A VOITENKO COMPRESSOR FOR SUBSONIC LOADING RATES

V. P. Alushev, A. S. Parasyna, S. N. Popov,
G. S. Romanov, and V. V. Urban

UDC 533.6.9.07

Results are presented of experimental and theoretical investigations and the possibility is shown of producing a laboratory source of a dense low-temperature plasma.

Experimental investigations of a Voitenko compressor [1] have been conducted up to now only for high velocities of hurling a plate in the direction of increasing loading rates [1-7]. Because of using high-explosive (HE) detonation products to hurl the plate (5-6 km/sec hurling rate) the extremal values of the plasma parameters in a spherical segment turn out to be enclosed in a comparatively narrow domain (~10 Mbar in pressure, 20-30 eV in temperature, ~10 g/cm^3 in density, and 40-80 km/sec velocity of plasma efflux from the segment [8, 9]). Investigation of a Voitenko compressor in a broader range of its operating characteristics is of indubitable interest for a more complete study of this apparatus and the development of new versions of its structure, that can broaden the spectrum of compressor applications for scientific and practical problems. The purpose of this paper is an experimental and theoretical study of the Voitenko compressor in a rate of plate (impactor) loading rates about 100 m/sec, realizable without using high explosives. In other words, determination of the lower boundaries of operability of this apparatus was the problem of the investigation.

DIAGRAM OF THE EXPERIMENT

The investigations were performed on a pneumatic installation. After the requisite gas pressure had been achieved in the working chamber of the installation, an aluminum projectile of 1-kg mass was fired from a barrel at an impactor (Al, Cu, Pb) loading the compressor fastened on the target (Fig. 1a, b). In the case of aluminum, the projectile itself was used as impactor. Photosensors, which were photodiodes exposed to an incandescent lamp through diametrically opposite holes in the barrel, were used to measure the projectile velocity. The light flux was covered successively during projectile motion and the velocity was determined from the time shift in the signals from the checking photodiodes.

A series of experiments to study the radiation parameters of compressors with the dimensions presented in Table 1 was conducted within the framework of the scheme described. A photodetector consisting of a lightguide and a silicon photodiode of the type FD-27K was used to record and measure the compressor optical radiation parameters. The photodetector was calibrated by using an SI-300 lamp, graduated according to brightness temperature by a brightness pyrometer at the wavelength 0.665 μm. Up to the temperature 3000°K the color temperature of tungsten corresponds to the true temperature with ≈3% accuracy. The temperature dependence of the photodetector integrated response, according to the spectrum, was deter-

TABLE 1. Versions of Compressor Models Being Investigated

Type	Dimensions, mm			
	R	D	l	d
1	6	12	7	1,5
2	10	18	7	1,5
3	15	18	8,5	1,5

Scientific-Research Institute of Applied Physics Problems, V. I. Lenin Belorussian State University, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 48, No. 4, pp. 670-675, April, 1985. Original article submitted February 24, 1984.

 0022-0841/85/4804-0500$09.50

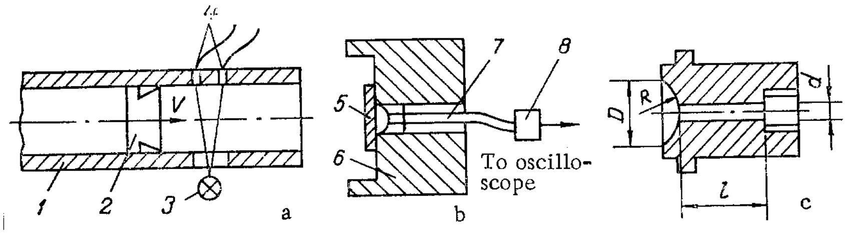

Fig. 1. Loading diagram (a) and compressor construction (b): 1) barrel of pneumatic installation; 2) projectile; 3) incandescent lamp; 4) checking photodiodes; 5) impactor (Al, Cu, Pb); 6) target; 7) lightguide; 8) photodiode.

