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RESISTANCE AND FLOW CHARACTERISTICS OF FREE AIR FLOWING THROUGH END VENT HOLE OF CYLINDRICAL PIPELINE IN UNLIMITED SPACE

In the article there are analyzed analytically and given approximate numerical values of resistance and flow characteristics of free air flowing through the end vent hole of cylindrical pipeline in unlimited space.

Key words: local resistance, flow characterastic, leakage, suction.

Проаналізовані аналітично і визначені наближені числові величини опірних і витратних характеристик вільного перетікання повітряного потоку через вільний отвір трубопроводу в необмежений простір.

Ключові слова: місцевий опір, витратна характеристика, витікання, всмоктування.

Statement of the problem

In the literature are ambiguously interpreted analytical basis to determine the resistance and flow characteristics of free end vent holes in the pipeline leakage air flow into unlimited space and air suction from the unlimited space. There is also no definite guidelines for the experimental determination of the local resistance of the holes, especially during the suction.

For example in the [5, 6, 7] the coefficient of local resistance by the free outflow air flow into the atmosphere $\zeta_{\text{вит}}$ equal to one, according to [5, 7] the coefficient of local resistance by the free suction $\zeta_{\text{всм}}$ is also taken as equal to one, although the phenomena that occur in outflow and suction is different [1, 2], indicating that at the air intake from the unlimited space in the hole pressure loss is always lower than the losses in the outflow of air flow in unlimited space.

Analysis of recent research and publications

In the local piping resistance changing the structure of the flow velocity and formed vortex, causing pressure loss. Thus, the movement of air flow through the local resistance is always accompanied by pressure loss. Universal analytical method for calculating the pressure loss of local resistance is absent, and therefore their value is determined by experimentally. The results of numerous experimentals proved that the pressure loss of local resistance proportional to the square of the average of the flow velocity [1, 2, 3, 4]. This fact is confirmed by the fact that the pressure loss for turbulent regime of the flow in the pipe is proportional to its kinetic energy as the tear-off and secondary currents and wortex – origin of inertial effects, the intensity of which depends on the square of the speed. Therefore, to determine the pressure loss in the local pipeline resistance used Veysbah dependence

$$\Delta p_{\text{M}} = \zeta \cdot \frac{\rho \upsilon^2}{2} , \tag{1}$$

where ζ – the coefficient of local pipeline resistance.

In formula (1) speed refers to the characteristic of the living section of the relevant local resistance to the pipeline or section of it, in which uniform flow. For the experimental determination of sufficient flow to measure air flow and the pressure difference in its two distinctive sections. This second section should be located at a distance of the flow, but within the influence of local resistance.

Numerous experimental studies have established that for, and its value depends only on the geometry of local resistance. Provided that the velocity field before and after the local resistance of the pipeline uniform as the density of air and the air flow in the pipeline about the same, the force of gravity can be ignored, and the flux density – considered approximately constant. For example, by varying the air pressure within ± 1000 Pa, changing the density of air at standard conditions is less than ± 0,6%. Thus, the study of the movement of air flow in ventilation system (VS), their density can be approximately be equal to the density of the surrounding air. Since the speed of air flow in pipelines VS is small (usually up to 12 m/s), they can be regarded as uncompressible gas flows conventionally, ie taking.

The aim of the article is an analytical evaluation of the coefficient of local resistance and flow free end vent hole piping for leakage and suction air flow from the unlimited space.

Resistance and flow characteristics of free air leakage end vent hole of the pipe into the atmosphere

Consider the isothermal leak free air flow with mechanical opening of the pipeline in the atmosphere. Scheme of leakage is shown in Fig. 1.

