Three-dimensional numerical simulation analysis of the influence of structural parameters on the performance of air ejector

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Abstract. Nowadays, CFD technology has become the third tool to study hydrodynamics problems after theoretical analysis and experimental research, especially in dealing with and solving complex engineering problems such as supersonic. In this paper, using the method of control variables, the system studied a type air ejector structure parameters within a certain range changes affect the performance of the work by means of FLUENT, at the same time, the optimal combination of the structural parameters are given, then three dimensional numerical simulation of the optimal combination model, and the simulation value and experiment value has carried on the contrast and analysis, Compared with the two-dimensional and axisymmetric model, Three-dimensional calculation model is more reliable and reasonable.

1. Introduction

Air ejector, as a basic unit component, It is a necessary device for vacuum in chemical, sanitation, medicine, refrigeration and other fields. It takes compressed air as the working medium, and extracts and presses the gas to obtain vacuum. With the rapid development of CFD technology, that has brought a major breakthrough in the numerical calculation of the ejector, because it is much easier to change the geometry, physical factors and environmental conditions in the calculation program than in the experiment, so it accelerates the development speed of numerical simulation. At present, there are few researches on the three-dimensional simulation of air ejector, and the existing researches are not systematic enough. Therefore, this paper uses the control variable method to systematically study the influence of the variation of structural parameters of air ejector on its performance, which provides a reference basis for the optimization design of air ejector [1-8].

2. Geometric models and governing equations

2.1. Geometric model of air ejector

Taking a certain type of air ejector as an example, its geometric model and the name of each component are shown in Figure 1, The original dimensions are shown in Figure 2.
2.2. Governing Equation

The steady-state flow transport equation can be written in the following unified form:

\[
\text{div}\left( \rho u \phi \right) = \text{div}\left( \Gamma \nabla \phi \right) + S_\phi
\]  

In Equation (1), \( \text{div}\left( \rho u \phi \right) \), \( \text{div}\left( \Gamma \nabla \phi \right) \) and \( S_\phi \) are convection term, diffusion term and source term in turn. The corresponding continuity equation, momentum conservation equation and energy conservation equation in \( x \) (\( y \) or \( z \)) direction are obtained by replacing \( \phi \) with \( U \), \( U \) (\( V \) or \( W \)) and \( T \) respectively. At the same time, because in FLUENT, the k-\( \omega \) model can more accurately reflect the internal flow of the structure or component, such as jet flow, large curvilinear flow and separated flow etc. k-\( \omega \) is selected as the turbulence equation in this paper [9-11].

3. Three-dimensional numerical simulation research

Ejector gas flow rate and vacuum pressure are two important indicators to measure the performance of the air ejector. Ejector gas flow rate represents the suction capacity of the air ejector, while vacuum pressure is an important measure of the suction capacity. In general, when air ejector working environment (humidity, temperature and pressure, etc.) is fixed, and vacuum pressure is mainly determined by the suction capacity, and air ejector pumping capacity is determined by its structure parameters, in other words, when the work environment and the structure parameters of a certain air ejector pumping capacity is certain. The following adopts the control variable method to systematically study the relationship between the vacuum pressure and the ejector gas flow when the structural parameters of the air ejector are single changed, so as to provide a reference for the structural optimization design of the air ejector [12-13].
Figure 3 shows the three-dimensional model and the grid section of the air ejector. Figure 3(a) shows the three-dimensional model of the air ejector using a top-down modeling approach. Figure 3(b) shows mesh generation with more than 100,000 nodes and more than 500,000 cells.

3.1. Influence of nozzle

3.1.1. Influence of nozzle inlet diameter. The inlet diameters of the nozzles are 40 mm, 50 mm and 60 mm, respectively. Figure 4 shows the relation curve between the ejection gas flow rate and the vacuum pressure when the nozzle inlet diameter changes. As can be seen from Figure 4, although the vacuum pressure will increase with the increase of ejected gas flow, when the vacuum pressure is constant, the ejected gas flow won't follow the nozzle inlet diameter changed, as it remains basically constant value.

3.1.2. Influence of nozzle throat diameter. Figure 5 shows the relation curve between nozzle throat diameter and ejected gas flow rate under different vacuum pressures. As can be seen from Figure 5, when the nozzle throat diameter is constant, the ejected gas flow rate will increase with the increase of vacuum pressure. However, when the vacuum pressure is constant, the ejected gas flow rate will decrease with the increase of nozzle throat diameter.

3.1.3. Influence of nozzle outlet diameter. Figure 6 shows the relation curve between nozzle outlet diameter and ejecting gas flow rate under different vacuum pressures. As can be seen from Figure 6, when the nozzle outlet diameter is constant, the ejected gas flow rate will increase with the increase of vacuum pressure. When the vacuum pressure is constant, the ejected gas flow will increase first and then decrease with the increase of nozzle outlet diameter, that is, there is an optimal nozzle outlet diameter.

