Influence of Initial Velocity and Temperature of Jet on Constants of Ventilating Outlets

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Introduction

For the calculation of velocities in air-jets behind the ventilating outlets, the constants of ventilating outlets must be known. These constants are specified for each type of ventilating outlets experimentally. They can be usually defined from measured behaviours of axis velocities in the main area of jet, which demands to measure velocity profiles in cross flow section, in several distances from the outlet. The constants of ventilating outlets can be also defined from the air-jet extension in the main jet area behind the ventilating outlet. There is a possibility to determine the jet boundaries and the angle of its extension from interferometric records.

Behaviour of Jets

If the air flows out from the ventilating outlet into a free space, the free jet is formed. If the temperature of supplied air is the same as the ambient air temperature, an isothermal jet is formed. In this jet, we distinguish a marginal area with a less angle of expansion and the main area with the expansion angle 2ϑ. In the marginal area, the axis flow velocity w_x remains constant and equals to the leaving velocity from the outlet w_o. In the main area, the axis velocity decreases gradually.

When a warmer or cooler air is supplied into the room, a non-isothermal jet is formed. The degree of non-isothermal action of the jet depends on the ratio of buoyant forces to inertial forces acting to air particles, which is expressed by Archimedean number. For the parameters in the outlet, the Archimedean number is defined by the relation

$$Ar_o = \frac{g\, l_o\, (T_o - T_i)}{w_o^{\,2}\, T_i} \tag{1}$$

in which g is an acceleration of free fall, l_o is a characteristic dimension of the ventilating outlet, w_o is an initial jet velocity, T_o is an initial air temperature and T_i is an ambient air temperature. The jets are lightly non-isothermal at $Ar_o \leq 0.001$ and strongly non-isothermal at $Ar_o \geq 0.01$. The most significant effect of buoyant forces is a vertical jet bend. In the case of lightly non-isothermal jets it can be presupposed that they spread straightly in the space, similar to isothermal jets. In non-isothermal jet, not only the momentum but also the heat is transferred between the flow and environment. Dimensionless temperature profiles in the main jet area are similar with velocity profiles (1).

Constants of Ventilating Outlets

For a free isothermal jet from the ventilating outlet of general shape, the ventilating outlet constant K_s related to initial jet cross-section from the ventilating outlet, is defined by the relation (2)

$$K_s = \frac{0.565\,\beta_o^{\,0.5}}{k\,\beta^{0.5}\,tg\vartheta} \qquad (2)$$

where β_o is a correction factor for the momentum in the discharge cross-section of the ventilating outlet which with the rectangular velocity profile in the discharge cross-section has the value $\beta_o = 1$, in other cases $\beta_o = \xi^{0.5}$ (ξ is a resistance factor of the ventilating outlet). In the equation (2) k indicates a velocity field factor - ratio of the mean velocity based on the cross-section to the axis velocity which, in the main area of jet, is independent on the distance from the ventilating outlet (for a circular jet, it has the value $k = 0.258$ and for a flat jet $k = 0.45$), β correction factor for a momentum - ratio of the mean velocity based on the momentum to the axis velocity, which is, in the main area of jet, independent on the distance from the outlet, too (for a circular jet, it has a value $\beta = 2.02$ and for a flat jet $\beta = 1.56$) and 2ϑ angle of free jet expansion in the main area.

If we substitute in the equation (2) the values for the factors k and β, we get

for a circular jet $$K_s = \frac{1.54\,\beta_o^{\,0.5}}{tg\vartheta} \qquad (3)$$

and for a flat jet $$K_s = \frac{1.005\,\beta_o^{\,0.5}}{tg\vartheta} \qquad (4)$$

Air-Jets Visualization

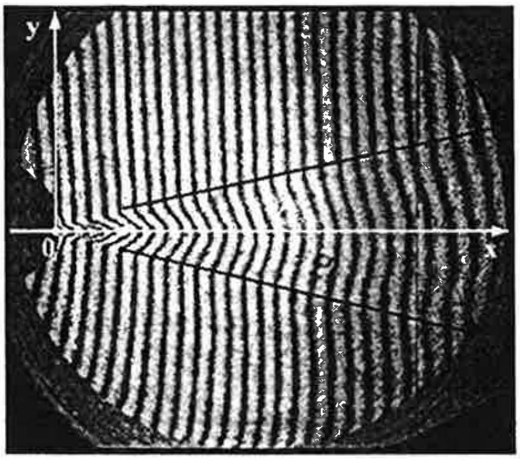

Figure 1 Interferogram of free jet from a slot ventilating outlet at $w_o = 7.5$ *m.s*$^{-1}$, $t_o = 26.0$°C, $t_i = 18.5$°C

