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Research of Integrated Passive Methods of Heat Dissipation Intensification to Improve the Efficiency of Gas-Dynamic Temperature Stratification

E.V. Tsvetova, V.N. Kovalnogov[1], R.V. Fedorov

Department of Heat and Power Engineering,
Ulyanovsk State Technical University,
Severny Venets str. 32, Ulyanovsk,
432027, Russia

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Abstract: A possibility was analyzed to increase the efficiency of the gas-dynamic temperature stratification process through the use of complex passive methods of heat transfer intensification: developed surfaces - longitudinal fins on the heat transfer surface in the subsonic flow path; additives to the gas flow of the disperse phase with a twisting flow.

Keywords: numerical simulation, gas-dynamic temperature stratification, dispersion flow, heat transfer coefficient, developed surfaces

Mathematics Subject Classification: 65R20 Numerical methods for integral equations

PACS: 02.60.Cb Numerical simulation; solution of equations

1. Introduction

The gas-dynamic method and temperature stratification device in a supersonic flow were proposed by A.I. Leontiev, Academician of the Russian Academy of Sciences [1], [2]. Temperature stratification is caused by the difference between the adiabatic wall temperature in the supersonic tract of the Leontiev tube and the adiabatic wall temperature in the subsonic tract. Under these conditions, heat exchange occurs between the flows in the subsonic and supersonic tract.

The efficiency of temperature stratification is due to the transmitted heat flow. The density of heat flow from gas in the subsonic path to gas in the supersonic path is determined by the equation:

$$q = k\left(T_{r1} - T_{r2}\right), \tag{1}$$

where the heat transfer coefficient k, neglecting the thermal resistance of the wall through which heat transfer occurs, can be found by expression:

$$k = 1/\left(1/\alpha_1 + 1/\alpha_2\right). \tag{2}$$

It is evident from expressions (1), (2) that in order to improve the efficiency of temperature stratification, it is necessary to strive for an increase in heat transfer coefficients α_1 and α_2, which determine the heat transfer coefficient k.

The main intensification mechanisms in turbulent and laminar flows are increasing the heat exchange surface, breaking the boundary layer, and rearranging the temperature profile [3]. The methods of heat transfer intensification were classified by A.E. Bergles et al. [4] and have been divided into passive and active methods. Passive methods include treated surfaces; roughened surfaces; developed surfaces;

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[1] Corresponding author. E-mail: kvn@ulstu.ru

stirring devices; twisting devices; coils; surface tension devices; additives for liquids and gases. Active methods: mechanical stirring; surface vibrations; flow pulsations; electrostatic fields; injection; suction; jets. The main differences in methods are that passive methods, unlike active methods, do not require an external energy supply for intensification. In addition, any two or more of these methods (passive and/or active) can be used simultaneously to increase the level of heat dissipation. In this case, they make up a complex method of heat dissipation. This paper will discuss the complex method of heat transfer intensification: developed surfaces - longitudinal fins on the heat transfer surface in the subsonic flow path; additives to the gas flow of the dispersed phase with a twisting flow.

To increase the efficiency of temperature stratification, in work [5] a dispersed flow (gas with condensed phase particles distributed in it) as a working body is used, which moves in a special way in the flow part of the device. The disperse phase contributes to the destruction of the boundary layer due to their collision with the wall and additional transfer of heat from the main flow to the walls. Practical realization of the disperse flow with inertial precipitation of particles is provided by its twisting in the supersonic path of Leontiev tube [2].

The increase in concentration of condensed particles in the duct (increase in complex [5]) contributes to an intensive increase in the transmitted heat flux (at small), and then (at large) the rate of its increase is significantly reduced. This is since the heat transfer coefficient in the supersonic path becomes significantly higher than the heat transfer coefficient in the subsonic path. In this connection, to further improve the efficiency of gas-dynamic temperature stratification, it is advisable to fin the surface with a lower heat transfer coefficient (in the subsonic path). For functional and technological reasons, we will execute longitudinal ribs.

We research straight flat longitudinal ribs of constant thickness. The coefficients of heat transfer to the fin surface and to the intercostal surface are taken as the same.

2. Computational model

For the advanced (finned) surface, the relative (in the form of [5]) heat flux at the main section of the gas-dynamic temperature stratification device (where the working body velocities in subsonic and supersonic paths are kept constant) is determined by the dependency:

$$\bar{q} = \varepsilon \cdot \frac{(1-r_1)\left(1+\frac{\gamma-1}{2}\mathrm{M}_1^2\right)^{-1} + (r_1-r_2) - (1-r_2)\left(1+\frac{\gamma-1}{2}\mathrm{M}_2^2\right)^{-1}}{\frac{F}{F_m+\eta_r F_r} + \frac{\alpha_1}{\alpha_2}}, \tag{3}$$

where complex ε is expressed as an addiction to:

$$\varepsilon = \frac{\lambda_1}{\lambda_0}\left[\mathrm{M}_1^2 \,\mathrm{Pr}\, \frac{\gamma R_0(\gamma_0+1)}{\gamma_0 R(\gamma+1)}\right]^{0.4} \left(\frac{2}{\gamma+1}\right)^{\frac{0.8}{\gamma-1}} \left(\frac{\gamma_0+1}{2}\right)^{\frac{0.8}{\gamma_0-1}} \left[\left(\frac{2}{\gamma+1}\right)\left(1+\frac{\gamma-1}{2}\mathrm{M}_1^2\right)\right]^{\frac{0.4(1+\gamma)}{1-\gamma}} . \tag{4}$$

