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The Effect of the Convergent Nozzle Fan on Air Pressure

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Abstract

This paper discusses the influence of a convergent nozzle (confusor) on the pressure and flow characteristics of axial fans. It explains how the addition of a convergent nozzle increases the air velocity and enhances the ejection effect while partially reducing the fan’s overall capacity and static pressure. The study presents mathematical relationships describing pressure drop, outlet resistance, and total aerodynamic resistance, highlighting the role of geometric parameters such as the nozzle’s contraction angle and cross-sectional area ratio. The pressure–flow (ΔP–Q) characteristics of fans with and without a convergent nozzle are compared to demonstrate performance differences. The results show that, despite a slight reduction in airflow, the use of a convergent nozzle can significantly improve energy efficiency and flow stabilization when appropriately designed.

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Keywords: Convergent nozzle, confusor fan, air pressure, airflow rate, outlet resistance, aerodynamic efficiency, pressure–flow characteristics, contraction resistance, diffuser effect, ventilation systems.

Introduction

In practice, to enhance the ejection effect, a convergent nozzle fan is often used, which narrows the outgoing air flow and increases its velocity. The presence of the convergent nozzle leads to a decrease in the fan's capacity and a partial reduction in the pressure in the convergent nozzle of the fan device. Here, f_k is the cross-section of the convergent nozzle, i.e., the outlet cross-section of the flow; f is the inlet cross-section of the air flow; q_k is the capacity of the convergent nozzle fan; $\Delta\pi_k(q_k)$ is the pressure characteristic of the convergent nozzle fan (i.e., the pressure characteristic of the fan without the convergent nozzle $\Delta\pi(q)$ minus the pressure drop in the convergent nozzle). In this case, formula (1) takes the following form:

$$\Delta P = \frac{Q^2}{\rho}\left(\frac{1}{S} - \frac{1}{F}\right) - \frac{(Q-q_k)^2}{\rho} \quad (1)$$

The q_k flow rate can be determined from the intersection point of the full pressure characteristic of the fan without the convergent nozzle.

$$\Delta\pi(q) + \frac{q^2}{2\rho f^2} \quad (2)$$

The quadratic parabola of the pressure drop at the fan outlet is Rq^2, where $R=R_v+R_{konf}$ - the total resistance of the outlet and the convergent nozzle [1]. Thus, q_2 is found from the equation.

$$\Delta\pi(q_k) + \frac{q_k^2}{2\rho f^2} = Rq_k^2 \quad (3)$$

In the correct analysis of the fans' operation process, determining the outlet resistance **(R_B)** is very important, but there is no universal formula for calculating this parameter. Therefore, the outlet resistance coefficient ξ_{out} (or ξ_{in}) is determined separately for each fan type and its operating conditions. This coefficient is a measure of the resistance that arises on the outlet side during the fan's operation process, and in determining this resistance, primarily the fan type and its resistance characteristics are taken into account.

$$R_{B0} = \frac{\left(\Delta\pi_0 + \frac{q_0^2}{2\rho f^2}\right)}{q_0^2} \quad (4)$$

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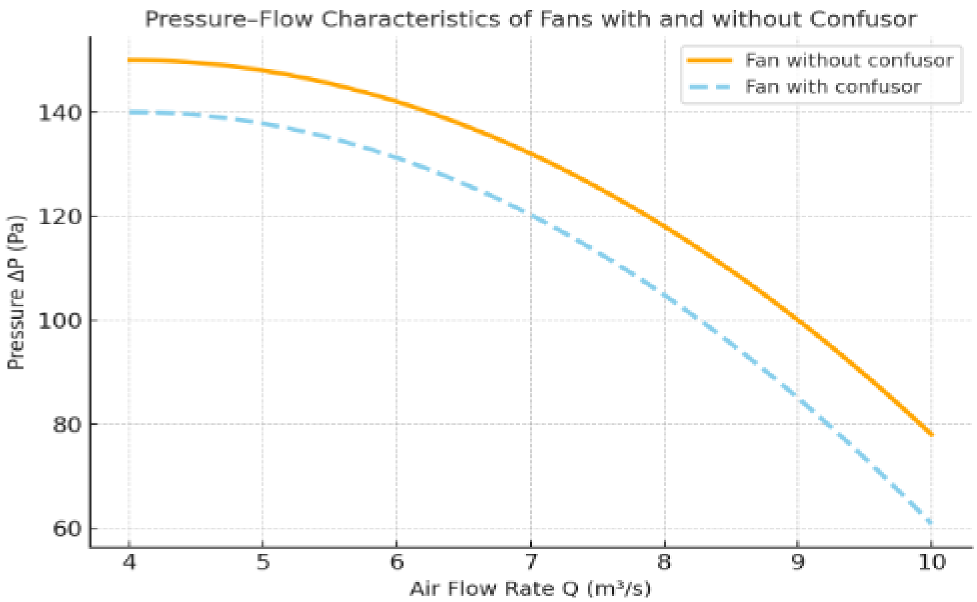
Here, $\Delta\pi_0$ and q_o are the pressure and flow rate at the last point of the pressure characteristic (for the fan, the resistance is only the outlet resistance). If the outlet resistance coefficient ξ_{out} is not dependent on the convergent nozzle section, then:

$$R_B = R_{B0}\left(\frac{f}{f_k}\right)^2 \qquad (5)$$

The main resistance component of convergent nozzles is the contraction resistance. Contraction, i.e., the reduction of the air flow's cross-section, increases the air flow's velocity and leads to a change in pressure. These processes are based on the efficient operation of convergent nozzles, as they help in properly organizing the flow direction. The contraction resistance depends on the geometric characteristics of the air flow (shape and size of the cross-section), and high resistance is generated in places where the air flow changes.



Pressure–flow rate (ΔP–Q) characteristics of fans with and without diffusers:
Yellow line: standard fan (without diffuser) — higher pressure.
Blue line: fan with diffuser — slightly lower pressure, but higher outlet velocity.

As for the resistance of the diffuser, it consists of two parts — frictional resistance and contraction (or narrowing) resistance.
The frictional resistance in the diffuser is relatively small compared to the contraction resistance, and can often be neglected.
To determine the latter, I.Ye. Idelchik's formula [6] is used:

$$R_{\text{конф}} = \frac{1}{\rho f_k^2}\left\{\left[-0.0125\left(\frac{f_k}{f}\right)^4 + 0.0224\left(\frac{f_k}{f}\right)^3 - 0.00723\left(\frac{f_k}{f}\right)^2 + 0.00444\left(\frac{f_k}{f}\right) + 0.00745\right] * \left[(0.0175\alpha)^3 - (0.1096\alpha)^2 - (0.1745\alpha)\right]\right\} \quad (6)$$

Here, α is the contraction angle of the diffuser, measured in degrees.

Research results show that a diffuser installed at the outlet of a fan plays an important role in increasing the air flow velocity and enhancing the ejection effect. Due to the diffuser's converging shape, the flow direction becomes more stabilized, kinetic energy increases at the outlet, and static pressure decreases.

As a result, additional induction of air or gases from the external environment occurs.

However, the presence of a confuser to some extent reduces the overall airflow rate of the fan, since the narrowing of the airflow cross-section increases the resistance in the system. Nevertheless, with a properly selected taper angle (α) and cross-sectional area ratio (fk/f), the overall efficiency of the fan can be high.

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