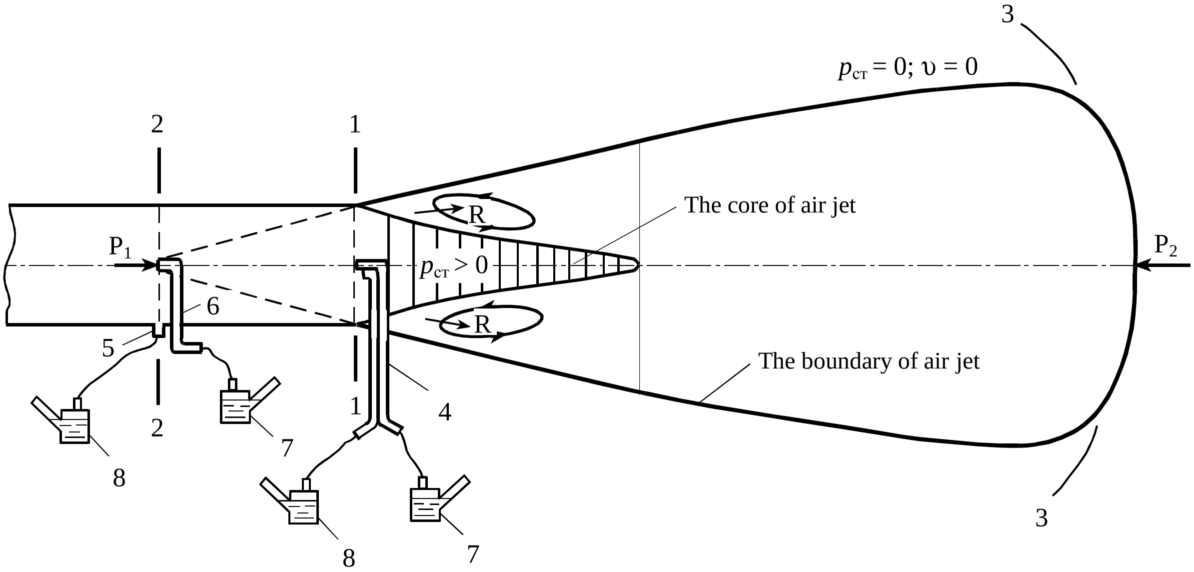

Fig. 1. The scheme of free air flow leakage from open hole of pipeline in unlimited space: 1, 2, 3 – typical cross flow; 4 – Pitot-Prandtl tube; 5 – device for measuring of static pressure; 6 – total pressure tube; 7, 8 – differential micromanometers

We believe that the structural parameters of the flow in the plane 1-1 hole is not different from a uniform flow in some neighbor-section 2-2, ie, $\alpha_1 = \alpha_2$ and $\upsilon_1 = \upsilon_2$.

Neglecting gravitational pressure Bernoulli equation for sections 1-1 uniform flow in the pipeline and the end hole sectional contour on the surface 2-2 of the bag overpressure can be written as

$$p_{\text{ст.1}} + \alpha_1 \frac{\rho\upsilon_1^2}{2} = p_{\text{ст.3}} + \alpha_3 \frac{\rho\upsilon_3^2}{2} + \Delta p_{\text{вит}} \ , \qquad (2)$$

where α – the Coriolis coefficient (coefficient of velocity distribution in the typical elementary strumintsiv sectional flow); $p_{\text{ст.1}}$ – hydrostatic overpressure in section 1-1 of air flow; $p_{\text{ст.3}}$ – hydrostatic pressure on the surface of the conventional bag overpressure, formed by supply air ($p_{\text{ст.3}} \approx 0$); $\Delta p_{\text{вит}}$ loss of pressure at the free airflow leakage into the atmosphere; υ_1, υ_3 – average flow velocity, respectively, in sections 1-1 and 3-3 ($\upsilon_3 = 0$).

If the velocity at all points of the live flow section of the same $\alpha = 1$, and if not identical $-$ $\alpha > 1$ [1, 2For major cases of the fluid in the pipes $\alpha = 1{,}04...1{,}08$.

From equation (2) we have

$$\Delta p_{\text{вит}} = (p_{\text{ст.1}} - p_{\text{ст.3}}) + \alpha_1 \cdot \frac{\rho\upsilon_1^2}{2} \ , \qquad (3)$$

or

$$\zeta_{\text{вит}} \cdot \frac{\rho\upsilon_1^2}{2} = (p_{\text{ст.1}} - p_{\text{ст.3}}) + \alpha_1 \cdot \frac{\rho\upsilon_1^2}{2} = (p_{\text{ст.1}} + \alpha_1 \cdot \frac{\rho\upsilon_1^2}{2}) - p_{\text{ст.3}} \ . \qquad (4)$$

where

$$\zeta_{\text{вит}} = \frac{p_{\text{ст.1}} - p_{\text{ст.3}}}{\rho\upsilon_1^2 / 2} + \alpha_1 = \frac{p_{\text{ст.1}} - 0}{\rho\upsilon_1^2 / 2} + \alpha_1 \ . \qquad (5)$$

As always $p_{\text{ст.1}}$ above zero (otherwise there happened to leakage flux in free space), and $\alpha_1 \geq 1$ ($\alpha = 1{,}06$ according to Bazin experiments [2]), the value $\zeta_{\text{вит}}$ slightly greater than one.

