EFFICIENCY OF A GAS BLANKET ON A CONVEX SURFACE IN THE PRESENCE OF A NEGATIVE LONGITUDINAL PRESSURE GRADIENT

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An experimental study has been made of the combined effect of a longitudinal convex curvature and a negative longitudinal pressure gradient on the gas-blanket efficiency on an adiabatic surface.

A gas blanket is used extensively in diverse technical equipment to protect heat-stressed elements (turbine blades, Laval nozzles, etc.). A blanket is formed in such equipment when a number of factors affect the efficiency, complicating the overall picture of the flow and requiring detail study. Primarily the curvature of the surface and the longitudinal pressure gradient should be classified among these factors.

Few studies have been devoted to a gas blanket on surfaces with a longitudinal curvature. It was shown in [1, 2] that for a convex wall the value of η on the main part is higher than for a flat surface while for a concave surface it is lower than for a flat surface. Quantitative relations reflecting the influence of the curvature on the efficiency have been given in only one study [3]. Experimental studies of the effect of a negative longitudinal pressure gradient on the protective properties of the blanket have been carried out only for flow past a flat plate [4-6]; no such data are available for a curvilinear wall.

Our aim is to experimentally investigate the combined effect of a convex curvature and a negative longitudinal pressure gradient on the gas-blanket efficiency; and to obtain computational relations for this case.

The experiments were carried out on an open gasdynamic circuit (Fig. 1). Atmospheric air was fed into the test section by a fan through a pipe, diffuser, receiver, a set of equalizing screens, a profiled rectangular nozzle with a 6:1 ratio of inlet and outlet areas, and a rectilinear segment whose cross-sectional dimensions (height 0.1 m and width 0.2 m) correspond to the dimensions of the test section. In front of the diffuser is a valve for regulating the flow rate. The incoming air was fed from a compressor through a slit at the inlet into a curvilinear segment with a cross section of $2 \cdot 10^{-3} \times 0.18$ m^2, made flush with the surface at an angle of 20° to it. The system for supplying the secondary gas also included a receiver, a diaphragm for measuring the flow rate, and a resistance heater. The temperature of the main flow and the injected flow was measured with chromel-copel thermocouples.

The test section consists of a lower experimental curvilinear plate with a width of 0.2 m, length 0.5 m, and thickness 0.1 m with a constant radius of curvature of 1.5 m, made of textolite glued onto a wooden base [the thermal resistance of the base was substantially (30-50 times) higher than $1/\alpha$, which was found from the relations for a slipstream, which allowed us to assume that the surface was adiabatic], and an upper moving curvilinear metal plate, one end of which was fastened in a cross section a distance of $1.5 \cdot 10^{-2}$ m lower with respect to the flow from the injection cross section, as well as flat side walls made of glass. By moving the upper plate we varied the cross-sectional area of the channel and thus generated a longitudinal pressure gradient.

Ten chromel-copel thermocouples were calked into the experimental surface to measure the longitudinal distribution of the temperature of the adiabatic wall. Moreover, eight holes were made in the experimental surface to sample the static pressure and each was connected to a differential manometer.

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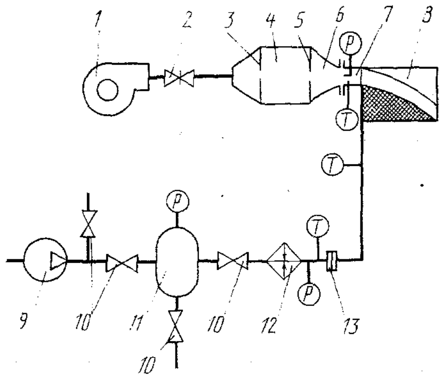

Fig. 1. Experimental arrangement: 1) primary-air fan; 2) valve; 3) equalizing screen; 4) primary-air receiver; 5) equalizing screen (baffle); 6) Vitoshinskii nozzle; 7) stilling chamber; 8) experimental segment; 9) secondary-air compressor; 10) valves; 11) secondary-air receiver; 12) resistance heater; 13) diaphragm.

