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IMPROVEMENT OF AIR DISTRIBUTION IN A ROOM WITH SWIRLED AIR JETS

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The study examines the velocity decay processes in an isothermal free swirled air jet to improve methods for controlling the aerodynamic characteristics of air flows. The objective is to intensify the velocity decay in the supply air of an isothermal free swirling jet, determine the decay coefficient, and analyze axial velocities by constructing their profiles in cross-sections. To simplify calculations, the velocity decay coefficient "m" is introduced. The decay coefficient is determined, an analysis of axial velocity distribution is conducted, and corresponding graphs are constructed. A comparison of experimental data with theoretical models is performed. The features of turbulent structures formed during the decay process are investigated. The possibilities of regulating jet dynamics by modifying input parameters are considered. The obtained results can be used to optimize processes in various technical and industrial applications, including ventilation systems, gas dynamic installations, and energy complexes.

Keywords: air distribution, swirled jet, air velocity, attenuation coefficient, aerodynamics, turbulence.

Introduction

Effective air distribution in indoor spaces is a crucial task for ensuring a comfortable microclimate, energy efficiency, and stable operation of ventilation systems (Almaras et al., 2012). Traditional air supply methods do not always provide uniform flow distribution, which can lead to the formation of stagnant zones or excessive turbulence (Dovhaliuk V. et al., 2018). One way to improve air distribution is through the use of swirling air jets. These jets retain velocity for a longer duration, enhance air mass mixing, and distribute more evenly within the space. Due to these properties, swirling jets can effectively optimize ventilation processes in various indoor environments (Dovhaliuk V., Mileikovskyi V., 2018). Studying the characteristics of swirling jet motion helps to better understand their development patterns and develop methods for controlling aerodynamic properties. This opens up opportunities for improving ventilation, air conditioning, and industrial aerodynamic processes (Kapalo P. et al., 2014).

Materials and Methods

The formation of planar, axisymmetric, and swirling jets with pulsating velocity is influenced by the discharge of supply air from both open and shaded ventilation system openings (Lorin E. et al., 2007).

Various factors affect jet characteristics, particularly the surfaces they interact with. Jets without obstacles are considered free, while those influenced by surfaces are constrained (Kapalo, P. et al., 2017). A jet is classified as isothermal if its outlet temperature matches the indoor air temperature, whereas it is non-isothermal if the temperatures differ (Kapalo P., et al., 2014).

When the Reynolds number (Re) is below 2300, the flow is laminar, while a value exceeding 10,000 indicates turbulence (Andersson H., et al., 2018). The jet core represents a region of the flow with constant velocity and temperature. The jet's pole O is located at a specific distance from the nozzle exit along its axis. By drawing lines from this point through the nozzle exit boundaries, the external jet boundaries can be determined (Bin Z., et al., 2003).

Fig. 1 showed in the primary formation region of the jet, a gradual decrease in axial velocity occurs V_x (in non-isothermal jets), along with a decline in excess temperature Δt_x, which is defined as the difference between the air temperature in the jet t_x and that in the room t_{in} : $\Delta t_x = t_x - t_{in}$ (Gumen O., et al., 2019).

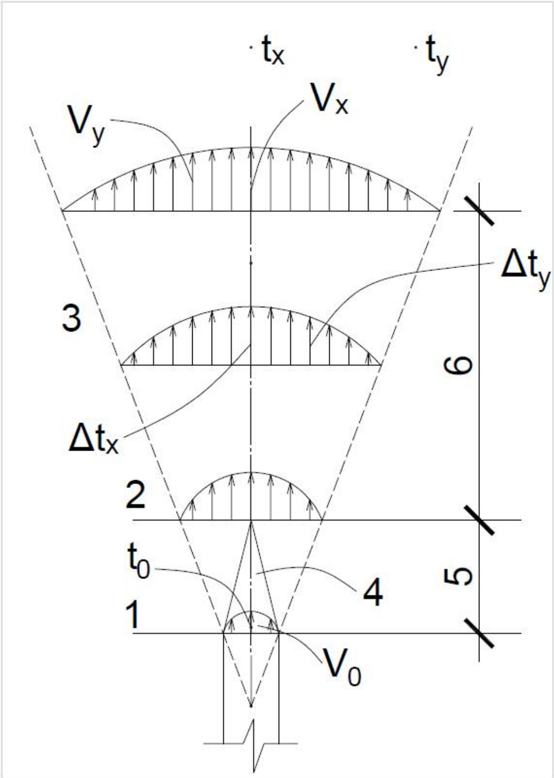

Fig. 1. Diagram of Free Air Jet Development: 1 – Initial cross-section; 2 – Transitional cross-section; 3 – Jet boundaries; 4 – Jet core; 5 – l_0 *(initial area); 6 –* l_x *(main area).*

Depending on the Ar_o parameter, supply jets are classified as weakly non-isothermal (barely affected by gravitational forces) and non-isothermal (significantly influenced by gravitational forces) (Gumen, O. et al., 2017).

