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Calculating the exhaust ejection system in the ventilation of the painting chamber

[1]Osipova L.E., [2]Telyakov E. Sh, [3]Osipov E.V., [4]Bugembe D.
[1,3]candidate of technical sciences, associate professor, [2]Kazan National Research Technological University, [3,4]Kazan National Research Technological,The organization address: 420015, Russia, Kazan, 68 Karl Marx street
[4]danielsmurts@gmail.com, [1]osipovalilija@mail.ru, [2]eduardvosipov@gmail.com, [3]eduardvosipov@gmail.com

Abstract

Problem statement: The ventilation system plays a decisive role in the creation of the microclimate in various premises. It is known that the ejection ventilation system is well proven both for high-rise residential and office buildings, and for industrial premises. All paint coatings are corrosive and easily flammable substances. In addition, solvent vapors are explosive. It is therefore desirable to use ejection ventilation system in the design of the ventilation system of paint booths. The ejector is simple in design; it can work in a wide range of parameters of state of steam-air mixtures.

Results: The calculation and design of a low-pressure ejector have been performed. An ejection ventilation system has been synthesized using the universal modeling package ChemCad that contains highly developed database to calculate thermophysical properties of various substances and their mixtures.

Conclusions: The obtained results can be recommended in the layout of the ventilation gadget of paint booths both new and reconstructed. The Usage of the software allows carrying out multiple calculations, which are indispensable for the solution of optimization problems.

Keywords: *paint booth, sustainable design, industrial ventilation, ejection system.*

Introduction:

Problems connected with microclimate that arise in multi-story residential buildings where a system of ventilation with a natural flow is designed [1-4]are well known. One of the effective ways of stabilizing the exhaust ventilation system of residential buildings is the use of ejection systems. In [5-6], a number of modular exhaust ventilation systems are described, where the ejection method is used, and which are stable in their operation, regardless of climatic conditions.

In industry, ventilation provides not only the regulatory parameters of the air environment in the production room, but also creates the necessary conditions for the functioning of technological equipment. If the air being removed contains explosive or aggressive gases, as well as solid suspended impurities, the ventilation tasks become more complicated, and for each individual case, its own supply and exhaust system is designed, taking into account the features of the process. It was proposed in [7-8] to remove the explosive and acting impurities that destroy the fan by the ejection method.

The effect of ejection is that the ejecting stream (active) with a higher pressure moves at a high speed, entrains the ejected low-pressure flow (passive). In Fig. 1 shows the structure of the ejector. The air

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injected by the high-pressure fan 5 located outside the vented equipment flows from the nozzle 1 into the mixing chamber 3In which, under the influence of a pressure difference, is sucked up by the air from the intake chamber 2, being removed from the painting chamber. Then the mixture of active and passive streams going through the diffuser 4 and the air duct are discharged into the atmosphere.

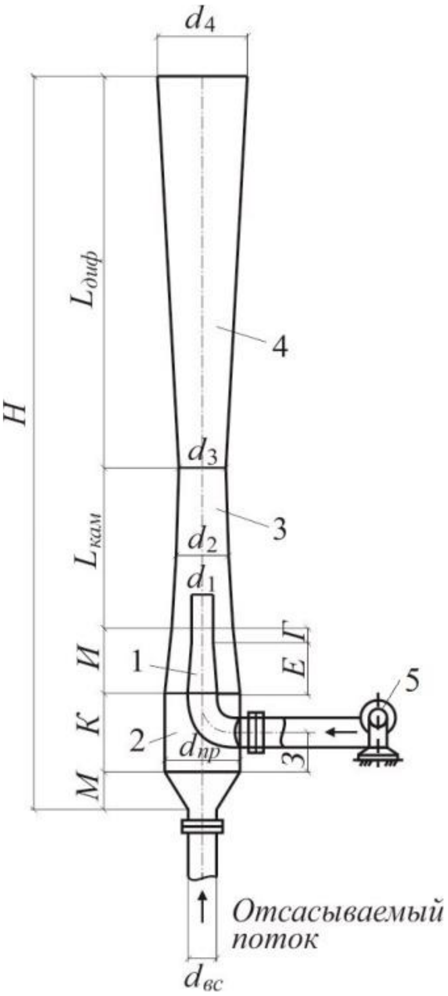

Fig. 1. *Scheme of the ejector: 1 - nozzle; 2 - the receiving chamber; 3 - mixing chamber; 4 - diffuser; 5 – fan*

In the work of T. Fialkovskaya. "Ventilation in the coloring of products" offers solutions for the organization of rational ventilation of painting shops of various products - from small parts to large-sized products. Further, all the necessary data on the size of the painting chamber, flow rate, temperature and air speed are adopted in accordance with these recommendations.

