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Numerical Study of the Effect of Geometric Parameters on the Performance of Solid-Liquid Ejectors

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ABSTRACT: The present research numerically studies the effect of geometric parameters on the performance of two-phase solid-liquid ejectors. The equations governing the flow inside the ejector include continuity and momentum equations from an Eulerian perspective using the control volume method. The geometric parameters under study were the convergence angle, divergence angle, area ratio (nozzle to the throat), and nozzle position (distance between the nozzle outlet and the start of the throat) in the ejector. In this study, significant design parameters, including the entrainment ratio, critical pressure, and ejector efficiency were introduced and calculated for all the geometric parameters. The homogeneous and the two-phase mixture models were employed to simulate the secondary flow. The results indicate that the data from the two models were in good agreement at low volume fractions (5%), such that the largest error occurred at an area ratio of 0.26 and was equal to 2.3%. The results also indicate that the ejector efficiency increases with an increase in the convergence angle up to 20°, after which it decreases. Moreover, an increase in the area ratio up to 0.22 improves the efficiency of the ejector, after which this efficiency is reduced. Decreasing the divergence angle and increasing the nozzle-to-throat distance also enhance the ejector efficiency. In addition, optimal values were obtained for the design parameters by varying the geometric parameters. These values can be employed according to the application for which the ejector is being used.

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1- Introduction

An ejector is a mechanical device that can transfer fluid flow or solid particles such as powder, granules, and sludge by creating a vacuum. The basis of the work of the ejector is to convert the pressure energy of a drive flow into velocity energy and create a low-pressure area for secondary flow suction [1]. Due to the absence of moving parts, the efficiency of ejectors is lower than pumps with mechanical parts [2] and the mixing of fluids with different pressures in the ejector causes a lot of energy loss in it [3]. Therefore, the study of ejector geometry in order to improve its performance has been the focus of researchers around the world.

An experimental investigation was carried out by Naik and Patel [4] to determine how the water ejector's performance would change if the diffuser's angle was changed. According to experimental findings, the diffuser's angle affects how the ejector behaves, with a 5-degree angle producing the most efficiency and suction.

Hassan et al. [5] investigated the effect of area ratio on water ejector performance numerically and experimentally. They investigated three different area ratios at different inlet pressures. The results showed that the highest efficiency occurs in the area ratio of 0.19.

Past research has mainly focused on water suction ejectors and modeled the flow inside the ejectors with a single-phase model; While few studies have been done in the field of solid-liquid two-phase ejectors. The studies conducted in this field have studied limited parameters (geometric parameters and ejector performance parameters) to analyze the performance of ejectors. Due to the widespread use of two-phase solid-liquid ejectors in modern industries (such as sewage treatment plants and dredging systems) and the significance of improving equipment efficiency to reduce energy consumption, it is necessary to investigate the geometry of this type of ejector to enhance its performance. Therefore, in this study, using the Computational Fluid Dynamics (CFD) method, the ejector used for solid-liquid two-phase flows is numerically studied and in addition to investigating the effect of different geometric parameters on solid-liquid ejector efficiency, the effect of these geometrical parameters on other ejector performance parameters has also been investigated. The studied geometrical parameters include the nozzle convergence angle, the diffuser divergence angle, the ratio of the nozzle area to the throat, and the position of the nozzle.

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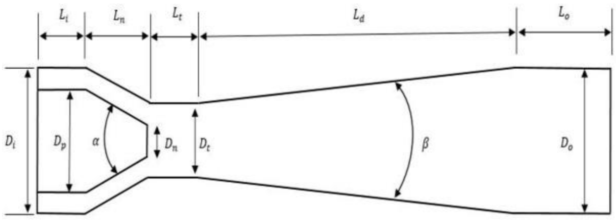

Z(-)	D_i(mm)	D_p(mm)	D_n(mm)	D_o(mm)	D_t(mm)	L_i(mm)	L_n(mm)	L_t(mm)	L_d(mm)	α(°)	β(°)
0	70	50	15	70	35	50	65.31	50	526.17	30	6

Fig. 1. Schematic of the primary geometry of the ejector

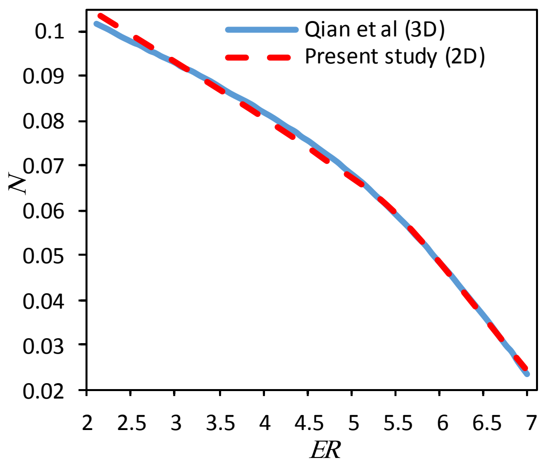

Fig. 2. Two-phase model validation

The schematic of the basic ejector geometry is shown in Fig. 1.

