ENERGY CHARACTERISTICS OF VORTEX MICROTUBES

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For cooling heat sources with a power of several watts or tens of watts it is expedient to use vortex tubes with small diameter. The smallest vortex tubes about whose investigations results were published had a diameter of 4 mm [1-3]. We made experimental investigations with cylindrical and conical adiabatic vortex tubes with diameters of 1, 2, and 3 mm, without turbulizer of the heated flow.

To reduce refrigeration losses, the section of the energy-separation chamber adjacent to the nozzle intake, 20 mm long, and the diaphragm are made of fluoroplastic, and the pipe for the cooled stream is made of organic glass (PMMA). The remaining parts including the nozzle intake and the inlet part of the energy-separation chamber were made of brass. In the tubes we used a spiral nozzle intake with rectangular cross section. The conical tubes had a taper angle of 3° and a cylindrical part at the outlet from the energy-separation chamber.

The investigations were carried out with nondehumidified compressed air in the range of degrees of expansion π = 3-7 at the initial temperature of the compressed air T_0 = 18-22°C.

Preliminary tests of tubes 2 mm in diameter with varying length enabled us to determine the optimum length: for cylindrical tubes 55-75 times the inner diameter, for conical tubes 20-30 times the inner diameter. The obtained values are close to the optimum values for vortex tubes with large diameter and without turbulizer.

For the further investigations we used cylindrical tubes, 60 i.d. long, and conical tubes, 26 i.d. long. The relative areas of the nozzle intake ω were 0.136, 0.094, and 0.098 for tubes with diameters of 1, 2, and 3 mm, respectively. The relative diameter of the diaphragm opening δ was equal to 0.5 in all cases.

The obtained temperature characteristics $\Delta T_x = f(\mu)$ are, on the whole, similar to the analogous dependences for tubes with large diameter.

The degrees for expansion π, optimal as to thermal efficiency η_t, were equal to 6 for tubes 1 mm in diameter, and 5 for tubes 2 and 3 mm in diameter. In the range of optimum values of π the thermal efficiency of conical tubes is slightly better than the efficiency of cylindrical tubes.

The degrees of expansion π, optimal as to adiabatic efficiency η_q, are 6-7, 4.5-5.0, and 4.0-4.5 for tubes with diameters of 1, 2, and 3 mm, respectively. The adiabatic efficiency of cylindrical tubes is on an average 10-12% higher than of conical tubes; this makes cylindrical tubes preferable in certain cases.

The dependence of the obtained maximum efficiency of cylindrical tubes on their diameter is shown in Fig. 1. It should be borne in mind that the presented results correspond to the above-mentioned optimum values of π which are different for tubes with different diameters.

As was to be expected, when the diameter of a vortex tube is smaller, its efficiency is lower. However, in the investigated range of diameters this dependence is not linear, whereas the dependence obtained in [2, 4] was linear.

Also plotted in Fig. 1 are values known from the literature: points for cylindrical tubes with 4 mm diameter, length 9 i.d., with turbulizer of the heated flow, tested with dehumidified air [1], for a conical tube with 4 mm diameter, length 10 i.d., with taper angle of 3° [2], and for a cylindrical tube with 4 mm diameter, length 62 i.d., without turbulizer [3]. The tests of [2, 3] were carried out in nondehumidified air. All the results are taken for a degree of expansion π = 6.

Extrapolation of the obtained results to larger diameters (dashed lines in Fig. 1) shows the substantial advantages of the tested tubes; this is apparently due to the use of fluoroplastic for the energy-separation chambers.

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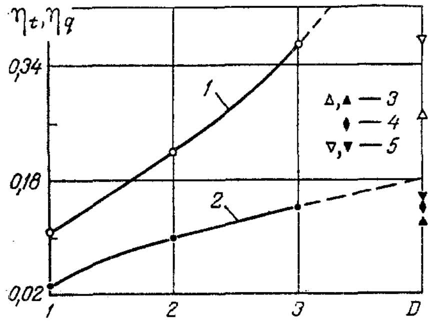

Fig. 1. Dependence of the thermal efficiency η_t and of the adiabatic efficiency η_q on the diameter D, mm, of the vortex tube: 1) $\eta_t = f_1(D)$; 2) $\eta_q = f_2(D)$; 3) after [1]; 4) after [2]; 5) after [3]. Unfilled points, η_t; filled points, η_q.

The full flow rates of compressed air with a degree of expansion $\pi = 6$ are $14.3 \cdot 10^{-5}$, $40 \cdot 10^{-5}$, and $94 \cdot 10^{-5}$ kg/sec, and the refrigeration capacity is 0.48, 4.54, and 15.5 W for tubes with diameters 1, 2, and 3 mm, respectively.

On the whole the results of the investigation showed that, regardless of the considerable reduction in efficiency due to the small dimensions, vortex microtubes can be successfully used for cooling objects with moderate heat liberation. The efficiency of such tubes can be improved by optimizing design parameters.

NOTATION

P_0, pressure of the compressed air ahead of the vortex tube; P_x, pressure of the cooled air at the outlet from the tube; $\pi = P_0/P_x$, degree of expansion; T_0, temperature of the compressed air ahead of the vortex tube; T_x, temperature of the cooled air at the outlet from the tube; $\Delta T_x = T_0 - T_x$, degree of cooling; $\eta_t = \Delta T_x/\Delta T_s$, thermal efficiency of the vortex tube; ΔT_s, decrease of air temperature in adiabatic inverse expansion upon termination of work; $\eta_q = \mu\eta_t$, adiabatic efficiency of the vortex tube; μ, relative flow rate of cooled air equal to the ratio of the flow rates of cooled and of compressed air; $\delta = d/D$, relative diameter of the diaphragm opening; d, diameter of the diaphragm opening; D, diameter of the vortex tube; ω, relative area of the nozzle intake equal to the ratio of the areas of the nozzle intake and of the vortex tube.

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