We will consider the technique for determining the required characteristics of the mechanical inflow and exhaust ventilation of the interior space of a painting chamber measuring 5.4 × 3.4 × 2.5 m. The inflow air is supplied from above evenly over the entire area of a false ceiling. Suction of air is carried out on the center of the chamber, the floor of which is equipped with floor grilles throughout the entire area. The inflow and exhaust system pass the purification system. The minimum temperature is 20-25 ° C (in the drying mode up to 50 ° C). The movement of air in the painting zone is 20-25 cm/s.

The air pressure in the chamber is just above the standard 100 kPa (atmospheric pressure or external pressure).

Let's take the quantity of fresh air to be 6600 m3 / h. It is required to remove 6000 m3/h of air at the resistance of the suction network Δp_2 = 230 Pa; The resistance of the discharge head of the ejector is Δp_3 = 80 Pa; The intermixing factor is w = 1.
Since during the application of paint and varnish materials, flammable solvents and their vapors that are explosive and corrosive, and paint coatings - light-fire substances enter the volume of the painting chamber, then it is proposed to use an ejection exhaust ventilation system when designing the ventilation of the chamber. When designing the equipment on the principles of ejection, it is necessary to determine the optimal shape and geometric dimensions of the ejector, as well as the characteristics of the fan, considering that the power consumed by its electric drive determines a significant fraction of the costs of the painting process.

The main design parameter of the ejector is the ejection coefficient, which refers to the ratio of the flow of the active (fan-injected) stream to the flow of the passive (suction from the painting chamber) stream. The higher the ejection factor, the lower the flow rate of the active stream, and, therefore, the fan consumes less power. The same ejection factor is a function dependent on the geometric characteristics of the ejector, so finding the optimal geometry of the ejector will reduce both the operational and capital costs of installing the ventilation system.
When modeling, the ejector is divided into three parts: a nozzle, a mixing chamber and a diffuser.

The pressure and temperature at the nozzle's section are determined by the relationships (1) and (2):

$$\frac{P_1}{P_2} = \left[1 + \frac{\gamma - 1}{2} M^2\right]^{\frac{\gamma}{\gamma - 1}} , \quad (1)$$

$$\frac{T_1}{T_2} = 1 + \frac{\gamma - 1}{2} M^2 . \quad (2)$$

The main relation used in simulating the ejector is:

$$\frac{A_2}{A_c} = \sqrt{\frac{\left[\left(\frac{2}{1+\gamma_1}\right)\left(1 + \frac{\gamma_1 - 1}{2} M_2^2\right)\right]^{\frac{\gamma_1 + 1}{\gamma_1 - 1}}}{M_2^2}} . \quad (3)$$

The pressure at the nozzle outlet is calculated as follows:

$$P_2 = \frac{P_1}{\left[\frac{\gamma_1 - 1}{2\eta_c} M_2^2 + 1\right]^{\frac{\gamma_1}{\gamma_1 - 1}}} . \quad (4)$$

Temperatures at the nozzle outlet:

$$T_2 = \frac{T_1}{1 + \frac{\gamma_1 - 1}{2\eta_c} M_2^2} . \quad (5)$$

Speed of sound

$$C_2 = \sqrt{\gamma_1 R_1 T_2} , \quad (6)$$

Actual flow rate

$$V_2 = C_2 M_2 . \quad (7)$$

The Mach number before mixing the active and ejected streams in the nozzle is expressed by the formula:

$$M_{v_2} = \sqrt{\frac{2}{\gamma_2 - 1}\left[\left(\frac{P_v}{P_2}\right)^{\frac{\gamma_2 - 1}{\gamma_2}} - 1\right]} . \quad (8)$$

