Particle velocity measurements in supersonic plasma flow of electric arc gas heater

Conference Paper

Author(s):
Chuprasov, V.V.; Nestsiarovich, D.V.; Penyazkov, O.G.; Shatan, I.N.; Stankevich, Y.A.; Tretyak, M.S.

Publication date:
2018-10-05

Permanent link:
https://doi.org/10.3929/ethz-b-000279172

PARTICLE VELOCITY MEASUREMENTS IN SUPERSONIC PLASMA FLOW OF ELECTRIC ARC GAS HEATER

V.V. Chuprasov, D.V. Nestsiarovich, O.G. Penyazkov,
I.N. Shatan[c], Yu.A. Stankevich, M.S. Tret`yak

A.V. Luikov Heat and Mass Transfer Institute, Minsk, 220072, Belarus
[c]Corresponding author: Tel.: +375172842246; Email: inshatan@gmail.com

KEYWORDS:
Main subjects: two-phase plasma flow visualization
Fluid: supersonic plasma flows
Visualization method(s): Particle Image Velocimetry
Other keywords: plasma, electric arc gas heater, supersonic flow

ABSTRACT:
The results of particles velocity measurements of two-phase supersonic plasma flow are presented. Heterogeneous plasma flow was formed by the electric arc gas heater of the linear scheme. This setup was developed in the Heat and Mass Transfer Institute for the testing of thermal shielding materials of space crafts. A powder of SiO_2 was used as a disperse phase. The size of the particles was not more than 50 microns. The dispensing device was used for the powder injection into the plasma flow. The results indicate the velocity field of one of the stable operation mode of the electric arc gas heater with the power of 1.5 MW. For the velocity measurements the high-speed camera and the two-pulse Nd:YAG laser were used. Particles velocity field was measured in the entire observed area. Velocity on the axis of the plasma flow reaches the value of about 1800 m/s.

1 Introduction

The important application area of electric arc gas heaters is the modelling of spacecraft entry in planetary atmospheres [1–4]. Electric arc gas heaters are the only way to produce high-enthalpy flows over a long time interval [1]. These flows are necessary for modelling of impact on the materials when entering the planet atmosphere at hypersonic speeds. High-enthalpy flow in the plasmatron is created by passing the gas through the arc and the subsequent output from converging or diverging nozzle. The study of parameters of high-speed two-phase flow and their thermal erosion of the structural elements of the thermal protection is of great practical interest.
The aim of this work was to perform measurements of the velocity of the dispersed phase in a supersonic heterogeneous plasma flow formed by the electric arc gas heater developed for the study of heat-shielding materials in the Heat and Mass Transfer Institute [5].

2 Electric arc gas heater

The two-phase flow of the electric arc gas heater of the linear scheme with gas-dynamic and magnetic stabilization was investigated. Schematic representation of the setup is presented in figure 1. The equipment needed for operation of the plasmatron includes a high voltage power supply, the gas supply system and a liquid cooling system. The total electrical power of the two power sources is 6 MW. Electrical power of plasma torch may vary in the range from 200 to 1500 kW. The power supply voltage is up to 2.3 kV and arc current is up to 1 kA. The bulk mean enthalpy of air is 15-20 MJ/kg. The pressure in the chamber of the plasma torch is up to 30 bar.

At the exit of the electric arc gas heater the special nozzle was mounted to provide supersonic gas flow velocity. The particles were fed into the plasma flow through the channels after the critical section of the nozzle.

