INVESTIGATION OF THE TWO-PHASE FLOWS OF WORKING BODIES IN AN ELECTROGASDYNAMIC EXPANDER BY USING A LASER DOPPLER ANEMOMETER

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The dependence of the fundamental characteristics of an electrogasdynamic expander on the velocity and mobility of the electrically charged two-phase flow particles is examined. Results are presented of an experimental investigation of the velocity of the condensed two-phase flow particles by using a laser Doppler anemometer.

One of the areas for the perfection of cryogenic support system in order to raise their lifetime, reliability, and thermodynamic efficiency is to search for solutions based on new internal cooling methods, in principle. In this area is obtaining low temperatures during expansion of the two-phase cryogenic agent flow in an electrogasdynamic (EGD) expander [1].

The operating principle of the EGD expander is based on interaction between the stream of the working body containing charged particles and an electrical field retarding the moving charges. Because of such interaction the uncharged part of the stream that communicates part of its kinetic energy to the charged component overcoming the retarding action of the field performs work against the external forces, is expanded and cooled. The condensed phase of the two-phase stream is used as the electrical charge carrier in the EGD expander. Charging the condensed particles can be realized by using a corona discharge, say.

The change in the enthalpy of the stream passing through the EGD expander under adiabatic conditions equals the difference in the powers removed from the collector N_{col} and supplied N_{cor} to sustain the corona discharge.

The adiabatic efficiency (η_{ad}), which can be written thus in general form in application to EGD expansion

$$\eta_{ad} = (N_{col} - N_{cor})/N_s, \tag{1}$$

is ordinarily used as the criterion of thermodynamic perfection of expanders.

Another important EGD expander characteristic is the value of the usefully activatable pressure drop Δp_{el} (converted into expansion power) per stage.

The quantity of EGD expander expansion stages that can be applied in specific low-temperature installation schemes depends on Δp_{el}.

Since the direct solution of the equations describing the EGD flow of the working body is impossible with assumptions satisfying the accuracy of engineering computations, we obtained expressions for η_{ad} and Δp_{el} in [2, 3] in the form

$$\eta_{ad} = \frac{1 - Z + (Z-1)/(\sqrt{(1-Z+Y)/ZY} + 1}{1 + Y(Z\sqrt{(1-Z+Y)/ZY} + 1)/(1-Z)}. \tag{2}$$

The values of the dimensionless complexes Z and Y are determined for the greatest possible volume charge density at the input to the zone of EGD expander energy conversion

$$Z = \frac{2bE/m}{\eta_{ef\,3}u}, \tag{3}$$

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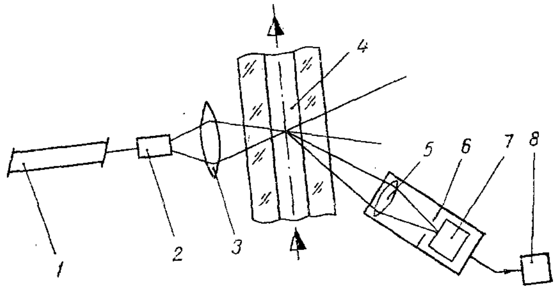

Fig. 1. Schematic diagram of the laser Doppler anemometer for investigation of the two-phase stream hydrodynamic characteristics.

$$Y = \frac{\xi_{fr} \rho v^3}{8\varepsilon\varepsilon_0 (E/n)^2 u}. \tag{4}$$

The usefully activatable pressure drop per stage equals

$$\Delta p_{ad} = \frac{4N_{col}}{\pi D^2 u} = \frac{4A(-B + \sqrt{B^2 + CR_{ed}})^2}{\pi D^2 u R_{ad}}, \tag{5}$$

where

$$A = (8\varepsilon\varepsilon_0 \pi D b u)^{-2}; \tag{6}$$

$$B = \varepsilon\varepsilon_0 \pi D^2 u^2; \tag{7}$$

$$C = \frac{16bED}{n} (\varepsilon\varepsilon_0 \pi D)^3 u^4. \tag{8}$$

It follows from (2)-(8) that information about the charged particle velocity u in an electrical field of intensity E and their coefficient of electrical mobility b is necessary for the computation of η_{ad} and Δp_{el}. To perform an effect expansion process it is also necessary to know the condensed phase distribution in the working body stream in the strong electrical field.

Such information can be obtained most reliably on the basis of direct measurements of the condensed particle velocities in the two-phase stream by using a laser Doppler anemometer (LDA) [4].

Diagnostics of low-temperature streams is complicated by the fact that the channel over which the working body flows should be such that the heat influx would be minimal to the measurement zone.

Taking this requirement into account as well as requirements of optical transparency and reliable EGD insulation, the channel was executed from organic glass. Its inner diameter and length were 4 and 25 mm, respectively.

Two-phase streams (vapor-solid particles, vapor-liquid) of carbon dioxide were used as working bodies. The velocity range of the vapor phase was V = (10-60) m/sec, the condensed particle mass-concentration was x = (0-18)%, and the pressure was p = (0.15-0.65) MPa.