The effect of the presented geometrical parameters on the performance parameters of the ejector including entrainment ratio (The mass flow rate ratio of the secondary flow to the primary flow), efficiency, and critical pressure has been investigated. The critical pressure is the maximum pressure that can be applied to the ejector outlet so that backflow does not occur in the ejector.

2- Numerical Modeling

To simulate the flow inside the ejector, the averaged Navier-Stokes equations and the continuity equation for the mixture model have been used. According to the symmetric geometry of the ejector, the axisymmetric boundary condition is used and the ejector is simulated in 2D. The equations of continuity, momentum in the direction of the radius (r), and momentum in the direction of the ejector axis (z) are expressed, respectively, in Eqs. (1), (2), and (3) [6].

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho_m V_{rm})+\frac{\partial}{\partial z}(\rho_m V_{zm})=0 \tag{1}$$

$$\begin{aligned}&\frac{1}{r}\frac{\partial}{\partial r}(r\rho_m V_{rm} V_{rm})+\frac{\partial}{\partial z}(\rho_m V_{rm} V_{zm})=-\frac{\partial p_m}{\partial r}+\rho_m g_{mr}\\&+F_{rm}+\frac{1}{r}\frac{\partial}{\partial r}\left\{r(\overline{\tau_{rr}}+\tau_{rr}^T+\tau_{rr}^D)\right\}+\frac{\partial}{\partial z}(\overline{\tau_{rz}}+\tau_{rz}^T+\tau_{rz}^D)\end{aligned} \tag{2}$$

$$\begin{aligned}&\frac{1}{r}\frac{\partial}{\partial r}(r\rho_m V_{rm} V_{zm})+\frac{\partial}{\partial z}(\rho_m V_{zm} V_{zm})=-\frac{\partial p_m}{\partial z}+\rho_m g_{mz}\\&+F_{zm}+\frac{1}{r}\frac{\partial}{\partial r}\left\{r(\overline{\tau_{rz}}+\tau_{rz}^T+\tau_{rz}^D)\right\}+\frac{\partial}{\partial z}(\overline{\tau_{zz}}+\tau_{zz}^T+\tau_{zz}^D)\end{aligned} \tag{3}$$

The inlet flow to the ejector is water and the flow of the suction part is a mixture of water and solid particles with a volume fraction of 5%. To simulate the flow of the suction part, two homogeneous and mixture models have been used. In the homogeneous model for the mixture flow in the suction part, the equivalent properties are considered and the two-phase mixture of a fluid with new properties is assumed. In this case, it is assumed that the flow inside the ejector is liquid-liquid. In the second case, the mixture flow of the suction part is simulated using the mixture model. In this case, the flow inside the ejector is considered as solid-liquid. To solve the equations The multiphase mixture model and commercial computational fluid dynamics solver ANSYS FLUENT R19.0 using the K-ε RNG turbulence model was used.

3- Results and Discussion

In this study, the effect of geometrical parameters on the performance of solid-liquid ejectors has been numerically investigated. The numerical data from Qian et al. was used to validate the results obtained in the present study; the results of which are displayed in Fig. 2. The results show that the maximum difference between the results of the two-dimensional model in the present study and the three-dimensional model used by Qian et al. is 6%.

To simulate the two-phase secondary flow, the homogeneous model (considering the secondary flow as a homogeneous fluid) and the two-phase mixture model (considering the secondary flow as water-sand) were used and the results were compared. The results show that in low volume fractions (5%) the data obtained from both models are in good agreement with each other so the largest difference in the area ratio is 0.26 and the value is 2.31%. The following are a few of this study's key findings:

Up to an angle of 60 degrees, increasing the convergence angle improves the entrainment ratio; and then it decreases.

Increasing the convergence angle up to 20 degrees increases the ejector efficiency and after that the ejector efficiency decrease.

The critical pressure rises as the convergence angle increases.

The critical pressure, ejector efficiency, and entrainment ratio decline as the divergence angle increases.

Increasing the ratio of the nozzle area to the throat (A_r) reduces the suction rate and critical pressure.

Increasing the ratio of the nozzle to the throat area (A_r) up to 0.22 increases the efficiency of the ejector, and after that, the efficiency of the ejector decreases.

Increasing the distance between the nozzle and the throat (Z) increases the entrainment ratio and the efficiency of the ejector.

Increasing the distance between the nozzle and the throat, up to a certain value ($Z = 4$), increases the critical pressure, and after that, it has the opposite effect.

4- Conclusion

The aim of the present study is to investigate the effect of the geometrical parameters of the ejector on various parameters that describe the performance of the ejector. The results of these investigations are presented for three parameters representative of ejector performance. Ejectors are used in different operating conditions and with different purposes; For this reason, in different conditions, each of the mentioned parameters can be considered as the main criterion for ejector design. In fact, it is not possible to use only one parameter as a criterion for designing and presenting the optimal geometry of the ejector. For this purpose, in this study, the effect of geometrical parameters on all three main criteria of ejector design is presented, so that in appropriate conditions, whichever one is more efficient can be used.

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