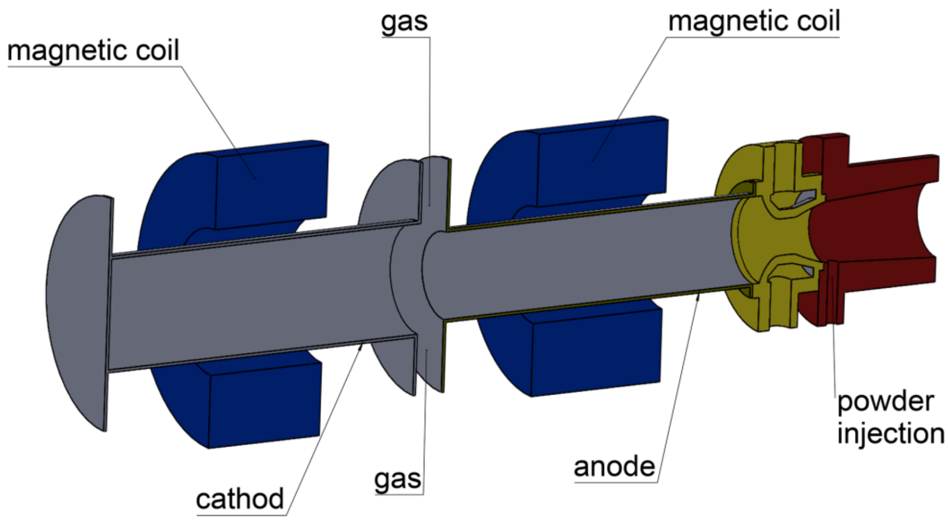

Fig 1. Schematic representation of the electric arc gas heater with the supersonic nozzle.

To inject particles into the plasma flow, a rotary table feeder that operates at overpressure has been developed. For the current experiments the powder of SiO_2 was used as the dispersed phase. The size of the particles was not greater than 50 microns. The average particle diameter of the SiO_2 powder is 14.2 μm. Figure 2 shows the function of the particles size distribution.

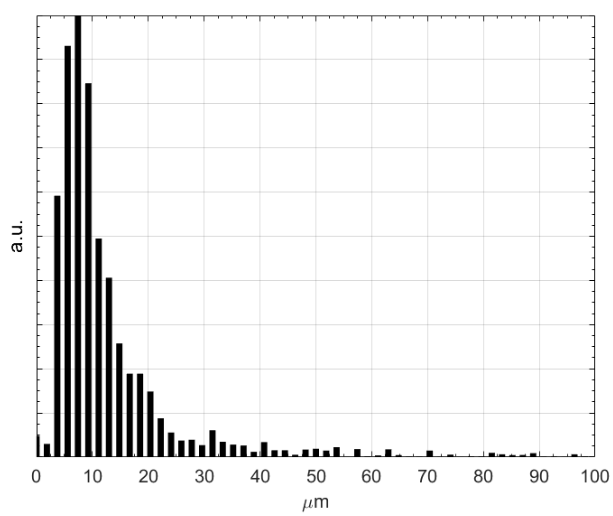

Figure 2. The SiO_2 particles size distribution.

Method

PIV-method [6] was used to measure the velocity of the SiO_2 particles in the plasma flow. The two-pulse Nd:YAG laser with Q-switching (Lotis Tii LS-2134D) was used as a laser light source. This laser generates pair pulses of 12 ns duration at a wavelength of 532 nm. The high-speed CCD camera with image intensifier (PCO DiCam-Pro) was used for plasma flow registration. The mode of two frames was used in which a pair of images can be recorded with a small time interval. For the recording, the «Nikor» lens with a focal length ranging from 80 to 400 mm was used.

Figure 3 shows a schematic diagram of the measurements. The velocity of the dispersed phase was measured in the plane passing through the axis of the plasma flow. The laser sheet illuminates particles in the region of ~120 mm along the axis of the plasma flow. The thickness of the laser sheet was ~ 0.5 mm.