Analyze the leakage of air from the hole in infinitely thin wall in unlimited space for isothermal conditions. Leakage circuit shown in Fig. 2.

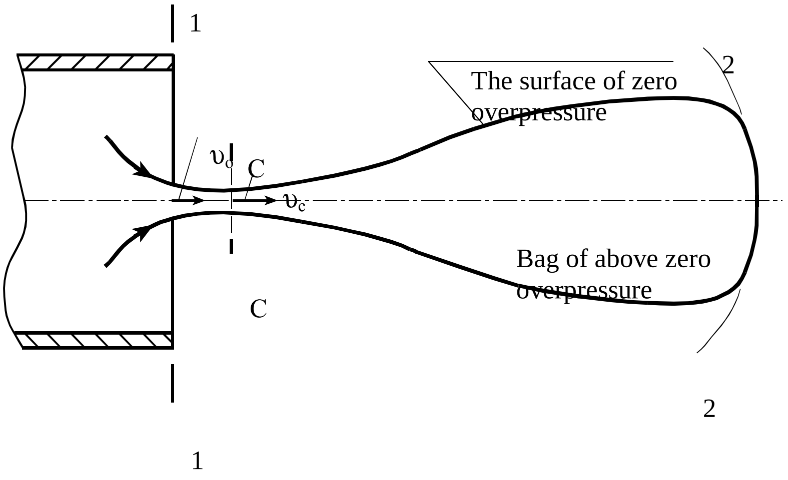

Fig.2. The scheme of free air flow leakage from the hole in infinitely thin wall

The Bernoulli equation for the characteristic cross of airflow

$$p_{\text{ст.1}} + \alpha_1 \cdot \frac{\rho\upsilon_0^2}{2} = p_{\text{ст.2}} + \alpha_2 \cdot \frac{\rho\upsilon_c^2}{2} + \zeta_{\text{зв}} \cdot \frac{\rho\upsilon_c^2}{2} \ . \qquad (6)$$

If the hydrostatic overpressure is $p_{\text{ст.2}} = 0$ then

$$p_{\text{ст.1}} + \alpha_1 \cdot \frac{\rho\upsilon_0^2}{2} = p_{\text{ст.2}} + (\alpha_2 + \zeta_{\text{зв}}) \cdot \frac{\rho\upsilon_c^2}{2} \ . \tag{7}$$

According to the formula continuity of flow $\upsilon_o \cdot \omega_o = \upsilon_c \cdot \omega_c$

Because $\upsilon_c = \varepsilon \cdot \upsilon_o$, then $\upsilon_o = \frac{\varepsilon \cdot \omega_c}{\omega_o} \cdot \upsilon_c = \varepsilon \cdot n \cdot \upsilon_c$,

where $\varepsilon = \omega_c / \omega_o$ – compression ratio jet.

If we accept

$$\zeta_{\text{вит}} = \alpha_2 + \zeta_{\text{зв}} , \tag{8}$$

then equation (7) can be written as

$$(p_{\text{ст.1}} - 0) = (\alpha_1 + \zeta_{\text{вит}}) \cdot \frac{\rho\upsilon_c^2}{2} \ . \tag{9}$$

Leakage speed air flow in the narrower section

$$\upsilon_c = \frac{1}{\sqrt{\alpha_1 + \zeta_{\text{вит}}}} \cdot \sqrt{\frac{2\ (p_{\text{ст.1}} - 0)}{\rho}} = \varphi \cdot \sqrt{\frac{2\ (p_{\text{ст.1}} - 0)}{\rho}} \ , \tag{10}$$

where φ – coefficient of initial velocity jet $\varphi = \frac{1}{\sqrt{\alpha_1 + \zeta_{\text{вит}}}}$

Consumption of air jet in cross-section C-C

$$Q_o = \omega_c \cdot \upsilon_c = \varepsilon \cdot \omega_o \cdot \upsilon_c$$

When substituting the value υ_c in the previous equation we obtain

$$Q_o = \varepsilon \cdot \varphi \cdot \omega_o \cdot \sqrt{\frac{2\Delta p_{\text{ст}}}{\rho}} = \mu_o \cdot \omega_o \cdot \sqrt{\frac{2\Delta p_{\text{ст}}}{\rho}} \ , \tag{11}$$

Where μ_o – hole expenses coefficient $\mu_o = \varepsilon \cdot \varphi$.

