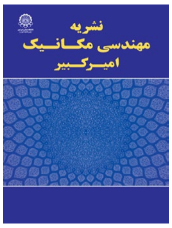
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# Shape Optimization of Supersonic Ejector to Enhance its Performance in Refrigeration Applications

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**ABSTRACT:** Due to an increasing need for refrigeration systems and their growing electrical demand and greenhouse gases production, using ejector refrigeration systems would be a suitable substitution for conventional cooling systems. Main drawback of ejector refrigeration systems is their low coefficient of performance. The key component to improve the cycle performance is the ejector. Prerequisite of improving ejector performance is an accurate computational fluid dynamics simulation for predicting its entrainment ratio. In this study, a two dimensional, axisymmetric, steady state, compressible flow computational fluid dynamics simulation of a supersonic ejector is performed. In the second part of this study, geometrical optimization of the simulated ejector for two different objective functions is performed. The first objective function considered was the ejector entrainment ratio. The optimization with this objective function led to 53% relative improvement in the entrainment ratio with a negligible decrease in critical pressure. The second, objective function considered was the exergy efficiency in which the optimization showed 39.6% relative improvement. The exergy efficiency is used for the first time in the literature as the objective function for optimization of ejector geometry.

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## 1- Introduction

Ejector refrigeration system seems a promising substitute for conventional compressor based refrigeration systems. This system benefits from working with low-grade heat sources, low initial and maintenance costs and structural simplicity. However, ejector refrigeration system has not yet been commercialized, because it has a low coefficient of performance and cannot operate well when the working condition is not the same as design condition.

Ejector is the most prominent component of the ejector refrigeration system and many studies have been conducted to enhance its performance.

A group of researchers have tried to enhance the performance of ejectors by changing their geometrical dimensions. However, they have considered the effect of each variable separately. For example, Hakkaki-Fard et al. [1] investigated the effect of four geometrical parameters. These parameters included: exit diameter of primary nozzle, exit position of the primary nozzle, constant area mixing section length and constant area mixing section diameter. They improved the entrainment ratio of an ejector approximately 29% with a negligible decrease in its critical pressure.

A number of studies have conducted geometrical optimization of ejectors. They have optimized all variables simultaneously. For instance, Lee et al. [2] optimized geometry of a two-phase ejector with R-600a as the working fluid by using multi-objective genetic algorithm. They have investigated five geometrical parameters. The purpose of this study was to improve entrainment ratio and compression ratio of the ejector.

To the best knowledge of the authors, exergy efficiency has not been applied as the objective function for optimizing geometry of ejectors. Furthermore, there are only a few studies that investigate all of the geometrical variables simultaneously. Thus, in this study geometrical optimization is carried out for two objective functions: entrainment ratio and exergy efficiency. In addition, the pattern search algorithm is used for the first time to optimize the ejector geometry.

## 2- Numerical Modeling

### 2- 1- Governing equations

Equations of continuity, momentum (in axial and radial directions) and energy are solved for an axisymmetric, compressible flow. The ejector is assumed to be at steady-state condition. For discretizing the advective-diffusive terms, the second order upwind scheme has been chosen except for the pressure term. The pressure staggering option has been applied to discretize the pressure terms. The SIMPLE algorithm has been used for coupling between velocity and pressure.

### 2- 2- Boundary condition

Pressure inlet boundary condition is applied for the inlets and pressure outlet boundary condition is used for outlet of the ejector. Walls are assumed to be adiabatic with no-slip condition.

### 2- 3- Validation

The numerical model has been validated against experimental study of Hakkaki-Fard et al. [3]. The Soave-Redlich-Kwong model was used as the equation of state and the $k$-$\varepsilon$ realizable

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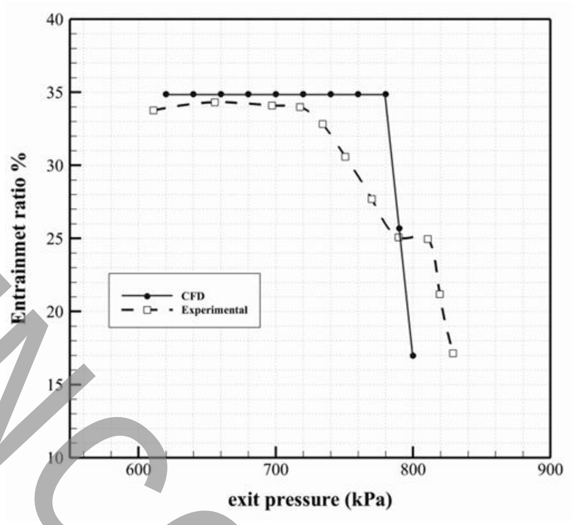