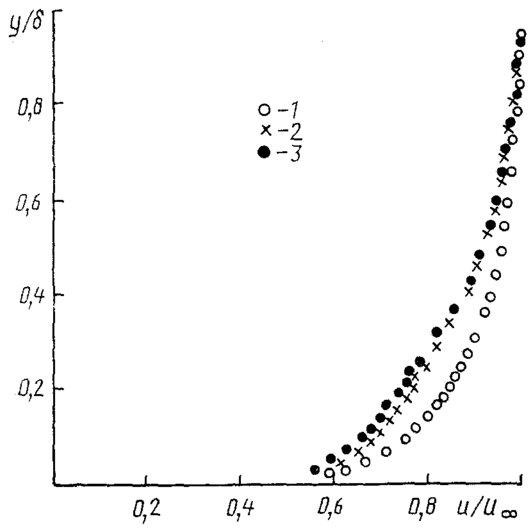

Fig. 2. Velocity profiles in the boundary layer at m = 0.783 and different values of the longitudinal coordinate: 1) x = 0.07 m; 2) 0.28 m; and 3) 0.39 m.

The velocity profiles were measured in four cross sections ($x = 7 \cdot 10^2$, 0.17, 0.28, and 0.39 m, origin in the injection cross section) with a velocity-head tube and an MMN-250 micromanometer. The velocity-head tube was made from a hypodermic needle with an outside diameter of $0.8 \cdot 10^{-3}$ m; the receiving thole was flattened into an elliptical shape. The velocity of the main flow at the inlet into the test section varied from 10 to 15 m/sec, the Reynolds number Re_h in this cross section was $(1\text{-}1.4) \cdot 10^5$, the injection parameter m varied in the range 0.2-1.4, and the ratios of the momentum thickness and the boundary-layer thickness to the radius of surface curvature were $6 \cdot 10^{-4} < \frac{\delta^{**}}{R_w} < 1.8 \cdot 10^{-3}$ and $0.01 < \frac{\delta}{R_w} < 0.02$, respectively.

The thermocouples were precalibrated with a UT-15 ultrathermostat and a mercury thermometer with a scale value of 0.1°C. The temperature was determined to within 0.5%, the efficiency parameter was 3.6, the flow velocity was 0.7, the injected-air flow rate was 2.5, and the Reynolds number Re_s was 2.6%.

First we carried out a series of experiments in which the aerodynamics of the flow and the efficiency of film cooling on the convex surface at zero longitudinal pressure gradient.

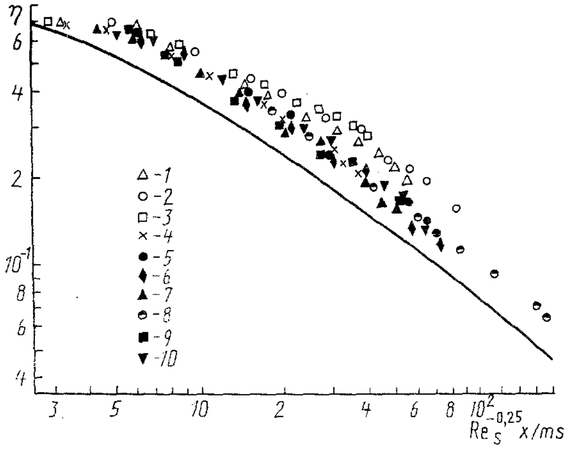

Fig. 3. Experimental data on the gas-blanket efficiency at $dp/dx = 0$: 1-3) data of [1]; 1) m = 0.5; 2) 0.7 m; 3) 0.9 m; 4-10) data of our experiments; 4-8) $Re_h = 1.4 \cdot 10^5$; 9, 10) $Re_h = 10^5$; 4) m = 0.996; 5) 0.593; 6) 0.582; 7) 0.783; 8) 0.235; 9) 0.648; 10) 0.737. The solid line is for a flat plate [7].