In general, to obtain the critical Mach number in any section, we can use the following relation:

$$M_i^* = \sqrt{\frac{M_i^2(\gamma+1)}{M_i^2(\gamma-1)+2}} \ . \quad (9)$$

If we take into account equation (9), then the critical Mach number on the nozzle cut is calculated by the formula:

$$M_2^* = \sqrt{\frac{M_2^2(\gamma_2+1)}{M_2^2(\gamma_2-1)+2}} \ . \quad (10)$$

By definition, the ratio for the ejection coefficient is calculated by the formula:

$$w = \frac{m_v}{m_1} .$$

The critical Mach number of the moving stream at the exit from the nozzle before mixing with the ejected stream:

$$M_{v_2}^* = \sqrt{\frac{M_{v2}^2(\gamma_1+1)}{M_{v2}^2(\gamma_1-1)+2}} \ . \quad (12)$$

When modeling the mixing process, the one-dimensional continuity equations in combination with the equations of motion and the energy equations can be combined into the following relationships to calculate the critical Mach number and the Mach number in the diffuser:

$$M_4^* = \frac{M_2^* + w M_{v2}^* \sqrt{\frac{T_v}{T_1}}}{\sqrt{(1+w)\left(1+w\frac{T_v}{T_1}\right)}} \ , \quad (13)$$

$$M_4 = \frac{\sqrt{2} M_4^*}{\sqrt{(\gamma_3+1) - M_4^{*2}(\gamma_3-1)}} \ . \quad (14)$$

To calculate the mixed active and ejected streams before the exhaust, the following relationship is used:

$$T_4 = \frac{T_2}{1+\frac{\gamma_3-1}{2}M_4^2} . \quad (15)$$

The Mach number at the entrance and exit from the diffuser:

$$M_5 = \sqrt{\frac{M_4^2 + \frac{2}{\gamma_3-1}}{\frac{2\gamma_3}{\gamma_3-1}M_4^2 - 1}} \ , \quad (16)$$

$$M_3 = \sqrt{\frac{M_5^2 + \frac{2}{\gamma_3-1}}{\frac{2\gamma_3}{\gamma_3-1}M_5^2 - 1}} \ . \quad (17)$$

It should be noted that the following relationships are used to calculate the temperature and pressure at the entrance to the diffuser:

$$T_3 = \frac{T_2}{1+\frac{\gamma_1-1}{2}M_3^2} , \quad (18)$$

$$P_3 = \frac{P_2}{\left(1+\frac{\gamma_3-1}{2}M_3^2\right)^{\frac{\gamma_3}{\gamma_3-1}}} \ . \quad (19)$$

The speed of sound and the actual speed are determined by the following dependencies:

$$C_3 = \sqrt{\gamma_3 R_3 T_3} \ , \quad (20)$$

$$C_4 = \sqrt{\gamma_3 R_3 T_4} \ , \quad (21)$$

$$V_3 = C_3 M_3 \ , \quad (22)$$

$$V_4 = C_4 M_4 \ . \quad (23)$$

The temperature and pressure at the exit from the diffuser are calculated as follows:

$$T_5 = \frac{1 + \frac{\gamma_3 - 1}{2} M_4^2}{1 + \frac{\gamma_3 - 1}{2} M_5^2} \ , \qquad (24)$$

$$P_5 = \frac{1+\gamma_3 M_4^2}{1+\gamma_3 M_5^2} P_4 \ . \qquad (25)$$

In order to determine the outlet pressure from the ejector, the following relationships can be used:

$$\frac{A_1}{A_d} = \frac{P_6}{P_1}\left(\frac{1}{(1+w)(1+w\frac{T_v}{T_1})}\right)^{1/2} \cdot \frac{\left(\frac{P_2}{P_6}\right)^{\frac{1}{\gamma_1}} \cdot \left(1-\left(\frac{P_2}{P_6}\right)^{\frac{\gamma_1-1}{\gamma_3}}\right)^{1/2}}{\left(\frac{2}{\gamma_1+1}\right)^{\frac{1}{\gamma_3-1}} \cdot \left(1-\frac{2}{\gamma_3+1}\right)^{1/2}} \ , \qquad (26)$$

$$P_6 = P_5\left(\eta_d \frac{\gamma_3-1}{2} M_5^2 + 1\right)^{\frac{\gamma_3}{\gamma_3-1}} . \qquad (27)$$

Thus, the output stream from the ejector:

$$m_6 = m_1 + m_v . \qquad (28)$$

Equations (1) - (28) allow you to calculate the ejector for a given output. Problems of this kind are effectively solved by using various modeling applications. In particular, the use of the universal simulation program (UMP) ChemCad allows you to calculate the thermal properties of air currents with volatile components of various paintwork materials. In [9-11] examples of solving applied problems with the help of UMP ChemCad are considered.