3.1.4. Influence of nozzle spacing. See Figures 1 and 2, set the distance between nozzle outlet and mixing chamber inlet as nozzle distance. Figure 7 shows the relation curve between nozzle distance and ejected gas flow rate under different vacuum pressures. As can be seen from Figure 7, when the nozzle distance is constant, the ejected gas flow will increase first and then decrease with the increase of vacuum pressure. Similarly, when the vacuum pressure is constant, the ejected gas flow rate will increase first and then decrease with the increase of nozzle spacing, therefore, there is an optimal nozzle spacing.

3.2. Influence of mixing chamber

3.2.1. Influence of access section taper of mixing chamber. Access section taper of mixing chamber = (ejector chamber radius-mixing chamber radius)/nozzle spacing. See Figures 1 and 2. Figure 8 shows the relation curve between the access section taper of mixing chamber and the ejected gas flow rate. It can be seen from Figure 8, that the change of the access section taper of the mixing chamber has little influence on the ejecting gas flow rate, which can be ignored.
3.2.2. **Influence of throat diameter of mixing chamber.** Figure 9 shows the relation curve between the throat diameter of the mixing chamber and the ejected gas flow rate. It can be seen from Figure 9 that ejected gas flow rate decreases with the increase of the throat diameter of the mixing chamber.

![Figure 7](image1.png) **Figure 7.** The relation curve between nozzle distance and ejector gas flow rate.

![Figure 8](image2.png) **Figure 8.** The relation curve between access section taper of mixing chamber and ejected gas flow rate.

![Figure 9](image3.png) **Figure 9.** The relation curve between throat diameter of mixing chamber and ejected gas flow rate.

3.2.3. **Influence of mixing chamber taper.** See Figures 1 and 2, the mixing chamber taper = (mixing chamber access radius - throat radius of mixing chamber) / mixing chamber length. Figure 10 shows the relation curve of mixing chamber access radius and ejected gas flow rate. It can be seen from Figure 10 that the ejected gas flow rate decreases with the increase of the mixing chamber taper.

![Figure 10](image4.png) **Figure 10.** The relation curve between mixing chamber access radius and ejected gas flow rate.

3.2.4. **Influence of mixing chamber length.** Figure 11 shows the relation curve between the mixing chamber length and the ejected gas flow. As can be seen from Figure 11, when the mixing chamber length is constant, the ejected gas flow rate will increase with the increase of vacuum pressure. However, when the vacuum pressure keep constant, the mixing chamber length changes in a certain range, which has little effect on the ejected gas flow rate.

![Figure 11](image5.png) **Figure 11.** The relation curve between mixing chamber length and ejected gas flow rate.

![Figure 12](image6.png) **Figure 12.** The relation curve between diffuser outlet radius and ejected gas flow rate.

3.3. **Influence of diffuser**

3.3.1. **Influence of diffuser taper.** Diffuser taper = (diffuser outlet radius - throat radius of mixing chamber) / diffuser length. Figure 12 shows the relation curve between diffuser outlet radius and ejected gas flow rate. As can be seen from Figure 12, when the diffuser taper is constant, the ejection gas flow rate will decrease with the increase of vacuum pressure. However, under the same vacuum pressure, the ejected gas flow rate decreases first and then remains constant with the increase of the diffuser taper.
3.3.2. Influence of diffuser length. Figure 13 shows the relation curve between the diffuser length and the ejected gas flow rate. As can be seen from Figure 13, when the diffuser length is constant, the ejection gas flow rate will increase with the increase of vacuum pressure. However, under the same vacuum pressure, the ejector gas flow rate decreases with the increase of the diffuser length.

**Figure 13.** The relation curve between diffuser length and ejected gas flow rate.

**Figure 14.** Experimental and simulation contrast curves of a certain type of air ejector.

4. Comparison and analysis of simulation results

Taking a certain type of air ejector as an example, modeling and 3D simulation were carried out respectively to draw the comparison curve as shown in Figure 14 [14].

As can be seen from Figure 14, The optimized simulation value is bigger than before optimization simulation value is obvious, so we can find the more optimized combination by the method of numerical simulation of structure parameters, but before optimization and after optimization simulation values are smaller than the experimental value, this main reason is that the experimental value for gas water vapor, and the numerical simulation model of the gas for ideal gas, water vapor density relative is bigger than the ideal gas. Therefore, the value of ejected gas flow rate measured in the experiment is relatively large. In the next step, we will conduct experimental research on the optimized model, at the same time, the numerical simulation will be modified to gas-liquid two-phase flow model as much as possible.

5. Conclusion

When the structural parameters such as nozzle, mixing chamber and diffuser change within a certain range, they will have a certain impact on the performance of the air ejector. This study shows that the selected air ejector model’s throat diameter nozzle is 18.5mm, the nozzle inlet diameter is 50mm, the nozzle outlet diameter is between 24mm and 26mm. the nozzle distance is between 25mm and 40mm, the throat diameter of the mixing chamber is 47mm, the mixing chamber taper is 0 degree, the length of the diffuser is 450mm, and the diffuser taper is greater than 3 degree, its working performance is relatively better.

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