Journal of Solid and Fluid Mechanics (JSFM), 13(5): 1-3, 2024

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/JSFM.2023.12917.3722

Manufacturing Engineering of Iran

Numerical investigation of the effects of Helmholtz resonator and primary flow oscillations on subsonic ejector performance

Mehdi Tavakoli [1], Hossein Davari[2], Amir Joulaei[2], Mahdi Nili-Ahmadabadi [3*]

[1] Bachelor Graduate, Mech. Eng., Isfahan University of Technology Univ., Isfahan, Iran
[2] MSc Graduate, Mech. Eng., Isfahan University of Technology Univ., Isfahan, Iran
[3] Assoc. Prof., Mech. Eng., Isfahan University of Technology Univ., Isfahan, Iran
*Corresponding author: m.nili@iut.ac.ir
Received: 04/05/2023 Revised: 07/16/2023 Accepted: 10/31/2023

Abstract

This paper investigates the effect of using a Helmholtz resonator with one or two pairs of deep cavities on the mixing chamber of a subsonic ejector to determine its impact on the ejector's entrainment ratio. The results showed that the presence of the cavity at the beginning, middle, and end of the mixing chamber reduces the entrainment ratio by 0.6%, 3.8%, and 6.6%, respectively, and the presence of the second cavity at the positions of 20, 40, and 60 mm to the first cavity reduces the entrainment ratio by 9.9%, 10.1%, and 10.2% respectively. In addition, the effect of the depth was studied at a distance of 20 mm for a pair of cavities at depths of 75, 100, and 125 mm causing a reduction of 4.9%, 9.9%, and 13.1% in entrainment ratio. In general, the Helmholtz resonator investigation results showed that the secondary flow oscillation reduces the entrainment ratio due to the blockage in the secondary flow path. Therefore, in the final part of the research, the effect of primary flow oscillation was investigated, the results of which showed that the primary flow oscillation increases the entrainment ratio by 5.2%.

Keywords: Helmholtz resonator; longitudinal and transverse oscillations; ejector; secondary mass flow rate; entrainment Ratio.

1. Introduction

One of the types of cavities that can create harmonic oscillations when connected to the flow channel with the opposite arrangement is the Helmholtz resonator, which has many factors, such as geometry, dimensions, and position affecting the oscillations in the resonator [1]. This type has many applications, including sound energy measurement [2], muffler [3], combustion chamber [4], and flow regulation [5]. Ejectors are fixed mechanical components with many applications in pumping compressible and incompressible fluids without needing external energy [6]. They are widely used in many industrial processes, such as heat pumps [7], refrigeration systems [8], vacuum generators [9], and desalination [10]. In the ejector, the primary fluid enters the primary nozzle at a high speed, which decreases the pressure. The pressure drop in the ejector suction chamber causes secondary fluid suction. After the two fluids are mixed in the mixing chamber, a diffuser is used to restore the pressure [11]. The entrainment ratio (ER) parameter is defined as the ratio of the mass flow rate of the secondary flow to the primary flow (Eq. 1). The pressure ratio (PR) in the ejectors is defined as the ratio of the diffuser pressure to the secondary flow pressure, which strongly affects the entrainment ratio (Eq. 2) [12].

$$ER = \frac{\dot{m}_s}{\dot{m}_p} \quad (1)$$

$$PR = \frac{P_e}{P_s} \quad (2)$$

Marum et al. [12] investigated numerically and experimentally a subsonic ejector at different operating conditions, and it was found that the k-w SST model has good accuracy. Tang et al. [13] added a secondary inlet in the middle and end of the mixing chamber and increased the ejector efficiency by 35%. Yadav et al. [14] presented an ejector whose mixing chamber did not have a fixed surface area by defining a parameter as the ratio of the distance from the primary flow nozzle to the mixing chamber to the diameter of the throat of the mixing chamber. Wu et al. [15] found that if the length of the fixed section of the mixing chamber is shorter than a certain limit, the velocity and pressure oscillations increase, which reduces the entrainment ratio. Wen et al. [16] found that the ratio of the mixing chamber's cross-sectional area to the primary nozzle's exit area affects the optimal length of the mixing and suction chambers. Wu et al. [17] proved that the length of the fixed part of the mixing chamber can indirectly affect the outlet pressure. They also investigated the ratio of the length of the mixing chamber to the diameter of the primary nozzle to find the optimal range. According to previous studies, the mixing chamber is very effective in increasing the entrainment ratio of the ejector. On the other hand, adding a Helmholtz resonator to the mixing chamber has not been investigated so far. Therefore, the effect of the Helmholtz resonator on the mixing chamber of a subsonic ejector was numerically investigated. In the final part of the research, the effect of primary flow oscillation on the entrainment ratio was also investigated by defining the UDF code in the primary inlet boundary condition.