Equations (1) - (28) were written into the algorithm for calculating the ejector for various operating modes (using the Data Map tool). A block diagram of the calculation of the ejector is shown in Fig. 2.

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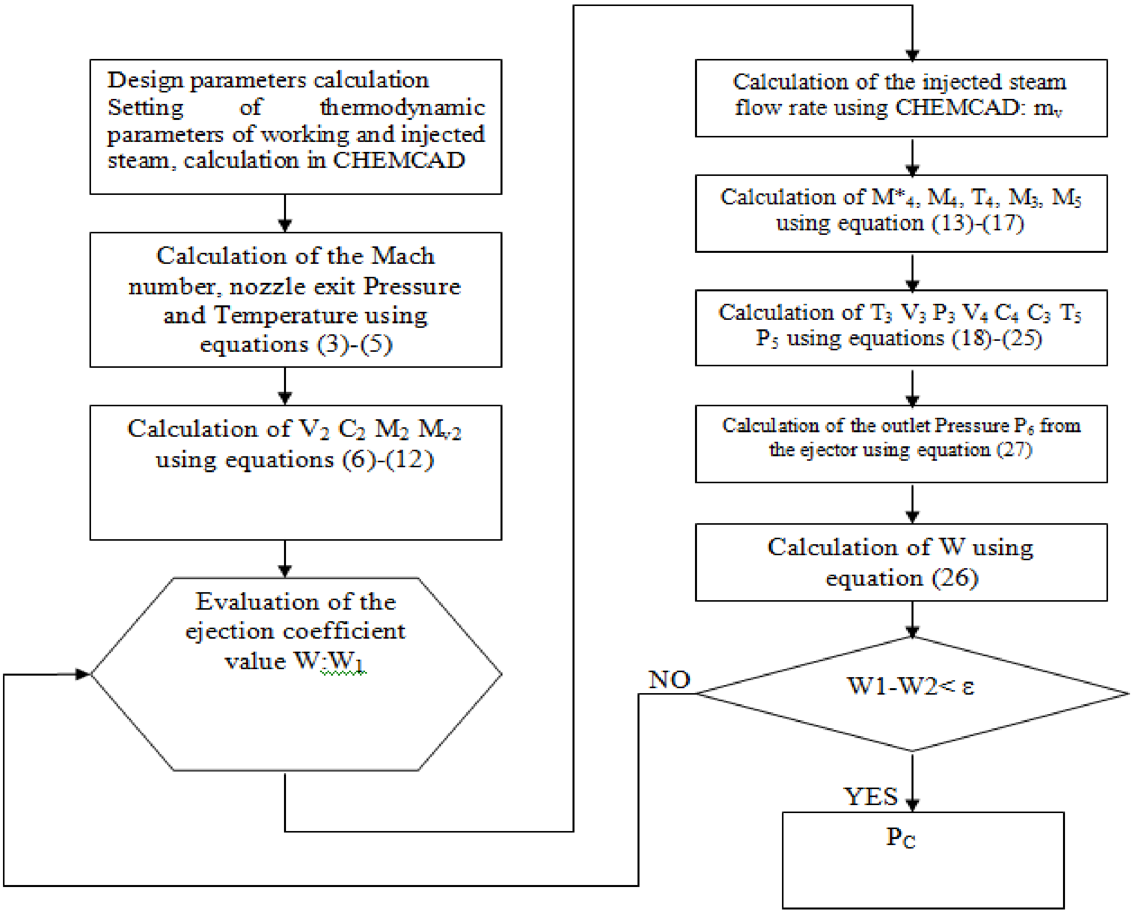

Fig. 2. Block diagram of the algorithm for calculating the ejector using equations (1) - (28)

Fig. 3 shows the design of the ejector in the UMP ChemCad. The square contours denote the following streams: 1 - passive stream (PS); 2 - gas on the suction nozzle of the ejector; 3 - mixture of AS and PS; 4 - gas at the outlet of the ejector; 5, 6 - active stream (AS). Circular contours denote the modules of the design circuit simulating an ejector and a fan, where module 3 (Mixer) is a mixer that mixes the input streams at a given output pressure; Module 1 (Pump) - the fan; Module 2 (Valve) - simulates the pressure drop on the suction line; Module 4 (Valve) - simulates the increase in pressure in the output cone of the ejector.