The value of this ratio for small holes, taking approximately equals

$$\mu_o = \varepsilon \cdot \varphi = 0{,}64 \cdot 0{,}97 = 0{,}62$$

So the equation for determining the expence of the leakage uncompressible airflow, that comes out of the hole unlimited thin wall into the atmosphere has the form

$$Q_o = \mu_o \cdot \omega_o \cdot \sqrt{\frac{2\ (p_{\text{ст.1}} - 0)}{\rho}} \ , \tag{12}$$

where μ_o – coefficient of consumption in the hole leakage flux in the atmosphere; ω_o – the live-sectional area of the hole, m^2; $p_{\text{ст.1}}$ – the hydrostatic overpressure in the plane of the hole, Pa.

$$\mu_o = \varepsilon \cdot \varphi = \varepsilon \cdot \frac{1}{\sqrt{\alpha_1 + \zeta_{\text{вит}}}} \ . \tag{13}$$

For air $\varepsilon = 0{,}64...0{,}74$ (0.74 – at the critical regime leakage; 0,64 – at leak from hole in the thin wall); $\alpha_1 = 1{,}04...1{,}08$ – for basic traffic cases in the airways.

In view of the above-mentioned values of free flow coefficient (not limited) end hole air ducts of circular cross section can be defined by the equation

$$\mu_o \approx \frac{0{,}64}{\sqrt{1{,}06 + \zeta_{\text{вит}}}} , \tag{14}$$

and the amount of air that comes out of the hole in the atmosphere is equal to

$$Q_{\text{вит}} = \mu_{\text{вит}} \cdot \omega_o \cdot \sqrt{\frac{2\ (p_{\text{ст.1}} - 0)}{\rho}} . \tag{15}$$

Accordingly, the equation for determining the flow conditional incompressible air flow is absorbed (numb) from the atmosphere into free final hole pipe of circular cross section, has the form

$$Q_{\text{всм}} = \mu_{\text{всм}} \cdot \omega_{\text{o}} \cdot \sqrt{\frac{2\,(0 - p_{\text{ст.2}})}{\rho}} \ ,$$

where $\mu_{\text{всм}}$ – flow rate ratio coefficient of pipe hole with free suction from the atmosphere; ω_{o} – the live-sectional area of the hole, m^2; $p_{\text{ст.2}}$ – hydrostatic pressure (vacuum) in the plane of the hole, Pa.

$$\mu_{\text{всм}} = \frac{\varepsilon}{\sqrt{\alpha_2 + \zeta_{\text{всм}}}} \approx \frac{0{,}64}{\sqrt{1{,}06 + \zeta_{\text{всм}}}} \ .$$

A generalized equation for determining the flow rate ratio coefficients of the final holes pipelines will look

$$\mu_{\text{вит, всм}} \approx \frac{0{,}64}{\sqrt{1{,}06 + \zeta_{\text{вит,всм}}}} \ . \tag{16}$$

where $\zeta_{\text{всм, вит}}$ – by the coefficient of local resistance of unlimited holes for suction air flow into it from conventionally fixed atmosphere and its leakage to the atmosphere.

Resistance and flow characteristics of the air suction from the atmosphere to the unlimited end hole pipe

The scheme of air sucking from the atmosphere in unlimited end hole pipe for isothermal conditions is shown in Fig. 3.

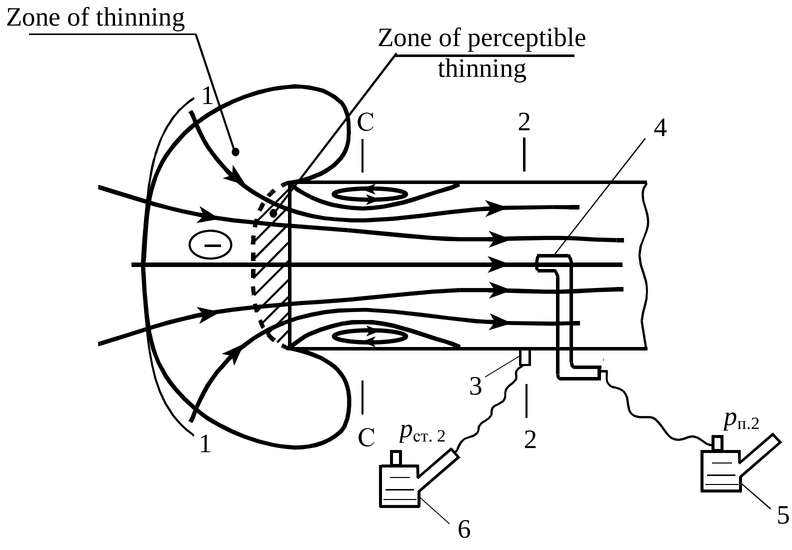

Fig. 3. Suction scheme of air flow from unlimited space in the open end hole pipeline: 1, 2 – typical cross flow; 3 – measure device of static pressure; 4 – total pressure tube; 5, 6 – differential micromanometers