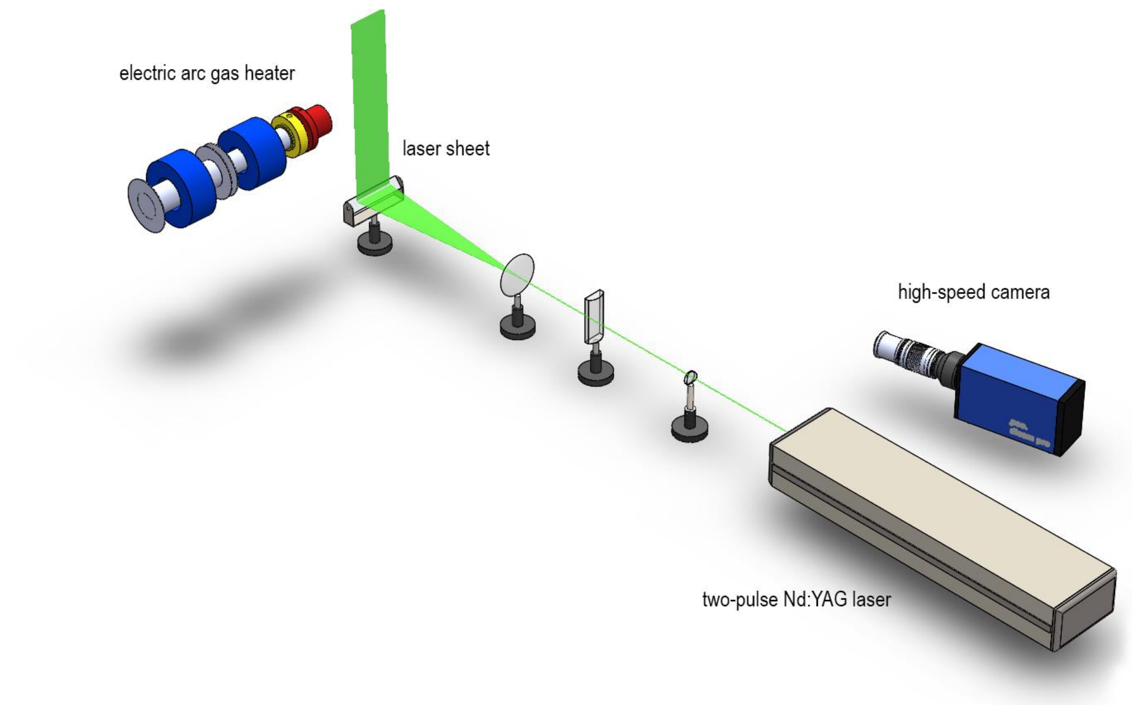

Fig 3. Representation of the measurements schema.

The registration of the plasma flow was carried out by the camera in a mode of two frames with external synchronization by the laser pulses. An interference filter was used to prevent registration of the high-temperature gas-plasma structures emission on the camera.

Results

Particles speed measurements were performed in the range of observed laser sheet with dimensions of approximately 100×100 mm. Paired laser pulses were repeated at a frequency of 10 Hz to illuminate the flow. In the corresponding moments of time the pairs of images were recorded. During the experiments the set of 30 image pairs was obtained. The time interval between the images in the each pair was 500 ns. The exposure time was 100 ns. Figure 4 shows a characteristic image.

