18. S. A. Fedotov, "Estimates of ash and pyroclastics removal by volcanic eruptions and fumaroles by the altitude of their jets and clouds," Izv. Akad. Nauk SSSR, Vulkanolog. Seismolog., No. 4 (1982).
19. P. S. Manins, "Cloud heights and stratospheric injections resulting from a thermonuclear war," Atmos. Environ., 19, No. 8 (1985).
20. G. S. Gorshkov and G. E. Bogoyavlenskaya, Nameless Volcano and Singularities of Its Latest Eruptions 1955-1963 [in Russian], Nauka, Moscow (1965).
21. The Effects on the Atmosphere of a Major Nuclear Exchange, Nat. Res. Council, National Academy Press, Washington, D.C. (1985).
22. H. E. Anderson, Sundance Fire: An Analysis of Fire Phenomena, Paper INT-56, U.S. Dept. Agriculture, Forest Service Res., St. Louis (1968).
23. Yu. A. Gostintsev and Yu. V. Shatskikh, "On the mechanism of longwave acoustic perturbation generation in the atmosphere by the floating cloud of explosion products," Fiz. Goren. Vzryva, No. 2 (1987).
24. B. Benech, "Experimental study of an artificial convective plume initiated from the ground," J. Appl. Meteorology, No. 15 (1967).
25. V. A. Aprodov, Volcanoes [Russian translation], Mir, Moscow (1982).

EFFECT OF PRESSURE ON THE EXCHANGE OF ENERGY IN A VORTEX TUBE

V. I. Kuznetsov

UDC 533.601.16

In a number of works [1, 2] it has been noted that the thermal efficiency of vortex tubes only depends on the level of gas expansion and it does not depend on the overall pressure at the inlet to a tangential nozzle (with a constant temperature for gas stagnation and the weight fraction of cold flux μ). Theoretical conclusions have been confirmed by experiments with overall pressure at the inlet to a vortex tube greater than atmospheric ($p_{*+} \geq 10^5$ Pa). Although from experiments [1] it followed that a reduction in overall pressure ε leads to a certain reduction in thermal efficiency, it was assumed that pressure level does not play a role in vortex-tube operation. From analysis of a mathematical model for the process of energy separation for gas in a vortex tube [3] it follows that the thermal efficiency depends on kinematic viscosity coefficient which, in turn, is a function of overall gas pressure at the inlet to a tangential nozzle. In addition, the Rank effect should be reduced both with a turbulent and with a laminar regime for gas movement.

The aim of this work is experimental verification of the effect of overall gas pressure at the inlet to a vortex tube on its thermal efficiency (with constant T_{*+}, μ, and $\varepsilon = p_{*+}/p_{--}$) with laminary or turbulent regimes for gas movement in an energy separation chamber.

In order to obtain a laminar regime it is necessary to reduce the Reynolds number. This may be done without changing ε as a result of increasing the kinematic viscosity coefficient ν which depends strongly on pressure and grows with a reduction of it. Therefore, experiments were performed in a vacuum unit (Fig. 1) which consists of a valve 1, filter 2, water trap 3, receiver 4, nozzle block 5, inlet tangential nozzle of rectangular shape 6, energy separation chamber 7, alignment apparatus 8, valve 9, heated gas receiver 10, diaphragm 11, through which cooling air emerges, cooled-air receiver 12, pipelines 13 and 14 for removing the heated and cooled air from the vortex tube to vacuum unit 15. Air is discharged to atmosphere from the vacuum unit.

Overall pressure at the inlet to the vortex tube was controlled by means of a valve and a laminar or turbulent air-movement regime was established. Existence of flow pulsation (air-movement regime) was monitored by three strain gauges with consecutive readout in a mirror-galvanometer oscillograph. Strain gauges were placed at the inlet to the tangential nozzle, on the wall of the energy separation chamber ahead of the valve, and on the diaphragm.

Omsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 4, pp. 72-74, July-August, 1989. Original article submitted July 13, 1987; revision submitted May 25, 1988.