The excess temperature $\Delta t_x = t_x - t_{in}$ (for horizontally directed weakly non-isothermal air jets) can be calculated using equation (1):

$$\Delta t_x = \frac{N}{x}, \tag{1}$$

where x is the current longitudinal coordinate (Janbakhsh, S., Moshfegh B., 2014); N is the thermal characteristic:

$$N = \frac{0{,}54}{tg\alpha}\sqrt{\frac{T_в}{T_o}} \cdot \frac{1}{\sqrt[4]{\xi}} \cdot \Delta t_o \cdot \sqrt{F_o}\,, \tag{2}$$

where α is the jet expansion angle, α = 12°25', with tgα = 0.22; ξ is the local resistance coefficient, ξ = 1; T_x is the absolute temperature at the nozzle outlet (Rumsey C.L., Spalart P.R., 2009).

To simplify calculations, the temperature decay coefficient n is introduced:

$$n = \frac{0{,}54}{tg\alpha}\sqrt{\frac{T_в}{T_o}} \cdot \frac{1}{\sqrt[4]{\xi}}\,. \tag{3}$$

The axial excess temperature Δt_x is given by (Srebric J., Chen, Q., 2002):

$$\Delta t_x = n \cdot \Delta t_o \cdot \frac{\sqrt{F_o}}{x}. \quad (4)$$

At any cross-section «x», at a distance «y», the excess temperature $\Delta t_y = t_y - t_v$ is calculated using Taylor's formula (5):

$$\Delta t_y = \Delta t_x \cdot \exp\left(-0{,}7\sigma_T \bar{y}^2\right), \quad (5)$$

where σ_T is the turbulent Prandtl number, $\sigma_T = 0.65 \div 0.7$ for compact jets; $\bar{y}$ is the current transverse coordinate, $\bar{y}$ = y/cx, with c = 0.28 as an experimental constant.

It is rational to use relative indicators of excess temperatures, both axial $\Delta \bar{t}_x = \Delta t_x / \Delta t_o$ and at any cross-section $\Delta \bar{t}_y = \Delta t_y / \Delta t_x$ (Voznyak O., et al., 2019).

The objective is to intensify the velocity decay in the supply air of an isothermal free swirling jet, determine the decay coefficient, and analyze axial velocities by constructing their profiles in cross-sections.

Result and discussion

To determine the axial velocity V_x in isothermal air jets, equation (6) is used:

$$V_x = \frac{M}{x}, \quad (6)$$

where ***x*** is the current longitudinal coordinate; *M* is the dynamic characteristic calculated as:

$$M = \tfrac{0{,}66}{tg\alpha} \sqrt{\frac{T_в}{T_o}} \cdot \sqrt[4]{\xi} \cdot V_o \cdot \sqrt{F_o}\ , \quad (7)$$

where α is the jet expansion angle, α = 12°25', with tgα = 0.22; ξ is the local resistance coefficient, ξ = 1; T_o, T_{in} are the absolute temperatures at the nozzle outlet and in the room, respectively; V_0 is the initial velocity (m/s); F_0 is the area of the supply nozzle (m²).

To simplify calculations, the velocity decay coefficient m is introduced:

$$m = \tfrac{0{,}66}{tg\alpha} \sqrt{\frac{T_{in}}{T_o}} \cdot \sqrt[4]{\xi}\,. \quad (8)$$

The axial velocity V_x is determined as:

$$V_x = m \cdot V_o \cdot \frac{\sqrt{F_o}}{x}. \quad (9)$$

At any cross-section «x», at a distance «y» from the axis, the velocity V_y is calculated using Schlichting's formula:

$$V_y = V_x \left[1 - \left(\frac{y}{y_b}\right)^{1{,}5}\right]^2. \quad (10)$$

For both axial $\bar{V}_x = V_x / V_o$ and cross-sectional velocity values $\bar{V}_y = V_y / V_y$, it is rational to use relative velocity indicators. In this case:

$$\bar{V}_x = \frac{0{,}48}{\frac{ax}{de} + 0{,}145}\ , \quad (11)$$

where *a* = 0,078; d_e is the equivalent nozzle diameter.