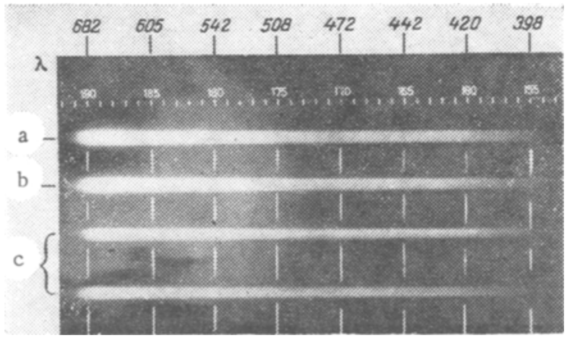

Fig. 2. Radiation spectra of a standard SI-300 lamp for exposure times (a, 17 msec; b, 8 msec; c, 15 μsec) of a compressor model (type 3) for an impactor velocity of 100 m/sec, T = 8700 °K; λ is the radiation wavelength, nm.

TABLE 2. Experimental Dependences of the Gas Radiation Brightness Temperature (°K) in the Tube on the Material and Impactor Velocity

V, m/sec	Type								
	1			2			3		
	Al	Cu	Pb	Al	Cu	Pb	Al	Cu	Pb
60	—	—	3350	—	—	3600	—	—	4200
80	2000	2240	4700	3100	3960	5150	3300	—	6800
100	2167	2467	6400	3333	4666	7600	3666	3966	—
120	2366	2699	9750	3666	4533	—	4033	5333	—

mined computationally by means of the Planck function and agreed with that recorded in the initial section (to 3000°K), which permitted the construction, in turn, of a temperature dependence of the photodiode current. Therefore, an estimate of the radiation intensity was carried out under the assumption that the air compressed in the compressor cavity emits as a block body in the photodetector spectral sensitivity range.

MEASUREMENT RESULTS

The air-brightness temperature at the exit from the spherical segment into the tube depends on the loading rate and the impactor model for each kind of model (Table 2). The radiation spectra of a standard SI-300 incandescent lamp with a 3000°K color temperature and 17 and 8 msec exposure times and the compressor model are represented in Fig. 2 (glow time is ≈15 μsec). The radiation temperature of the model, as determined from the spectrogram by a sensitometry method, was 8700°K, which is in good agreement with the method of photodiode pyrometry.

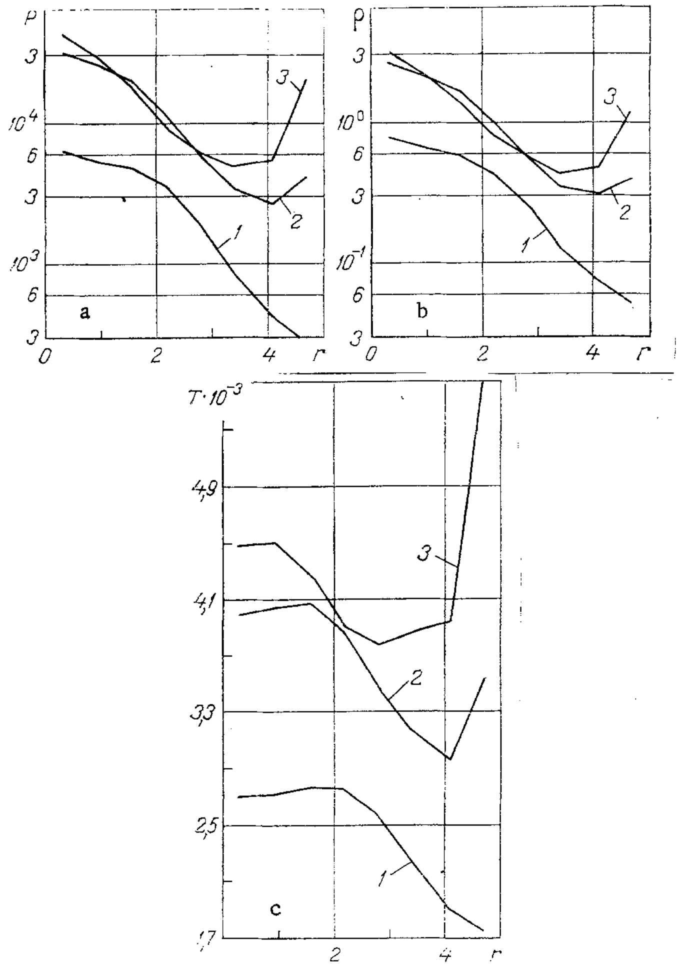

Fig. 3

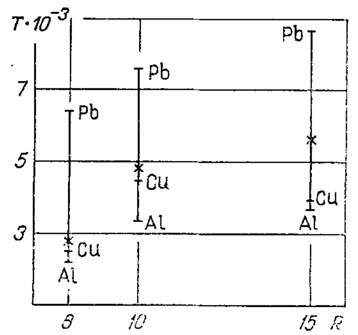

Fig. 4

Fig. 3. Dependences of the gas pressure P (bar) (a), density ρ (g/cm³) (b), and temperature T (°K) (c) in the compressor on the radius r (mm) at the time of plate exit into the tube. The numbers 1-3 correspond to the model types in Table 1.