Radiation from the laser 1 (Fig. 1) in the differential LDA scheme used for CO_2 stream diagnostics was directed to the ultrasonic modulator 2 operating in the Raman—Nata diffraction mode. After the modulator, a pair forming the initial sounding beams is selected out of the beams diffracted by the traveling ultrasonic wave, whose radiation frequencies differ by f_M. The initial probing beams are focused and directed by the lens 3 at the two-phase stream point being investigated 4. Light scattered by the condensed woreking body particles is collected by the receiver consisting of an objective 5, an iris σ, a photomultiplier 7, and a set of standard radio measuring devices 8 that includes a S4-25 panoramic spectrum analyzer, a high-frequency G4-102 signal generator, and an electronically-counting frequency meter ChZ-34. Such a selection of the apparatus for processing the Doppler signal was governed by the low "signal-noise" ratio at the input of the measuring system, eliminating the application of special electronic processors of the counting or following types.

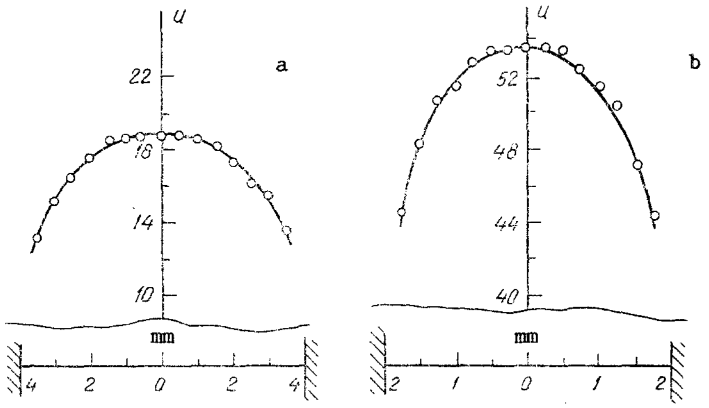

Fig. 2. Profiles of the velocities u, m/sec of condensed particles for channels D = 8 mm ($v_{m.vap}$ = 15 m/sec) (a) and D = 4 mm ($v_{m.vap}$ = 49 m/sec) (b).

The fundamental LDA parameters are the following:

Laser radiation wavelength $\lambda = 0.6328 \cdot 10^{-6}$ m;
Angle of probing beam reduction $\alpha = 4.95^0$;
Modulation frequency f_M = 7.5 MHz;
Section of the measuring volume $2.33 \cdot 10^{-3}$ mm^2.

Among the features of LDA utilization for stream diagnostics in the EGD channel should be, firstly, the absence of accurate initial data on the dimensions and shape of the light-scattering centers, secondly, substantial fluctuations in the condensed particle concentration as the operating mode of the installation under investigation changed, and thirdly, the fact that sounding the CO_2 stream was realized through a thick (~30 mm) cylindrical wall of the working part of the channel fabricated from organic glass.

The measuring system permits a distribution of the condensed particle velocities to be obtained over the EGD channel diameter and length (Fig. 2). As is seen from the figure, the velocity profile over the channel diameter is close to the distribution characteristic for a developed turbulent flow.

Processing the condensed particle velocities obtained experimentally showed that slip of the working body phase is 8-10% with an error not exceeding 1.5%. The magnitude of particle slip relative to the vapor at high stream velocities and the form of the velocity profile permit making a qualitative deduction about the mean size of the condensate particle in a two-phase carbon dioxide stream not exceeding 1 μm.

Measurements of the condensed phase velocities with and without an electrical field superposed permitted estimation of the electrical mobility of the CO_2 particles. In an electrical field of E = 3.5 Mv/m intensity for a mean stream velocity of v = 49 m/sec and a pressure p = 0.21 MPa, the electrical mobility had the value $b = 3.7 \cdot 10^{-7}$ m^2/V·sec).

Limit values of the adiabatic efficiency η_{ad} [2] and the pressure drop Δp_{el} activated in an EGD expander [3] were estimated on the basis of data from experimental investigations. In particular, for two-phase CO_2 stream η_{ad} can reach 65-75% and the pressure drop Δp_{el} up to 0.1 MPa.

Therefore, by using laser Doppler diagnostics the low value of condensed particle slip relative to the vapor (up to 10%) in an EGD expander could successfully be confirmed experimentally in the regimes investigated. Measurements of the internal working body parameters in an EGD expander channel by using a LDA permitted reliable determination of the charged particle mobility and computation of the magnitude of the pressure drop and adiabatic efficiency of the EGD expansion process on this basis. The legitimacy of the assumptions used in [2, 3] to derive η_{ad} and Δp_{el} is verified by direct measurement of the two-phase stream phase velocities and the condensed particle distribution in the EGD expander channel.

The results obtained in measuring the condensed particle velocities and their distributions in a two-phase stream are an important first step in the investigations. Their main problem is utilization of laser diagnostics to develop such EGD expander processes for which the maximal specific power would be extracted from the expanding working body for high values of η_{ad}. This multiple-factor problem associated with optimizing the two-phase stream parameters and profiling the EGD expander channel, can be solved successfully by using measurements of the internal EGD expander characteristics.

NOTATION

N_s, power of an isentropic expansion process; m, coefficient characterizing the influence of the stream velocity on the volt-ampere characteristics of a corona discharge; n, coefficient taking account of inhomogeneity of the electrical field; $\eta_{ef.e}$, coefficient characterizing the efficiency of the working body charge in a corona discharge field; v, stream velocity; ξ_{fp}, friction resistance coefficient; ρ, stream density; D, EGD expander channel diameter; R_{el}, collector electrical resistance; ε, dielectric permittivity of the medium; $\varepsilon_0 = 8.85 \cdot 10^{-12}$ F/m.

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