentropic efficiency (nozzle, suction chamber, mixing chamber and diffuser) are detailed in Table 1.

Generally, the roughness values of ejector internal surface is various for each different machining process; therefore, it is unreasonable to determine the component efficiencies in 1-D ejector model without considering the effects of friction losses. Nevertheless, few investigations have actually been conducted on efficiency calculations by considering the variable friction losses.

However, the roughness will cause geometric change, which was also consistently ignored in above studies. Due to the differences in machining technology, the roughness values will be varied for different ejectors. Unfortunately, few reported researches have been conducted to determine the coefficient of friction losses.

In this study, numerical studies were conducted to analyze the relationship between the ejector efficiencies and roughness values. A series of CFD simulations was conducted by dividing the ejector into five specific components: the nozzle, suction chamber, mixing chamber, constant-area section and diffuser. The efficiency of each component was calculated and analyzed mathematically by considering the effect of friction, respectively. The simulation results were validated by using an ejector based refrigeration platform. The ejector component efficiencies, effects of friction and their correlation were studied in-depth.

## 2. Ejector efficiency description

A schematic view of a typical supersonic ejector is shown in Fig. 1. An ejector usually consists of five key components: primary nozzle, suction chamber, mixing chamber, constant-area section and the diffuser. Within the ejector, the primary flow is introduced into the nozzle in which the first flow accelerates from subsonic to supersonic, creating a low pressure region at the nozzle outlet in the suction chamber. The entrained flow is then drawn into the mixing chamber by the pressure differential. The mixing flow may also have mixing layers with shockwaves in the constant-area section. In the diffuser, the mixed fluid is then decelerated and recompressed.

The ejector performance is often measured by the entrainment ratio (Er), which is defined below:

**Table 1**
Ejector efficiencies from the relevant research [19–24].

| Reference | $\eta_{nozzle}$ | $\eta_{suction}$ | $\eta_{mix}$ | $\eta_{diffuser}$ |
|---|---|---|---|---|
| Huang and Chang [15] | 0.9 | – | 0.95 | 0.9 |
| Cizungu et al. [19] | 0.95 | 0.95 | – | 0.85 |
| El-Dessouky et al. [28] | 1 | 1 | – | 1 |
| Selvaraju and Mani [29] | 0.95 | 0.95 | – | 0.85 |
| Yapici and Ersoy [30] | 0.85 | – | – | 0.85 |
| Zhu et al. [16] | 0.9–0.95 | 0.85 | 0.765–0.8075 | – |
| Godefroy et al. [31] | 0.8 | 0.95 | 0.935 | 0.8 |
| Yu et al. [32] | 0.9 | 0.85 | – | 0.85 |