Fig. 4. Change in the brightness temperature T (°K) as a function of the compressor radius R (mm) and the impactor material. Loading rate 100 m/sec. The crosses denote computed value of the true temperature.

NUMERICAL MODELING

We limit ourselves to the consideration of gasdynamic processes in the compressor consisting of a plate, a spherical segment, and an air-filled exit tube in setting up the problem. We do not take account of the heat transfer, evaporation, friction, etc. We assume that the plate acquires the given velocity instantaneously at time $t = 0$ and is sufficiently bulky so as not to be slowed down during motion in the exit tube. We therefore allow formulation of the problem in a gasdynamic approximation without taking into account the counterpressure of the working gas [8]. The air equation of state is used in the form of tabulated dependences [10] of the pressure and temperature on the density and specific internal energy extrapolated into the high-density domain.

The method of coarse particles [11], modified to take account of a moving boundary (plate) and a domain with curvilinear geometry (spherical segment), is used for numerical integration of the initial system of gasdynamic equations. We divide the integration domain by an orthogonal irregular mesh with cells of integer and fractional (on the segment surface) types. The analysis of the system of finite-difference equations is performed in several steps according to [11]. Moreover, as the plate approaches the cell boundary of the Euler mesh, the procedure of combining a small size and integer cell is performed, where the linear dimension of the new cell becomes equal to the sum of the two previous cells. Values of the gasdynamic quantities in the combined cell are determined from the mass, momentum, and total energy conservation conditions. The Courant criterion is used as stability criterion for the numerical computation. Details of the description of the method can be found in [8].

RESULTS OF COMPUTATIONS

The structure of the gasdynamic flow in a compression for the loading cases under consideration differs substantially from that investigated earlier [8, 9, 12], which is due to the subsonic velocity of the plate motion. The gas compression regime in this case is close to isentropic with relatively low gas heating. As the plate advances in the direction of the exit hole, a smooth growth of the gasdynamic parameters is observed within the segment, equilibration of the pressure, density, velocity, and temperature profiles occurs here in the flow because of the multiple passage and reflection of the perturbations from the wall into the bulk of the compressor. The sound velocity in the gas increases simultaneously with the rise in pressure and density, and the subsonic flow regime is conserved almost to the very time of plate exiting into the tube.

From the initial instant of plate motion the compression pulse is propagated over the gas in an axial direction to the exit hole into the tube, where the sound efflux regime is built up. As the gas is compressed in front of the plate, reconstruction of the efflux regime in the exit tube occurs simultaneously because of phase acceleration, which specifies the appearance of fluctuations in the profiles of the gasdynamics quantities along the axis of symmetry as well as growth in the amplitude of the shock being propagated in the tube. Analysis of the development of the gasdynamic flow in time shows that a corresponding rise in the gasdynamic parameters of the working gas is observed in the computation in conformity with the abrupt increase in the phase velocity of the line joining the plate and the spherical segment near the exit hole. The maximal values of the pressure, density, and temperature are here achieved in a comparatively narrow layer adjoining the plate (Fig. 3). It follows from these figures that an extremely dense (about 1-10 g/cm^3) plasma with temperature to 5600°K is generated in the Voitenko compressor for a subsonic plate hurling regime for the versions presented in Table 1.

As is seen from Fig. 4, the experimental values of the brightness and the computed values of the true air temperatures are in good agreement. The significant increase in temperature when using lead as impactor is due to its higher plasticity as compared with copper and aluminum. Under identical initial loading conditions in the experiment, the lead continues to flow after emergence into the tube while the aluminum and copper do not flow into the exit tube cavity. Consequently, the temperature in the computation of the plate arrival time in the tube is closer to its experimental values for the Al and Cu impactors (Fig. 4).

The results of numerical computations and their comparison with experiment permit making a deduction about the possibility of extending the design model of a Voitenko compressor [8] to the domain of low plate hurling velocities and a subsonic quasiisentropic gas compression regime in a spherical segment. The experimental and theoretical investigations of the presented typical compressor dimensions displayed the possibility of reaching sufficiently high temperatures in a working gas at the exit from the compressor and, therefore, the possibility of producing a laboratory source of a radiation plasma without using the energy of an explosion or an electrical discharge.