Attitude α_1/α_2 is determined by addiction [5]:

$$\frac{\alpha_1}{\alpha_2} = \left(\frac{\rho_1 u_1}{\rho_2 u_2}\right)^{0.8}\left(1+r_2\frac{\gamma-1}{2}\mathrm{M}_2^2\right)^{-0.11} = \left(\frac{\mathrm{M}_1}{\mathrm{M}_2}\right)^{0.8}\left(\frac{1+\frac{\gamma-1}{2}\mathrm{M}_1^2}{1+\frac{\gamma-1}{2}\mathrm{M}_2^2}\right)^{\frac{0.4(1+\gamma)}{1-\gamma}} \frac{\left(1+r_2\frac{\gamma-1}{2}\mathrm{M}_2^2\right)^{-0.11}}{\left(1+5\cdot 10^9\,\mathrm{Re}_{wx2}\mathrm{G}^2\right)^{-0.2}} . \tag{5}$$

In the subsonic path of the temperature stratification device for the flow of dispersed flow is characterized by the absence of transverse movement of particles in the boundary layer, as well as low temperature and speed phase slip. Then, the temperature recovery factor is acceptable to determine the dependence for a homogeneous gas flow.

$$r_1 = \sqrt[3]{\mathrm{Pr}} . \tag{6}$$

The recovery factor in the supersonic path (where the movement of high-speed disperse flow with transverse movement of particles in the boundary layer occurs) is determined (see [5]) by the dependence:

$$r_2 = \frac{\sqrt[3]{\mathrm{Pr}}}{1 + 28.67\mathrm{G}^{0.3}}, \tag{7}$$

where $\mathrm{G} = \frac{|s_v|\mu_0}{(u_{sm} - u)\rho_0^2 u_0^2}$ - a generalized variable, which has the meaning of a similarity criterion describing the influence of condensed particles.

The intensity of internal sources of movement in the boundary layer of the disperse flow s_v carrier medium is determined by the expression:

$$s_v = \frac{3}{4}\frac{\rho}{\rho_B}\sum_{i=1}^{n}\frac{\rho_{si} c_{fsi}}{d_{si}}|u_{si} - u|(u_{si} - u). \tag{8}$$

The coefficient of rib efficiency η_p is determined by the formula

$$\eta_r = \mathrm{th}\left(\frac{l}{\delta}\sqrt{2\mathrm{Bi}}\right) \Big/ \left(\frac{l}{\delta}\sqrt{2\mathrm{Bi}}\right), \tag{9}$$

where $\mathrm{Bi} = \alpha_1 \delta / \lambda_м$ - Bio number.

3. Research results and conclusion

The results are presented in Figs. 1, 2.

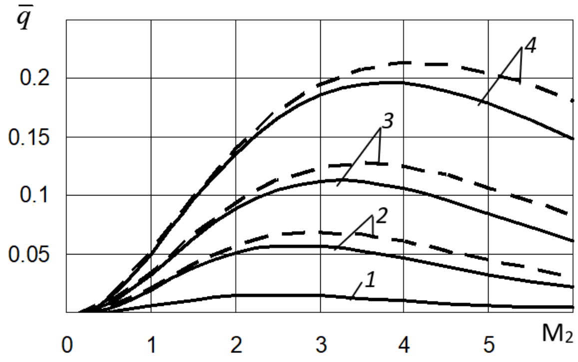

Figure 1. Effect of condensed particles on temperature stratification efficiency: 1 – G = 0 (homogeneous air flow); 2 – disperse flow at G = $5 \cdot 10^{-8}$; 3 – $5 \cdot 10^{-7}$; 4 – $5 \cdot 10^{-6}$; continuous lines – $\mathrm{Re}_{wx2} = 10^7$; dotted line – 10^8

The influence on the efficiency of temperature stratification of the additive in the gas flow of the disperse phase with twisting flow is illustrated in Fig. 1. The results in Fig. 1 are obtained for $\mathrm{M}_1 = 0{,}5$. It should be noted that the relative heat flow when using a dispersed working body is significantly higher in comparison with a homogeneous flow.

The influence of the developed (finned) surface of heat exchange in the subsonic flow path on the efficiency of temperature stratification is shown in Fig. 2. Calculations were performed for $\mathrm{Pr} = 0{,}547$; $\mathrm{M}_1 = 0{,}82$; $\mathrm{Re}_{wx2} = 10^7$; $\mathrm{G} = 5 \cdot 10^{-7}$.

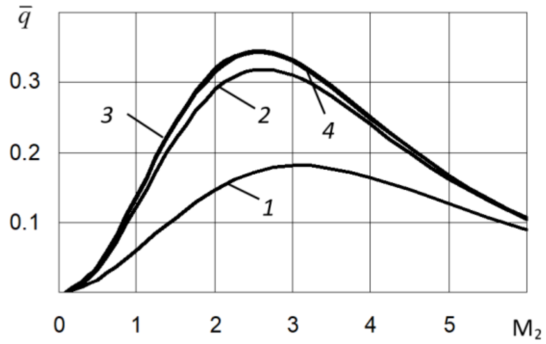

Figure 2. Influence of Mach number M_2 and relative rib length on temperature stratification in a dispersed flow: 1 – l/δ = 0 (ribless); 2 – 2; 3 – 5; 4 – 10

The results shown in Figure 2 are for Bi = 0.1. We conclude that ribbing the heat exchange surface leads to a significant improvement in the efficiency of temperature stratification.

Thus, based on the conducted research, it has been established that it is possible to significantly increase the efficiency of temperature stratification by using complex passive methods of heat transfer intensification.

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