2. Methodology

In this simulation, the Unsteady Reynolds Average Navier-Stokes equations were solved. According to the research done by [18, 19], the k-ε turbulence model was chosen, and the ejector geometry studied by Marum et al. [12] was chosen. The width of the cavity was equal to the height of the ejector's mixing chamber (34.2 mm). The cavity's depth (L = 50, 75, 100, 125, and 150 mm) was investigated, as shown in Fig. 1. A structured grid was generated, and the grid independence was evaluated on the entrainment ratio. Finally, a grid with 40,000 cells with a time step 0.0001 was used for more accuracy and better convergence.

According to the research done by Selamat et al. [18], the ideal gas assumption was used for air. For the primary and secondary flow, an inlet velocity of 35 m/s and an inlet stagnation pressure of 99961.75Pa were defined, respectively. Atmospheric pressure was used for the outlet. For the ejector walls and cavity walls, the no-slip and slip condition was used [20, 21], respectively. The pressure-velocity coupling was used as COUPLED, and the spatial discretization was set as the second-order upwind. After the flow became completely harmonic, the residuals were monitored to be less than 10-4. To validate the methodology in the present study, the geometry of research [1] was numerically investigated, and the acoustic frequency of the oscillations was found to have an error of 2% compared to the experimental results.

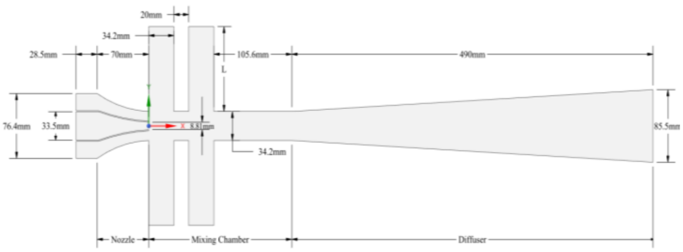

Figure 1. Parts and dimensions of the geometry [13] with two pairs of cavities

3. Results and Discussion

At the starting time of the solution, the pressure oscillations' graphs did not follow a specific pattern. As the solution continued, stable pressure harmonic oscillations were formed. It was observed that the single pair of cavities at the beginning of the chamber has a better entrainment ratio than those in the middle and end of the mixing chamber. Adding a single pair of cavities led to a sharper decrease in the entrainment ratio. Afterward, numerical simulation was performed for different depths of 50, 75, 125, and 150 mm for the cavities. The 50 and 150-mm cavities did not form harmonic oscillations. Therefore, the study of pressure oscillations and the entrainment ratio of the ejector was investigated with depths of 75, 100, and 125 mm at different operating conditions, and the results are given in Table 1. It can be seen that the entrainment ratio decreases with the increase in the depth of the cavity and the pressure ratio. Therefore, the maximum entrainment ratio is for the ejector without cavities, and it can be concluded that the presence of any cavity with different depths also has an opposite effect on the entrainment ratio. In other words, the oscillations created in the flow next to the wall of the mixing chamber affect the secondary flow more than the shear layer between the primary and secondary flow. Therefore, the oscillations of the secondary flow cause a blockage and decrease the entrainment ratio.

Table 1. ER of the ejector with and without Helmholtz resonator in various depths and pressure ratios

PR	Depth of cavity			
	-	75 mm	100 mm	125 mm
1.014	1.345	1.281	1.224	1.189
1.015	1.324	1.263	1.196	1.177
1.016	1.299	1.246	1.177	1.162
1.017	1.277	1.228	1.170	1.128
1.018	1.252	1.209	1.152	1.121

It was mentioned that the presence of the Helmholtz resonator in the mixing chamber of a subsonic ejector reduces the entrainment ratio, which is due to the blockage caused by the secondary flow oscillations in the mixing chamber. Thus, the effect of the primary flow oscillation was also investigated. Therefore, the primary nozzle was removed, and the primary flow oscillation was defined as the fluctuating inlet velocity using a UDF code. The results showed that the optimized frequency and amplitude for an oscillatory y-velocity were 1000Hz and 20m/s, respectively. The results of Table 2 showed that the presence of oscillations in the primary flow increases the entrainment ratio. Even with increasing the pressure ratio, the entrainment ratio of the ejector with the oscillation of the primary flow is higher than that of the base ejector. Increasing the entrainment ratio by oscillating the primary flow is due to improving the mixing performance between the primary and secondary flows in the mixing chamber. Fig. 2 shows how the jet moves up and down, increasing the momentum exchange between the primary and secondary flows.

Table 2. ER of the ejector with and without primary flow oscillation in various pressure ratios

PR	Without oscillation	With oscillation	ER Change
1.014	1.345	1.415	+5.20%
1.016	1.299	1.367	+5.23%
1.018	1.252	1.318	+5.27%