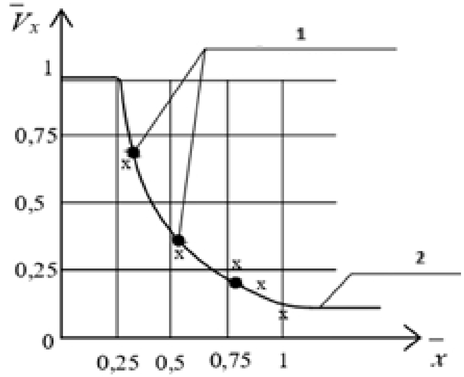

Fig. 2. Dependence of relative axial velocity on relative longitudinal coordinate

The Archimedes number Ar_o describes the ratio between gravitational and inertial forces:

$$Ar_o = \frac{g\sqrt{F_o} \cdot \Delta t_o}{V_o^2 \cdot T_{in}}, \tag{12}$$

where g = 9.81 m/s²; F_0 is the nozzle area (m²); Δt_0 is the initial excess temperature, $\Delta t_y = t_y - t_v$ (K); T_v is the absolute air temperature in the room (K); V_0 is the initial velocity (m/s).

For the calculations, a testo-405 thermal electrical anemometer was used. The initial velocity V_0 was measured. By selecting x_i values in the range 0.7 ÷ 2.2, relative velocities were computed using formula (11) for the respective jets, and graphs were constructed $\overline{V}_x = f(\overline{x})$, where $\overline{x} = x/\sqrt{F_o}$.

Fig. 2 showed a satisfactory agreement of the obtained experimental results with theoretical data. $\overline{V}_x = f(x)$: where 1 – experimental points; 2 – graphical dependency.

Conclusions

1. The study of velocity decay in an isothermal free swirled air jet provided valuable data for improving methods of controlling the aerodynamic characteristics of the air flows.

2. The distribution of axial velocities was analyzed.

3. A comparison of experimental results with theoretical models confirmed their consistency, indicating the reliability of the obtained data and their potential application in technical and industrial processes.

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ВДОСКОНАЛЕННЯ ПОВІТРОРОЗПОДІЛУ У ПРИМІЩЕННІ ЗАКРУЧЕНИМИ ПОВІТРЯНИМИ СТРУМЕНЯМИ

У роботі досліджено процеси затухання швидкості в ізотермічному вільному закрученому струмені з метою вдосконалення методів керування аеродинамічними характеристиками потоків. Метою є інтенсифікація загасання швидкості у поданому повітрі ізотермічного вільного закрученого струменя, визначення коефіцієнта загасання та аналіз осьових швидкостей шляхом побудови їх профілів у поперечних перерізах. Для спрощення розрахунків введено коефіцієнт загасання швидкості "m". Визначено коефіцієнт затухання, проведено аналіз розподілу осьових швидкостей, а також побудовано їх графіки. Виконано аналіз розподілу осьових швидкостей повітря. Запропоновано раціональний метод визначення відносного показника швидкості. Для опису взаємозв’язку між гравітаційними та інерційними силами обрано критерій Архімеда, а для опису профілю швидкості запропоновано математичну модель Шліхтінга. Отримані результати подано у вигляді графічних залежностей, а також аналітичних рівнянь із введенням коригувальних коефіцієнтів. Здійснено порівняння експериментальних даних із теоретичними моделями. Досліджено особливості турбулентних структур, що формуються в процесі затухання. Розглянуто можливості регулювання динаміки струменя шляхом зміни вхідних параметрів. Порівняння експериментальних результатів із теоретичними моделями підтвердило їхню узгодженість, що свідчить про достовірність отриманих даних і їхній потенціал для застосування в технічних та промислових процесах. Отримані результати показали задовільну відповідність експериментальних даних із теоретичними розрахунками. Вони можуть бути використані для оптимізації процесів у різних технічних і промислових сферах, зокрема у вентиляційних системах, газодинамічних установках та енергетичних комплексах.

Ключові слова: розподіл повітря, закручений струмінь, швидкість повітря, коефіцієнт затухання, аеродинаміка, турбулентність.