Modeling the Air Flow Cooling Process and Determining the Geometric Dimensions of the GASK Model

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Abstract. The article is devoted to the calculation of the parameters of the air flow cooling process and the determination of the geometrical dimensions of a model of a gas-jet apparatus of a special design with a gas flow bifurcation (GASK). The article discusses the device and the principle of operation of the GASK, calculates the dependences of temperature on the pressure drop, gas flow rate on the gas pressure ratio. The calculated parameters of the process under consideration and the geometric dimensions of the GASK are given.

1. Introduction

Cooling of the air flow can be done in various ways and devices. Heat exchangers or cooling devices are used to cool the air flow. Cooling methods with such devices are subdivided into direct cooling and cooling with a liquid coolant (indirect cooling method). The features that influence the technological process determine the area of application of a particular method. For direct and indirect cooling, refrigeration units are used, which include finned pipes that are now widespread. There is also a battery cooling system. Such systems are often used in conjunction with air cooling systems that have a suction duct in their design (with ducted air blowing). Also, the cooling of the air flow in the room can be carried out by means of a panel cooling system with a duct with isolation in the dynamics.

Airflow cooling systems can differ in the way of air distribution. The use of a distributed type duct system is often found in refrigeration plants. This system is called ducted air distribution system. There are systems with ejector air distribution: with suspended air coolers and floor air coolers. The channelless air distribution system has received widespread use. However, taking into account the peculiarities of the technological process within the framework of the task of designing a laboratory sample of an absorption air conditioner, to ensure the process of cooling the air flow, the most rational is the use of gas-jet devices of a special design.

Gas-jet apparatus with a specially designed bifurcated gas stream (hereinafter - GASK) is ravnofaznym jet apparatus ohm, in which the working (active) and ejected (passive) flows are elastic.
medium (air). GASK carries out the implementation of cooling the air leaving the first (absorption) unit of the air conditioner.

2. Structure and working principle GASK
As part of the design of a laboratory sample of an absorption air conditioner, the following GASK design was adopted, shown in Figure 1.

![Figure 1. Accepted design of GASK.](image)

GASK is a technical device consisting of: fan, receiving chamber, working nozzle, expansion chamber, mixing chambers.

The fan is a typical model with technical characteristics: D_v - diameter; P_v - pressure; G_v - consumption.

The inlet chamber is a cylindrical branch pipe with the following characteristics: L_p - length; D_p - diameter.

The ejector nozzle is a channel (truncated cone) smoothly tapering in the direction of flow (nozzles of this profile are used at subsonic flow velocities). Ejector nozzle characteristics: L_e - length; S_c1 - area at the inlet of the gas flow; S_c2 - area at the outlet of the gas flow.

The body is an insulated (to ensure the adiabaticity of the processes) box.

The expansion chamber is a truncated cone with the following characteristics: L_rk - length; S_rk1 - area at the gas flow inlet; S_rk2 - area at the outlet of the gas flow.

Thus, all surfaces that make up the GASK have a circular cross-section. In the future, it is planned to investigate how significantly the geometric shapes affect the output characteristics of the GASK, and, if necessary, to optimize them.

The air flow, leaving the first (absorption) unit of the air conditioner, is blown by the fan into the intake chamber. Then there is a bifurcation of the air flow:
- one part (working stream) enters the ejector nozzle;
- the other part (ejected flow) enters the expansion chamber.

The working flow is inside the GASK, and the ejected flow is at the periphery. The expansion chamber is thus an annular nozzle.

The air flow entering the expansion chamber slows down and expands. The temperature in the expansion chamber decreases. The expansion of the air and the associated decrease in temperature is determined by the ejection characteristics of the nozzle channel and the air flow rate through the expansion chamber.

The ejector nozzle is designed to increase the kinetic energy (speed) of the flow. The air flow leaving the nozzle into the mixing chamber creates a vacuum zone into which air from the expansion chamber is sucked in.

Vacuum at the inlet of the mixing chamber, which allows the injection of low-pressure gas into the ejector, is ensured due to the continuous capture by the high-pressure jet that leaves the nozzle, particles of the ejected gas at the beginning of the mixing chamber section, and is carried away by it into the mixing zone. Thus, the evacuation of the air flow from the expansion chamber into the mixing chamber is carried out and, further, it is released outside. GASK works without a diffuser, the final
section of the mixing chamber is at the same time the outlet section. The mixed flow at the outlet has a pressure higher than the pressure of the ejected flow at the inlet to the apparatus, but lower than the pressure of the working flow.

The mixed flow pressure at the outlet is higher than the pressure of the ejected flow in front of the apparatus, but lower than the pressure of the working flow.

The movement of air masses inside the GASK is provided by a duct fan ERA PROFIT 4 12V. Fan characteristics are presented in table 1.