0021-8944/89/3004-0577$12.50

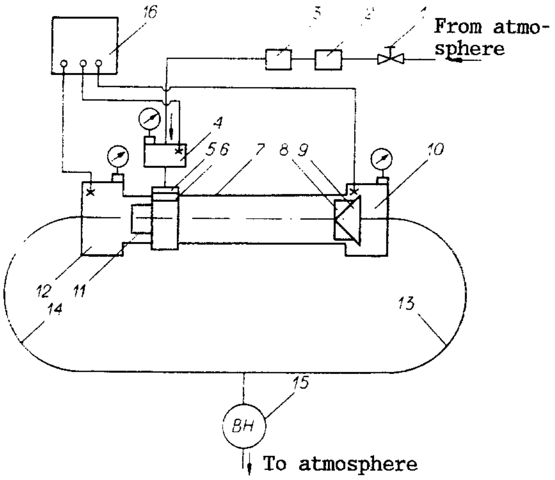

Fig. 1

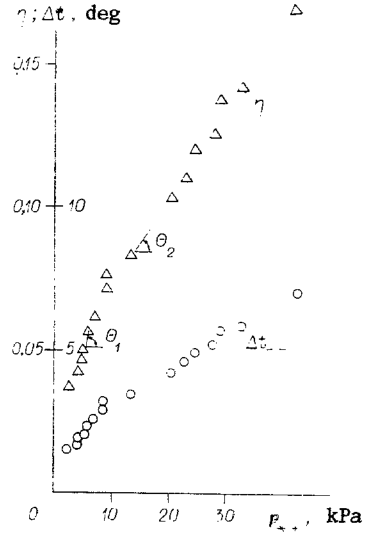

Fig. 2

If a strain-gauge reading was equidistant to its characteristic with a nonoperating vortex tube, then the air-movement regime was assumed to be laminar. If the strain-gauge reading differed from its characteristic with a nonoperating vortex tube, then the air-movement regime was assumed to be turbulent. Calculation showed that a laminar regime is maintained up to Re ≈ 4500, i.e., flow rotation promoted partial suppression of pulsation.

The main dimensions of the test counterflow vortex tube are $h_1 = 3.5$ mm, $b_1 = 7.0$ mm for the height and width of the inlet nozzle, respectively; $d_T = 15$ mm is energy separation chamber (ESC) diameter where it joins the nozzle plate; $\ell_T = 150$ mm is ESC length; $\alpha = 3.7°$ is ESC diffuseness angle. Stagnation temperature and overall air pressure were determined in three sections, i.e., at the tangential nozzle inlet, at the outlet from the diaphragm and the valve. In addition, the barometer reading was recorded. Temperature was measured by a platinum-silver resistance thermometer with readout in a digital voltmeter. The error was ±0.1°. During testing there was little variation of stagnation temperature at the tangential nozzle inlet ($T_{*+} = 293$-296 K). The temperature drop with isoentropic expansion Δt_S and thermal efficiency η of the vortex tube was calculated by the equation $\Delta t_S = T_{*+}[1 - (p_{*--}/p_{*+})^{(k-1)/k}]$ [$T_{*+} = (t_{*+} + 273)$ K, k is the air adiabat index], $\eta = \Delta t_{--}/\Delta t_S$.

Results of processing experimental data are given in Fig. 2, where it can be seen that, in the same vortex tube with an identical degree of air expansion in it, $\varepsilon = p_{*+}/p_{--} \approx 1.7$, and the temperature drop Δt_{--} and thermal effectiveness η depend markedly on the overall air pressure at the inlet to the tangential nozzle. The slope of characteristics Δt_{--}, $\eta = f(p_{*+})$ with a laminar regime for gas movement is greater than with a turbulent regime ($\Theta_1 > \Theta_2$). The thermal efficiency of this vortex tube increased to $\eta = 0.52$ with an increase in overall pressure at the inlet to the tangential nozzle up to $p_{*+} = 175$ kPa ($T_{*+} = 295$ K), for which use was made of a normal compressor unit. With an increase in pressure in the region $p_{*+} > 175$ kPa the value of η was almost unchanged.

In conclusion, we note the following:

1. The amount of gas cooling Δt_{--}, thermal efficiency η and refrigerating capacity $\mu\Delta t_{--}$ of a vortex tube are markedly affected by the overall pressure at the inlet to the tangential nozzle p_{*+} (in the range $p_{*+} < 10^5$ Pa); with constant values of the level of gas expansion ($\varepsilon = p_{*+}/p_{--} = \text{const}$) the overall gas temperature at the inlet to the tangential nozzle T_{*+} and the weighting fraction of the cold flux μ for the value of Δt_{--}, η, and $\mu\Delta t_{--}$ increases with an increase in p_{*+}.