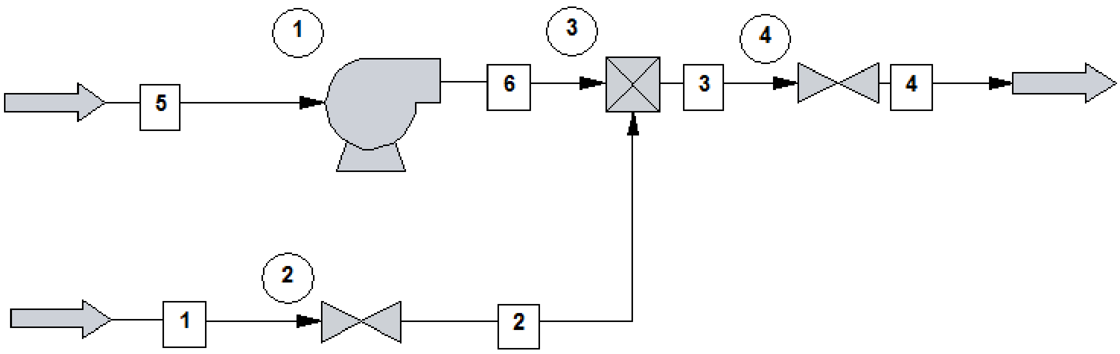

Fig. 3. The design scheme of the ejector

The table shows the calculated geometric dimensions and parameters of the ejector for a capacity of 6,000 m^3/s, which can be recommended for ventilation of a painting chamber measuring 5.4 × 3.4 × 2.5 m:

Table1:*Parameters of the Ejector*

Parameters of the Ejector	Geometric size, mm
Diameter of nozzle outlet section, d_1	211
Diameter of the beginning of the mixing chamber, d_2	470
Diameter of ejector neck, d_3	376
Diameter of diffuser mouth, d_4	800
Suction diameter, d_s	560
Diameter of pressure pipeline, d_n	500
Length of mixing chamber, L_{ch}	1320
Length of the diffuser, L_{dif}	4240
Height of the cylindrical part of the nozzle, G	106
Height of nozzle fusion, E	422
Distance from the center of the pressure duct to the bottom of the intake chamber, З	500
Height of the receiving chamber, K	1000
Diameter of the receiving chamber, d_r	1000
Length of the diffuser of the receiving chamber, M	560
The length of the confuser of the receiving chamber, I	528

To the ejector it is proposed to install a fan of the brand VTS5-35-8V1.01, an electric motor AM132M4 and a consumed power of 11 kW. The speed of rotation is 1500 rpm, the developed total pressure is 2900 - 2060 Pa.

Conclusion: Since all paint and varnish coatings are lightly combustible substances, it is desirable to use an ejection exhaust ventilation system when designing the ventilation of the painting chambers (both new and those to be refurbished). Using the Data Map tool (UMP built-in function), which connects the body of the universal simulator of the ChemCad UMP with a user file, it is possible to integrate the thermophysical properties of the flows into formulas (1) - (28), thereby automating the calculation process.

The obtained results can be recommended for calculation in the design of the ventilation system of painting chambers by the ejection method.

List of symbols

P - pressure, kPa; T- temperature, ^{o}k; A- cross-sectional area, m^2; γ- the adiabatic exponent; C- speed of sound, m/s; V- actual speed, m/s; M-Mach's criterion; R– Universal gas constant, kJ / (kg ^{O}K);w - Ejection coefficient; η- Efficiency; m- mass flow rate, kg/s.

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v - Passive stream parameters; 1 - parameters of the active stream; 2 - parameters on the nozzle section; 3 - parameters of the mixed stream; 4 - parameters before entering the diffuser; 5 - parameters at the exit from the diffuser; 6 - parameters at the exit from the ejector; c- parameters relating to the nozzle; d - parameters related to the diffuser; * - Critical parameters.

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