Table 1. Technical characteristics of the ERA duct fan PROFIT 4 12V.

| Nomination                              | Value |
|-----------------------------------------|-------|
| Maximum air flow (m3 / h)              | 107   |
| Pressure (Pa)                           | 46    |
| Sound pressure level at dist . 3 m     | 35    |
|  ( dB ( A))                             |       |
| Voltage (V)                             | 12    |
| Frequency ( Hz )                        | Fifty |
| Current (A)                             | 1.33  |
| Current type                           | Variable |
| Power consumption ( W )                 | Sixteen |
| Protection class ( IP )                 | 24    |
| Weight ( kg )                           | 0.38  |

Taking into account the given data, the parameters of the air flow cooling process were calculated.

3. Calculation of the parameters of the air flow cooling process

Since the working and ejected flows are in the same phase (gas), the operation of the gas-jet apparatus is significantly related to the compression ratio of the ejected medium, and to the expansion ratio of the working medium. The ratio of the final compression pressure to the initial pressure is called the compression ratio . In the same way, the expansion ratio of the working flow is the ratio of the initial pressure at the inlet to the nozzle to the final pressure at the outlet of the nozzle .

In calculating accept that the flow of gas in the Inside of the nozzle is adiabatically s nature , because of the small flow time of gas particles through the nozzle of the heat exchange with the environment can be said not to occur . From this it follows that when calculation e nozzle can Utilized be Equation e adiabatic flow. Neglecting the effect of friction on the process , the flow inside the nozzle should be considered isentropic. Based on the experience of loss, obrazovavshiesya under the influence of friction I in short nozzles n eznachitelny .

The state of the gas at each point is characterized by thermodynamic parameters:

\[ P \] - pressure;
\[ T \] - temperature;
\[ \omega \] - speed;
\[ \nu \left( or \ \rho = \frac{1}{\nu} \right) \] - specific volume.

In the case of adiabatic gas outflow from the nozzle channel, the internal energy of the gas is converted into kinetic energy of directed motion. The outflow rate increases, and the gas pressure and temperature decrease along the channel in the direction of flow in accordance with the Poisson equation (1):

\[ \rho = \frac{1}{\nu} \]
According to the above graph (Figure 2), you can navigate how the temperature \( T_2 \) will decrease depending on the pressure difference at the inlet and outlet of the nozzle \( \left( \frac{P_2}{P_1} \right) \).

The high-pressure air flow leaving the nozzle into the mixing chamber creates a vacuum in the expansion chamber. Thus, the air flow is evacuated from the expansion chamber into the mixing chamber and, then, is released outside. The temperature in the expansion chamber will decrease according to dependence (2):

\[
T_1 \left( \frac{v_2}{v_1} \right)^{k-1} = \text{const}, \quad T_1 = \left( \frac{P_1}{P_2} \right)^{1/k},
\]

where

\( k = 1.4 \) is the adiabatic index for air;

\( v_1 \) - specific volume in the inlet section of the chamber;

\( v_2 \) - specific volume of gas in the outlet section of the chamber.

The flow density is \( \rho \) determined from the ideal gas equation (3):

\[
P = \rho R T,
\]

where \( R \) is the universal gas constant.

The hydraulic calculation of the nozzle is reduced to determining the dimensions of the nozzle outlet section \( \Sigma \) to a given gas flow rate \( G \) and a given outflow velocity \( w_2 \).

The velocity \( w_2 \) at the exit from the nozzle for a real gas is determined by the formula (4):

\[
w_2 = \sqrt{2(h_1 - h_2) + w_1^2},
\]

where

\( w_1 \) - speed at the entrance to the nozzle channel;

\( h_1, h_2 \) - enthalpy of the gas at the inlet and outlet from the nozzle.
The enthalpy difference is set according \( h_{2, h} \) to the diagram. Having known values of the gas state at point 1 and at least one value at point 2, one can find \( h_{2} \).

Also, the flow rate from the nozzle \( w_2 \) can be calculated by the formula for an ideal gas (5) (air under normal conditions is an ideal gas):

\[
w_2 = \frac{2k}{k-1} p_1 v_2 \left[ 1 - \left( \frac{p_2}{p_1} \right)^{\frac{k-1}{k}} \right] + w_1^2 ,
\]

(5)

And of equation (5) it is known that the gas outflow speed from the nozzle \( w_2 \) is greater, the smaller the value of ratio indices pressures \( \frac{p_2}{p_1} \).