**Fig. 1. Validation of numerical results against experimental data presented by Hakkaki-Fard et al. [3]**

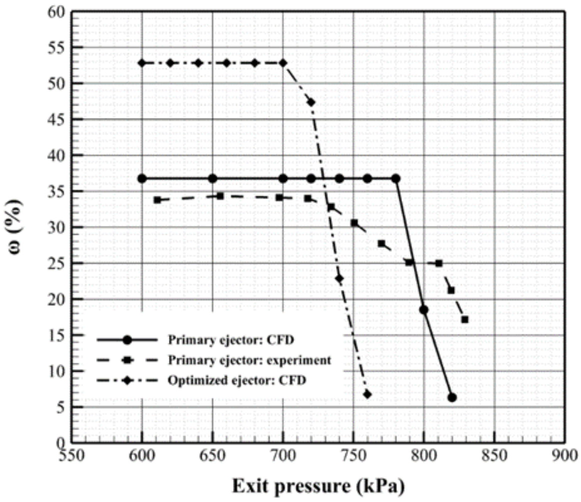


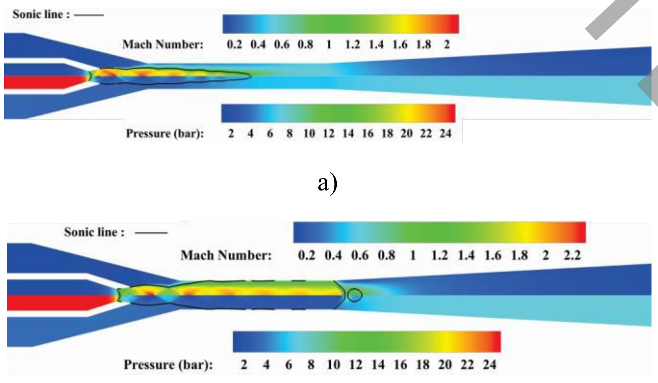
**Fig. 3. Changes in entrainment ratio via exit pressure for the initial and optimized ejectors (objective function: entrainment ratio)**

**Table 1. Geometrical dimensions and entrainment ratio of the initial and optimized ejectors (objective function: entrainment ratio)**

| Ejector | $L_{CA}$ (mm) | $NXP$ (mm) | $R_{NE}$ (mm) | $R_{CA}$ (mm) | $P_{Outlet}$ (kPa) | $\eta$ (%) | $\omega$ (%) |
|---|---|---|---|---|---|---|---|
| Initial | 89 | 29 | 4.5 | 8.31 | 720 | 24.0 | 36.76 |
| Optimized | 124 | 33.5 | 5.16 | 8.94 | 720 | 31.0 | 47.37 |

**Table 2. Geometrical dimensions, exit pressure and, exergy efficiency of the initial and optimized ejectors (objective function: exergy efficiency)**

| Ejector | $L_{CA}$ (mm) | $NXP$ (mm) | $R_{NE}$ (mm) | $R_{CA}$ (mm) | $P_{Outlet}$ (kPa) | $\eta$ (%) | $\omega$ (%) |
|---|---|---|---|---|---|---|---|
| Initial | 89 | 29 | 4.5 | 8.31 | 720 | 24.0 | 36.76 |
| Optimized | 128.2 | 34.1 | 4.2 | 9.0 | 610 | 33.5 | 77.7 |



a)

b)

**Fig. 2. Mach and pressure contours inside the ejector: a) optimized case and b) initial case (objective function: entrainment ratio)**

model was applied as the turbulence model. Fig. 1 illustrates the validation in terms of entrainment ratio for different back pressures.

## 3- Geometrical Optimization

The optimization process works as follows: first, initial guesses for the geometrical parameters are made and their allowed range of variations are determined. Using the initial guesses, geometry of the ejector is built. Then, computational grid is created on the geometry. The computational grid enters the developed Computational Fluid Dynamics (CFD) solver and the solver calculates the objective function (entrainment ratio or exergy efficiency). Based on the obtained value of the objective function and the initial guesses, the pattern search algorithm updates the parameters values and a new geometry will be made by using the updated values. This cycle continues until the convergence criteria are reached.

### 3- 1- Geometrical optimization to maximize entrainment ratio

In this section, four geometrical parameters including: primary nozzle exit radius, primary nozzle exit position, constant area mixing section length and constant area mixing section radius are investigated to maximize the entrainment ratio of the ejector. Table 1 presents the geometrical parameters, outlet pressure, entrainment ratio and exergy efficiency of the initial and optimized ejectors.

According to Table 1, the geometrical optimization has increased the entrainment ratio from 36.76% to 47.73% while the outlet pressure has been remained constant.

Fig. 2 presents Mach and pressure contours of the initial and optimized ejectors. This figure shows that the area in which shock waves occur becomes smaller after the optimization.

Thus, geometrical optimization reduces the irreversibilities inside the ejector. Fig. 2. Mach and pressure contours inside the ejector: a) optimized case and b) initial case (objective function: entrainment ratio)

Fig. 3 presents changes in entrainment ratio via back pressure for the initial and optimized ejector. This figure shows that the on-design entrainment ratio of the optimized ejector is 53% but its critical pressure is reduced from 720 kPa to 700 kPa. Thus, for a small decrease in the critical pressure, the entrainment ratio has increased 44% compared to the initial ejector.

### 3- 2- Geometrical optimization to maximize exergy efficiency

For this part, in addition to the parameters investigated in the previous section, the back pressure of the ejector is also studied. Without considering the back pressure, the obtained results for optimization with exergy efficiency as objective function would be the same as results obtained for the optimization with entrainment ratio as the objective function.

According to Table 2, the optimization has increased the exergy efficiency of the ejector from 24% to 33.5%. Entrainment ratio of the ejector is also increased from 36.76% to 77.7%. However, it should be mentioned that the critical pressure of the ejector is decreased from 720 kPa to 610 kPa. This critical pressure is very low and in practice, the obtained ejector cannot be used in a refrigeration system.

## 4- Conclusions

In this study, geometrical optimization of a supersonic ejector has been carried out. Four geometrical parameters are investigated. The optimization is applied for two separate objective functions: entrainment ratio and exergy efficiency. It is shown that the geometrical optimization with entrainment ratio as the objective function has increased the entrainment ratio from 36.76% to 53% but has decreased the critical pressure from 720 to 700 kPa. So, with a negligible decrease in the critical pressure, the entrainment ratio is 44% increased. In the second part, optimization is carried out to maximize exergy efficiency. It is demonstrated that the exergy efficiency is increased from 24% to 33.5% but the critical pressure is reduced from 720 to 590 kPa. Because of the low critical pressure, the obtained geometry is not appropriate for using in a refrigeration applications.

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