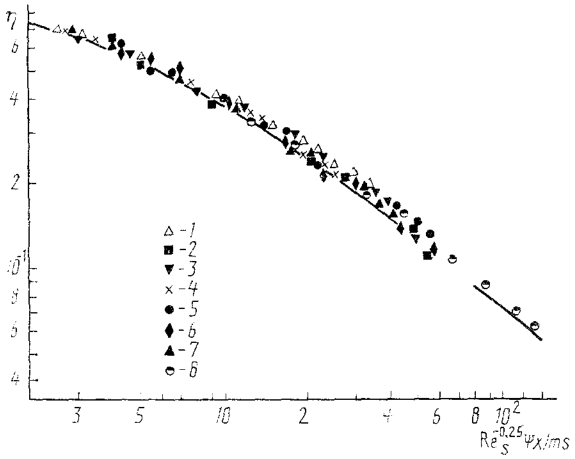

Fig. 4. Experimental data on the efficiency of a gas blanket with allowance for curvature: 1) data of [1]; m = 0.7; 2-8) data of our experiments; 2, 3) $Re_h = 10^5$; 4-8) $Re_h = 1.4 \cdot 10^5$; 2) m = 0.648; 3) 0.737; 4) 0.996; 5) 0.593; 6) 0.582; 7) 0.783; 8) 0.235. The solid line is for a flat plate [7].

Figure 2 shows velocity profiles measured in different cross sections of the working section. We see that as the boundary layer develops the degree to which the profiles are filled decreases, despite the comparatively low value of the parameter of relative curvature. This indicates a stabilizing action by the convex curvature on the hydrodynamics of the flow.

Our study of the effect of convex curvature on the gas-blanket efficiency supported the conclusions of [1, 2] that this factor results in an increase on the main segment in comparison with a flat surface (Fig. 3). Figure 3 also shows the data of [1] (R_u = 0.61 m, injection slit at a 20° angle), which lie above the results reported here, since a higher value of the parameter of relative curvature $\left(\frac{\delta^{**}}{R_w} = 0{,}0023\text{—}0.0052\right)$ was used in those experiments.

Curvature as a factor was taken into account in much the same way as [3] by introducing corrections into the asymptotic Kutateladze—Leont'ev relation for a flat plate [7], in which case the relation for the effectiveness is given in the form

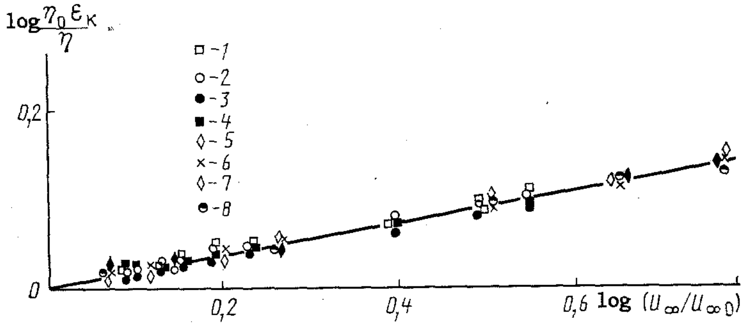

Fig. 5. Generalization of experiment on the gas-blanket efficiency when a negative longitudinal pressure gradient exists: 1-4) Position I of the upper plate; 1) m = 0.248; 2) 0.565; 3) 0.702; 4) 0.964; 5-8) position II of the upper plate; 5) m = 0.389; 6) 0.591; 7) 1.193; 8) 1.43.

$$\eta = \left[1 + 0.24\,\mathrm{Re}_s^{-0,25} \frac{x}{ms} \Psi_c\right]^{-0,8}. \tag{1}$$

The correction Ψ_c is a relative function of friction $(C_f/C_{f0})_{\mathrm{Re}^{**}}$ (C_f and C_{f0} are the coefficients of friction for a curvilinear and flat wall, respectively). This correction was calculated by the method described in [8], using experimental values of the momentum thickness.

Data on the gas-blanket efficiency with allowance for the curvature are shown in Fig. 4. We see from Fig. 4 that points corresponding to the results of this study and of [1] are grouped around the line corresponding to Eq. (1) for $\Psi_c = 1$. The slight deviation (no more than 5%) of the data for curvilinear surfaces form the values of η for $\Psi_c = 1$ are evidently due to the existence of a nonzero initial boundary-layer thickness.