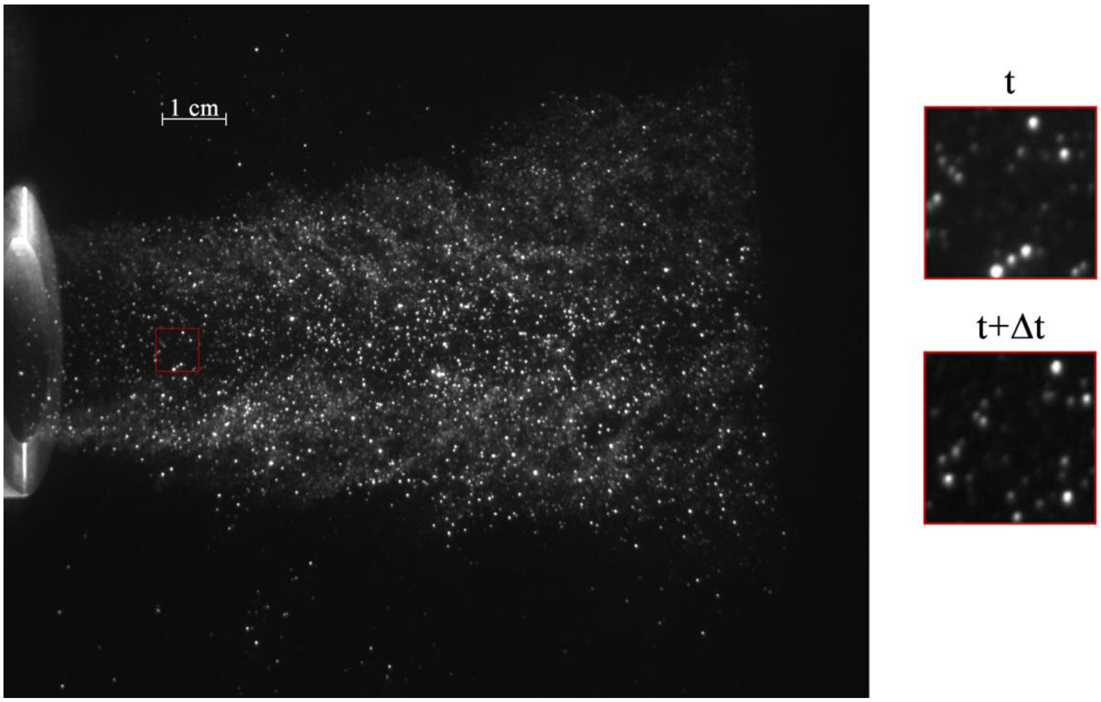

Fig 4. Characteristic images of the SiO_2 particles in the supersonic plasma flow.

The processing of the experimental data was performed in Matlab. Processing of PIV data was carried out with the window of 32 px width. This size corresponds to the spatial resolution of 3mm for the velocity data. As an example, figure 5 shows the results of the SiO_2 particles velocity calculations for two pairs of images registered during the operation of electric arc gas heater. Presented results show significant instability of the flow of the particles.

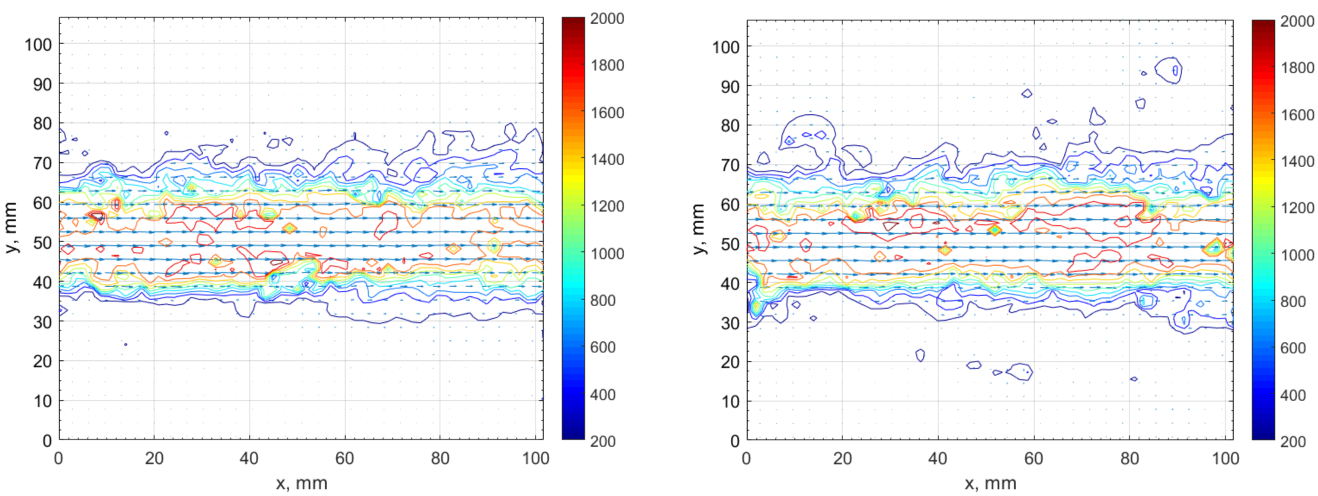

Fig 5. The distribution of the velocity of SiO_2 particles measured from different recorded images of the same experiment.