LITERATURE CITED

1. A. E. Voitenko, "Obtaining high velocity gas jets," Dokl. Akad. Nauk SSSR, 158, No. 6, 1278-1280 (1964).
2. A. E. Voitenko, "Gas acceleration during compression under acute-angled geometry conditions," Zh. Prikl. Mekh. Tekh. Fiz., No. 4, 112-116 (1966).
3. A. E. Voitenko, I. Sh. Model', and I. S. Samodelov, "Brightness temperature of shocks in xenon and air," Dokl. Akad. Nauk SSSR, 169, No. 3, 547-549 (1966).
4. D. R. Sawle, "Characteristics of the Voitenko high-explosive-driven gas compressor," Astronaut. Acta, 14, 393-397 (1969).
5. B. K. Crowley and H. D. Glenn, "Numerical simultation of a high-energy (Mach 120-40) air shock experiment," Proc. 7th Int. Shock Tube Symp., Univ. Toronto Press (1970), pp. 314-342.

6. Yu. N. Kiselev and B. D. Khristoforov, "Explosive source of powerful light radiation of continuous spectrum," Fiz. Goreniya Vzryva, No. 1, 116-119 (1974).
7. A. E. Voitenko and V. I. Kirko, "Efficiency of an explosive plasma compressor," Fiz. Goreniya Vzryva, No. 6, 956-958 (1975).
8. G. S. Romanov and V. V. Urban, "Numerical modeling of an explosive plasma generator in a gasdynamic approximation," Inzh.-Fiz. Zh., 37, No. 5, 859-867 (1979).
9. G. S. Romanov and V. V. Urban, "Numerical modeling of an explosive plasma generator taking into account radiation energy transfer and wall evaporation," Inzh.-Fiz. Zh., 43, No. 6, 1012-1020 (1982).
10. N. M. Kuznetsov, Thermodynamic Functions and Shock Adiabats of Air at High Temperatures [in Russian], Mashinostroenie, Moscow (1965).
11. O. M. Belotserkovskii and Yu. M. Davydov, "Nonstationary 'coarse particles' method for gasdynamic computations," Zh. Vychisl. Mat. Mat. Fiz., 2, No. 1, 182-207 (1971).
12. G. S. Romanov and V. V. Urban, "Theoretical model of an explosive plasma generator," in: Dynamics of a Continuous Medium. Nonstationary Hydrodynamics Problems [in Russian], No. 48, Inst. Hydrodynamics, Siberian Branch, Acad. of Sci. of the USSR, Novosibirsk (1980), pp. 121-129.

INFLUENCE OF DIFFUSELY SPECULAR REFLECTION ON THE TRANSFER PROCESS IN A GAP

G. I. Vorob'eva

UDC 533.6.011.8

A quasidiffusion approximation is constructed for the problem of radiation transfer in a narrow gap in the case of diffusely specular reflection by the walls. The accuracy of the approximation obtained is investigated.

The quasidiffusion approximation proposed by Smoluchowski [1] is used extensively in studying the radiant or free-molecule transfer in long channels. It is shown in [2, 3] that this method can be extended to the transfer problem in the narrow gap between parallel plates. The assumption about the diffuse nature of the radiation played a substantial part in these papers. However, there is a significant quantity of experimental data indicating that the reflexivity of many materials has a substantial specular component: $\rho = \rho^s + \rho^d$. As is shown in [4], the problem of determining the effective fluxes reduces in this case to the numerical solution of an integral equation. An assumption about the smallness of the gap is made in this paper that affords a possibility of constructing a quasidiffusion approximation that allows of analytical solution in a number of cases.

1. PLANE-PARALLEL GAP

Let us consider a domain V, the gap between two plane-parallel walls, each of which occupies a domain S bounded by a contour L in a plane. A diffuse flux of density Q, homogeneous along the height of the gap and dependent only on the location of the point on the con-

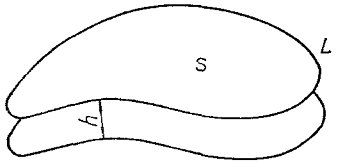

Fig. 1. Diagram of the domain under consideration.

Physicotechnical Institute of Low Temperatures, Academy of Sciences of the Ukrainian SSR, Kharkov. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 48, No. 4, pp. 675-681, April, 1985. Original article submitted January 3, 1984.

 0022-0841/85/4804-0504$09.50