Bernoulli's equation of curved surface on the marginal conditional fixed ambient air (section 1-1) and near the extreme section of the suction pipe with a uniform air flow (section 2-2).

$$p_{\text{ст.1}} + \alpha_1 \cdot \frac{\rho \upsilon_1^2}{2} = (\,p_{\text{ст.2}} + \alpha_2 \cdot \frac{\rho \upsilon_2^2}{2}\,) + \Delta p_{\text{всм}} \ . \tag{17}$$

Since $p_{\text{ст.1}} = 0$ and $\upsilon_1 = 0$, the equation (17) takes the form

$$\zeta_{\text{всм}} \cdot \frac{\rho \upsilon_2^2}{2} = p_{\text{ст.1}} - p_{\text{ст.2}} - \alpha_2 \cdot \frac{\rho \upsilon_2^2}{2} = (0 - p_{\text{ст.2}}\,) - \alpha_2 \cdot \frac{\rho \upsilon_2^2}{2} \ , \tag{18}$$

or

$$\zeta_{\text{всм}} = \frac{0 - p_{\text{ст.2}}}{\rho\upsilon_2^2 / 2} - \alpha_2 \ . \tag{19}$$

Since the value $p_{\text{ст.2}}$ is below zero, and $\alpha_2 \approx 1$ (for uniform traffic flow in section 2-2) and $\alpha_2 = 1{,}06$ (compressed section C-C, according to Bazin experiments [2], the value $\zeta_{\text{всм}}$ will be much less than one.

The main source of pressure loss in this case is the area of separated flow, which occurs due to compression of the flow when it is flowing in the pipeline, followed by its extension. By the action of centrifugal forces warped air streams elementary stream is compressed and a short distance from the edge of a live stream of the minimum cross section (section C-C). This phenomenon is called the effect of compression flow.

Analytical effect of compression, a sudden decrease in cross-sectional flow in the pipeline Kirkhofom investigated. Dependence of the ratio ε ($\varepsilon = \omega_c / \omega_2$) of the class (power) reduction of flow area *n* ($n = \omega_2 / \omega_1$, where ω_1, ω_2 – area of flow in sections 1-1 and 2-2) indicated in the table. 1.

Table. 1

Dependence of the degree of compression reduced the area of flow n

ε	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8
n	0,611	0,612	0,616	0,622	0,633	0,644	0,662	0,687	0,722

Note: The numerical values relating to flat slotted holes

Analysis of the variables that are listed in the Table. 1 shows that the change of n from 0 to 0.5 magnitude is almost constant and equal to the average of 0.62. These data are flat slotted holes, but they are valid for holes of circular cross section. Because $\mu_{\text{всм}} = \varepsilon \cdot \varphi = \varepsilon \cdot \frac{1}{\sqrt{\alpha_2 + \zeta_{\text{всм}}}}$, then $\zeta_{\text{всм}} = 0{,}4$ provided, we get $\mu_{\text{всм}} = 0{,}64 \cdot \frac{1}{\sqrt{1{,}06 + 0{,}4}} = 0{,}53$.

At $\zeta_{\text{вит}} \approx 1$ we get $\mu_{\text{вит}} = 0{,}64 \cdot \frac{1}{\sqrt{1{,}06 + 1}} \approx 0{,}45$

Conclusions

1. Analysis of the process of free air flow leakage from the end hole pipe into the atmosphere in isothermal conditions suggests that the coefficient of local resistance, attributed to the dynamic pressure in the opening section slightly greater than one.
2. Analysis of the process of free air flow into the suction end hole pipe for isothermal conditions shows that the coefficient of local resistance, attributed to the dynamic pressure in the near-section of uniform flow is less than one.
3. To determine the numerical values of the coefficients of local resistance into free leakage from end hole to the atmosphere and free suction from atmosphere in the end hole pipe requires appropriate experimental studies.

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