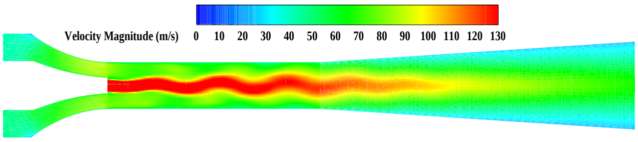

Figure 2. Velocity magnitude of ejector with primary flow oscillation

4. Conclusions

In this study, the effect of the Helmholtz resonator on the mixing chamber of a subsonic ejector was investigated to observe the change in the entrainment ratio. After simulating the flow field at different depths and numbers of cavities, it was observed that increasing the depth of the cavities increases the range of pressure oscillations and decreases the acoustic frequency, and the acoustic frequency is the same in both pairs of cavities. The results of measuring the entrainment ratio showed that the presence of Helmholtz resonator hurts secondary fluid suction. Also, by examining the effect of the number of cavities, it was found that in the case of two pairs of cavities, it has a more negative impact on the entrainment ratio of the ejector than a single pair of cavities. Further, the effect of the cavities' depth showed that increasing the depth weakens the suction effect. Also, with an increase in the ejector pressure ratio, the entrainment ratio decreases. Overall, it was concluded that adding cavities to the mixing chamber causes blockage in the secondary flow and a reduction in the entrainment ratio. In the second phase of the study, the effect of primary flow oscillation on the entrainment ratio was numerically studied. The fluctuating y-velocity at the primary inlet was defined using a UDF code in Fluent software. The results showed that the entrainment ratio increases by primary flow oscillations.

5. References

[1] Mohammadpour J (2017) Experimental investigation of Helmholtz resonator geometrical parameters on its flow structures using PIV technique. MSc Thesis. Isfahan University of Technology.

[2] Nagaya K, Hano Y, Suda A (2001) Silencer consisting of two-stage Helmholtz resonator with auto-tuning control. *The Journal of the Acoustical Society of America* 110.

[3] Dupe`re I D J, Dowling A P (2005) The Use of Helmholtz Resonators in a Practical Combustor. *Journal Eng. Gas Turbines Power* 127(2): 268–275.

[4] Arthurs D, Ziada S (2009) Flow-excited acoustic resonances of coaxial side branches in an annular duct. *Journal of Fluids and Structures* 25(1): 42–59.

[5] Sun D W, Eames I W (1995) Recent developments in the design theories and applications of ejectors. *Journal of Institute of Energy* 68: 65-79.

[6] Kong F, Kim H (2015) Analytical and computational studies on the performance of a two-stage ejector–diffuser system. *International Journal of Heat and Mass Transfer* 85: 71-87.

[7] Chen W, Shi C, Zhang S, Chen H, Chong D, Yan J (2017) Theoretical analysis of ejector refrigeration system performance under overall modes. *Applied Energy* 185(2): 2074-2084.

[8] Tang Y, Liu Z, Shi C, Li Y (2018) A novel steam ejector with pressure regulation to optimize the entrained flow passage for performance improvement. MED-TVC desalination system, *Energy* 158: 305-316.

[9] Askalany A, Ali E S, Mohammed R H (2020) A novel cycle for adsorption desalination system with two stages-ejector for higher water production and efficiency. *Desalination* 496.

[10] Balamurugan S, Gaikar V G, Patwardhan A W (2008) Effect of ejector configuration on hydrodynamic characteristics of gas–liquid ejectors. *Chemical Engineering Science* 63: 721-731.

[11] Chunnanond K, Aphornratana S (2004) Ejectors: applications in refrigeration technology. *Renewable and Sustainable Energy Reviews* 8: 129-155.

[12] Marum V J d O et al. (2021) Performance analysis of a water ejector using CFD simulations and mathematical modeling. *Energy* 220.

[13] Tang Y, Liu Z, Li Y, Shi C (2018) Combined auxiliary entrainment and structure optimization for performance improvement of steam ejector with consideration of back pressure variation. *Energy Conversion and Management* 166.

[14] Yadav R L, Patwardhan A W (2008) Design aspects of ejectors: Effects of suction chamber geometry. *Chemical Engineering Science* 63: 3886–3897.

[15] Wu Y, Zhao H, Zhang C, Wang L, Han J (2018) Optimization analysis of structure parameters of steam ejector based on CFD and orthogonal test. *Energy* 151: 79-93.

[16] Wen H, Yan J (2021) Effect of mixing chamber length on ejector performance with fixed/varied area ratio under three operating conditions in refrigerated trucks. *Applied Thermal Engineering* 197.

[17] Wu H, Liu Z, Han B, Li Y (2014) Numerical investigation of the influences of mixing chamber geometries on steam ejector performance. *Desalination* 353: 15-20.

[18] Selamet E, Selamet A, Iqbal A, Kim H (2011) Effect of Flow on Helmholtz Resonator Acoustics: A Three-Dimensional Computational Study vs. Experiments. *SAE Technical Paper*: 15-21.

[19] Buehn J P, Slaboch P E (2015) Computational Study of Active Flow Control of a Flow-Excited Helmholtz Resonator. *22nd AIAA Computational Fluid Dynamics Conference*.

[20] Ghanadi F, Arjomandi M, Zander A C, Cazzolato B S (2013) Velocity Oscillations within the Turbulent Flow over a Flow-excited Helmholtz Resonator: The 2013 *International Conference on Mechanical and Materials*. Stockholm, Sweden.

[21] Kweon Y H, Aoki T, Miyazato Y, Kim H D, Setoguchi T (2006) Computational study of an incident shock wave into a Helmholtz resonator: *Computers & Fluids*. 35: 1252–1263.