For making the air-jet from the ventilating outlet visible, the Mach – Zehnder interferometer with the diameter of the viewing field of 200 mm can be applied. The interferograms are recorded by a CCD camera connected to the computer. The interferograms of non-isothermal jet behind the ventilating outlet give the information of the distribution of temperatures in the jet as well as the information of the velocity distribution based on a similarity of temperature and velocity fields. On the interferograms of non-isothermal jets, the boundaries of the temperature field of a visible flow (Figure1) are evident, which correspond with the boundaries of the velocity field being more distinct in addition.

The interferometric visualization of the jet can be carried out only under non-isothermal conditions. For the interferometric definition of a ventilating outlet constant it is necessary to secure that the non-isothermal jet was not influenced by buoyant forces, i.e. it must be only lightly non-isothermal.

Evaluation of Interferograms

From an interferogram, it is possible to specify the angle of lightly non–isothermal jet expansion in the main jet area $2\vartheta_t$ as can be seen on the Figure 1. From the angle it is possible to determine the ventilating outlet constant K_s from the relations (2)

for a circular jet

$$K_s = \frac{1.54\,\beta_0^{\,0.5}}{tg\vartheta_t}\sqrt{\frac{T_0}{T_i}} \tag{5}$$

and for a flat jet

$$K_s = \frac{1.005\,\beta_0^{\,0.5}}{tg\vartheta_t}\sqrt{\frac{T_0}{T_i}} \tag{6}$$

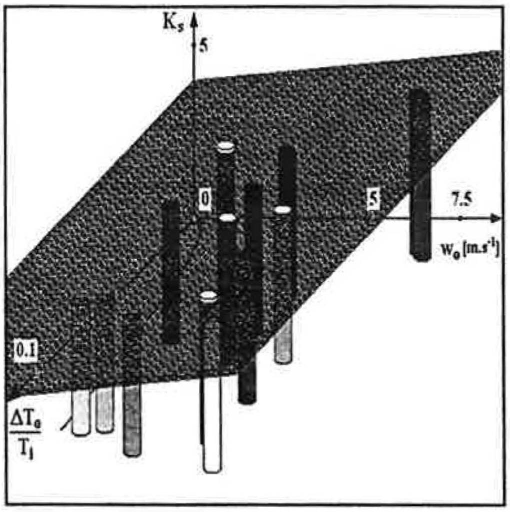

Figure 2. Dependence of ventilating outlet constant on the velocity w_o and on the ratio of temperatures $\Delta T_o/T_i$ for a slot ventilating outlet

On the Fig. 2 for the slot ventilating outlet of nozzle-shape with the ratio of sides 37 : 1 there is given the dependence of ventilating outlet constant K_s on the initial jet velocity w_o and on the ratio $\Delta T_o/T_i$, where $\Delta T_o = T_o - T_i$ is a temperature difference between the initial air temperature T_o and the ambient air temperature T_i. On the figure the plane is interpolated by measured values. The constant of the slot ventilating outlet in the nozzle-shape can be expressed by the equation

$$K_s = 3.949 + 9.979\cdot 10^{-2}\, w_o - 3.454\,\frac{\Delta T_o}{T_i} \tag{7}$$

Conclusion

The interferometric research has proved that the constants of outlets can be defined effectively from the interferograms of free lightly non-isothermal jets. Using the interferometric research of the jet from the slot outlet with a free discharge section, it has been found out that the angle of jet expansion in the main area $2\vartheta_t$ equals to 25° for the temperatures of outflowing air near to the ambient temperature, which is in accordance with the data in literature. The angle of the jet expansion $2\vartheta_t$ can be read from the interferogram with the accuracy 1°. This error of angle $2\vartheta_t$ represents the determination of the ventilating outlet constant with the error about 4%. For the ventilating outlet followed - slot nozzle in the discharging section of which the uniform velocity profile (β_o = 1) can be presupposed, the dependence of ventilating outlet constant K_s on the temperature and velocity of outflowing air has been specified. With the leaving velocities from 2.5 up to 5 m.s^{-1} the ventilating outlet constant is increased by 5.8 %, which corresponds with the data given in the literature. The works have been realized within the project solution COST - G3 „Industrial ventilation" and within the project solution of the Ministry of Education „Numerical and physical modelling of problems of thermofluid mechanics, mechanics of solids and phase changes".

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