2. The author assumes that in the region of $p_{*+} < 175$ kPa with these μ, ε, and T_{*+} there is a laminar-turbulent transition. In this case, with the different nature of the dependence $\eta(p_{*+})$ in the test range and with pressures greater than atmospheric (η ≈ const), it would be possible to explain, for example, the fact that, in laminar and turbulent flows, the resistance coefficient ζ behaves differently, having an effect on the work of the vortex tube.

The author gives his thanks to M. A. Gol'dshtik for help in defining the problem and for critical comments in carrying out the work.

LITERATURE CITED

1. A. P. Merkulov, The Vortex Effect and Its Application in Technology [in Russian], Mashinostroenie, Moscow (1969).
2. A. D. Suslov, S. V. Ivanov, A. V. Murashkin, and Yu. V. Chizhikov, Vortex Apparatus [in Russian], Mashinostroenie, Moscow (1985).
3. S. I. Barsukov and V. I. Kuznetsov, The Rank Vortex Effect [in Russian], Irkutsk. Gos. Univ., Irkutsk (1983).

DETERMINATION OF STRESSES AT A FIXED POINT WITH SYMMETRICAL IMPACT OF PLANE JETS TAKING ACCOUNT OF COMPRESSIBILITY, VISCOSITY, AND STRENGTH OF MATERIALS

V. A. Agureikin and A. A. Vopilov

UDC 532.522

A method is suggested for approximate calculation of stresses at a fixed point for flow characterizing the existence of plane or axial symmetry, taking account of the effects of compressibility, viscosity, and strength. At a fixed point, additions to hydrodynamic pressure caused by the effects listed assuming smallness of them are calculated. The method for determining additions is based on use of an iteration method [1], where as a zero approximation, flow of an ideally incompressible fluid is used. The addition as a result of compressibility is calculated in an acoustic approximation, and models for an ideally elastoplastic medium and a Newtonian fluid are used in calculating the additions resulting from strength and viscosity, respectively. The procedure for determining corrections makes it possible to use more complex rheological models. A process is given in detail for calculating corrections for the problem of impact of plane jets. Results are given for the problem of steady-state penetration of a plane jet into a half-space. A correction is determined for the velocity of a fixed point.

The set of equations describing steady-state planar flow of a compressible medium characterized by a nonspherical stress tensor is written in the form

$$\begin{gathered}
u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}+\frac{1}{\rho_0}\frac{\partial p}{\partial x}=\frac{\nu}{\rho_0}\frac{\partial p}{\partial x}+\left(\frac{1}{\rho_0}-\frac{\nu}{\rho_0}\right)\left(\frac{\partial s_{xx}}{\partial x}+\frac{\partial s_{xy}}{\partial y}\right),\\
u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+\frac{1}{\rho_0}\frac{\partial p}{\partial y}=\frac{\nu}{\rho_0}\frac{\partial p}{\partial y}+\left(\frac{1}{\rho_0}-\frac{\nu}{\rho_0}\right)\left(\frac{\partial s_{xy}}{\partial x}+\frac{\partial s_{yy}}{\partial y}\right),\\
\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=\frac{1}{\nu-1}\left(u\frac{\partial \nu}{\partial x}+v\frac{\partial \nu}{\partial y}\right),\quad \nu=1-\rho_0/\rho,
\end{gathered}\tag{1}$$

where x and y are coordinates; u and v are components of the velocity vector; ρ is density, ρ_0 is initial density; p is pressure; s_{ij} are stress deviator components. Set (1) is written so that the right-hand parts of the equations are small if the effects of compressibility, viscosity, and strength are small. Assuming smallness for these effects in accordance with the iteration method in [1] at first flow is determined for the zero approximation, i.e., set (1) is resolved with zero right-hand parts. Then the solution of the zero approximation, together with the rheological model for the medium connecting stress-tensor components with components of the strain tensor, is used in order to calculate the right-hand parts of the set of equations of the first approximation

$$\frac{\partial(u^0u^1)}{\partial x}+v^0\frac{\partial u^1}{\partial y}+v^1\frac{du^0}{\partial y}+\frac{1}{\rho_0}\frac{\partial(p^0+p^1)}{\partial x}=\frac{1}{\rho_0}\left(\nu^0\frac{\partial p^0}{\partial x}+\frac{\partial s_{xx}^0}{\partial x}+\frac{\partial s_{xy}^0}{\partial y}\right),$$

Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 4, pp. 75-79, July-August, 1989. Original article submitted January 28, 1988; revision submitted March 15, 1988.