Our study of the combined effect on the blanket parameters from the curvature and the negative longitudinal pressure gradient was carried out at three different positions of the upper moving plate. The maximum ratio of the flow velocities at the outlet from the working section and at the inlet to it was 5.8 and the acceleration parameter K in our experiments varies over the range $(0.1\text{-}2)\cdot 10^{-6}$.

We assume that the longitudinal pressure gradient and the curvature affect the efficiency of the gas blanket independently of each other, then η can be represented as a product

$$\eta = \eta_0 \varepsilon_c \varepsilon_p, \tag{2}$$

where ε_c and ε_p are factors that take the curvature and the pressure gradient, respectively, into account. The value of ε_c, which is equal to the ratio of the efficiencies of curvilinear and flat walls at $\partial p/\partial x = 0$, with allowance for (1), can be written as

$$\varepsilon_c = \left[\frac{1 + 0{,}24\,\mathrm{Re}_s^{-0,25} \frac{x}{ms} \Psi_c}{1 + 0{,}24\,\mathrm{Re}_s^{-0,25} \frac{x}{ms}}\right]^{-0,8}. \tag{3}$$

To find the factor ε_p in Eq. (2), we measured the efficiency and the velocity profile in different cross sections in the simutlaneous pressure of a pressure gradient and the flow curvature. Using the computational method given in [8] on the assumption that the factors act independently, we determined the value of Ψ_c, ε_c, and then ε_p. The dependence of ε_p was, as in [4], written as a power function

$$\eta = \eta_0 \left[\frac{U(x_s)}{U(x)}\right]^n. \tag{4}$$

Generalization of the experimental data (Fig. 5) enabled us to verify Eq. (4), while the value of n ws 0.19, which is close to that obtained in [4] for a flat surface. This can serve as confirmation that the curvature and longitudinal pressure gradient have an independent effect on the efficiency of the gas blanket.

NOTATION

Here u denotes the velocity; m is the injection parameter $U_s \rho_s / U_\infty \rho_\infty$: Re_h and Re_s are the Reynolds numbers, for which the average parameters of the main flow were assumed to be the determining factors and the height of the working chamber at the inlet and the height of the slit for secondary-gas injection, respectively, were taken to be the characteristic dimensions; δ and δ^{**} are the boundary-layer and momentum thicknesses; R_w is the radius of surface curvature; x is the longitudinal curvilinear coordinate; $\eta = \frac{T_w^* - T_\infty}{T_s - T_\infty}$ is the efficiency of the gas blanket; and $K = \frac{\nu}{U_\infty^2} \frac{dU_\infty}{dx}$ is the acceleration parameter. Subscripts and superscripts: s pertains to the injection cross section; ∞ denotes parameters at the outer boundary of the boundary layer; w denotes parameters at the wall; 0 pertains to a flat plate; and * denotes parameters at an adiabatic wall.

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INFLUENCE OF SURFACTANT ADMIXTURES ON THE ACOUSTIC CHARACTERISTICS OF A CLOSED HYDRAULIC LOOP

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Results are presented of measurements of the friction drag, acoustic spectra of pipeline wall and pump pedestal vibrations as well as of the hydrodynamic noise during the motion of a fluid with surfactant admixtures of different nature in a closed hydraulic loop.

On the effective methods of reducing turbulent friction drag, diminishing the intensity of forced thermal and mass transfer and changing the acoustic characteristics of a stream is the injection of admixtures of high-molecular polymers, micelle-forming surfactants, and anisotropic particles into the fluid [1]. However, polymer admixtures cannot be used in systems having pumps and elements with high local drag because of the significant mechanical destruction [1]. As is shown in [2], surfactant admixtures possess high stability with respect to prolonged mechanical actions and their application is justified in closed hydraulic systems. Up to now a significant number of researches have been executed [1, 3, 4] to investigate the influence of polymer admixtures on different acoustic characteristics of a turbulent stream, however, there is no data on surfactant influence on flow acoustics yet.

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