The gas flow through the nozzle \( G \) is calculated in this way. The volume of gas that leaves the nozzle in one unit of time is known to be equal to the expression (6)

\[
V_2 = v_2 \cdot G ,
\]

(6)

where \( v_2 \) is the specific volume of gas in the nozzle section at the outlet.
Nevertheless, the same quantity \( V_2 \) can be determined in the form of expression (7)

\[
V_2 = \Sigma \cdot w_2 ,
\]

(7)

This shows that

\[
G = \frac{\Sigma \cdot w_2}{v_2} .
\]

Substitutions in this with ootnoshenii \( v_2 \) by adiabatic equation (8)

\[
\frac{1}{v_2} = \left( \frac{p_2}{p_1} \right)^{\frac{1}{k}} \cdot \frac{1}{v_1} ,
\]

(8)

Get them expression (9):

\[
G = \frac{\Sigma \cdot w_2}{v_1} \left( \frac{p_2}{p_1} \right)^{\frac{1}{k}} ,
\]

(9)

and whether (10)

\[
G = \Sigma \cdot \frac{2k}{k-1} \frac{p_1 v_1}{v_2} \left[ \left( \frac{p_2}{p_1} \right)^{\frac{2}{k}} - \left( \frac{p_2}{p_1} \right)^{\frac{k-1}{k}} \right] ,
\]

(10)

The resulting equation (10) relates the mass flow of an ideal gas at reversible adiabatic flow through a nozzle outlet cross-sectional area \( \Sigma \) and the parameters \( p_1, v_1, p_2 \).

The gas temperature at the outlet of the nozzle \( T_2 \) can be calculated using known parameters \( p_2 \) and \( v_2 \) from the Clapeyron equation.

Using this equation, the inverse problem is also solved - to find what the area of the nozzle exit section \( \Sigma \) should be in order to provide a given gas flow \( G \) rate through the nozzle for given gas parameters at the nozzle inlet and outlet.
Figure 3. Dependence of the flow rate $G$ on the gas pressure ratio.

Analysis of the nature $G$ of the dependence of the flow rate on the ratio of the gas pressure at the outlet from the nozzle to the pressure in front of the nozzle $\frac{p_2}{p_1}$ shows that this dependence has the form shown in Figure 3.

The central element of the GASK is the ejection nozzle, which is designed to increase the kinetic energy (speed) of the flow. Since GASK operates in the range of subsonic speeds and pressures close to 1 atm. (normal pressure), a simple tapered converging nozzle is used.

When designing a nozzle, it is necessary to minimize energy losses, its dimensions and weight.

On the basis of the above calculated ratios, as well as taking into account the experimental data, the parameters of the air flow cooling process and the geometric dimensions of the GASK model were obtained, which will be used as part of a laboratory sample of an absorption air conditioner to ensure the indoor microclimate (Table 2).

Table 2. Parameters of the air flow cooling process and geometric dimensions of the GASK model.

| Parameter name                        | Meaning | Unit of measure |
|---------------------------------------|---------|-----------------|
| Inlet air temperature                 | 21.4    | WITH            |
| Outlet air temperature                | 19.1    | WITH            |
| Air consumption                       | 107     | $m^3$/h         |
| Inlet pressure                        | 101,371 | Pa              |
| Outlet pressure                       | 101,325 | Pa              |
| Inlet nozzle diameter                 | 90      | mm              |
| Outlet nozzle diameter                | 64      | mm              |
| Nozzle length                         | 350     | mm              |
| Expansion chamber diameter at inlet   | 100     | mm              |
| Expansion chamber diameter at outlet  | 160     | mm              |
| Mixing chamber length                 | fifty   | mm              |

Existing methods and analytical dependencies do not allow to correctly calculate the required geometric parameters (configuration) and pressure-energy characteristics of GASK. To increase the efficiency, it is necessary to find the optimal distance from the nozzle outlet to the mixing chamber inlet. As the nozzle moves away from the mixing chamber, the cross-sectional area of the expanding jet at its inlet increases, which may turn out to be larger than the cross-section of the mixing chamber. And, therefore, the outer part of the jet will not pass into the mixing chamber, causing turbulence in the GASK. As a result, the efficiency of the GASK will decrease due to the energy losses arising from the eddies.
4. Conclusion
An important role in determining the efficiency of the GASK operation is played by the size and configuration of the mixing chamber, the main task of which is to mix and equalize the speeds of the working and passive streams. For a cylindrical mixing chamber to equalize the field of speeds of the working and ejected flow, the length of the mixing chamber should be 6-8 of its diameters. With an increase in the length of the mixing chamber, the process of equalizing the velocities ends long before the outlet section and a fraction of the energy of the mixed flow is spent on overcoming the friction against the inner surface of the remaining part. Mixing is incomplete with a short mixing chamber. With a decrease in the relative length of the mixing chamber \( L_{ks} / D_{ks} \) to a certain value:
- the maximum efficiency increases;
- the pressure increases;
- the mass ejection coefficient increases
For conical nozzles, it is recommended that the distance between the outlet section of the nozzle and the inlet section into the mixing chamber tends to zero.
The presented GASK model is planned to be modified in order to be able to determine the optimal configuration and study the operating modes. For this, it is planned to implement a collapsible modular GASK design. This will allow:
- change working nozzles;
- adjust the distance between the outlet section of the working nozzle and the mixing chamber;
- change the volume of the expansion chamber and the mixing chamber.
To obtain an optimal GASK model, it is necessary to obtain and process a sufficient array of experimental data.

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