The resulting particle velocity field was averaged over the all data measured during the recording of the experiment. Figure 6 shows vector field with isolines for the velocity component u parallel to the axis of the plasmatron for the averaged particles velocity.

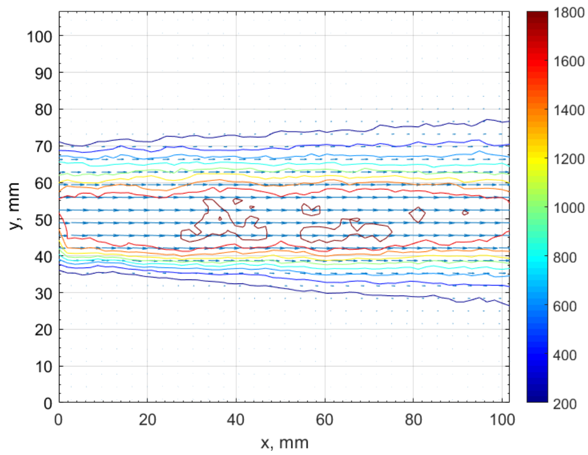

Fig 6. The averaged SiO_2 particles velocity field recorded during the experiment.

Values of the perpendicular to the flow axis velocity component v is insignificant in comparison with the component u. Figure 7 presents the standard deviation for the calculated velocity field based on the values of individual images velocity measurements.

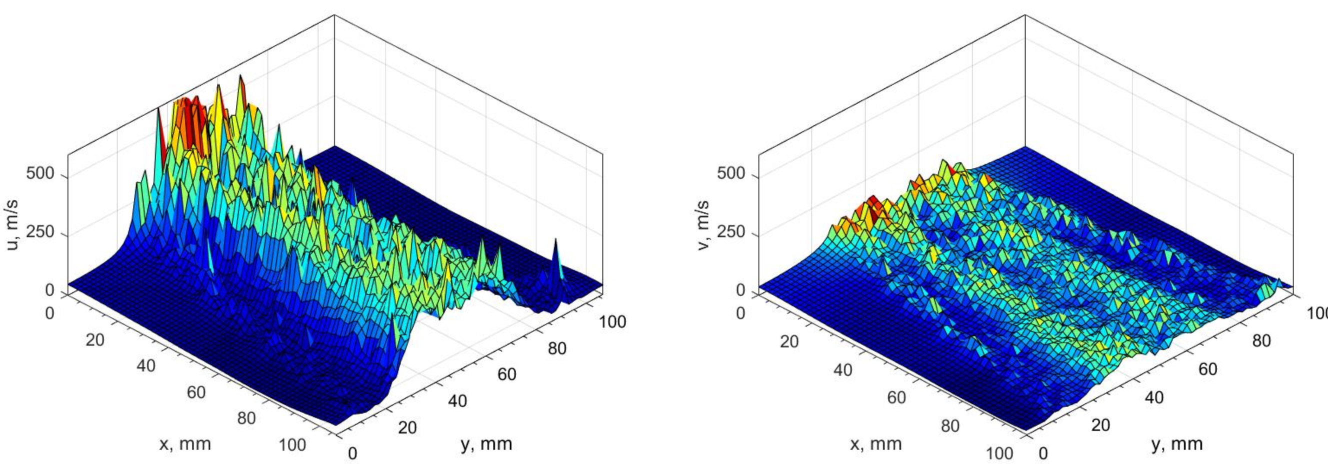

Fig 7. Standard deviation for both components of the particles velocity.

Figure 8 shows the distribution of u velocity component for cross sections of the plasma flow for distance of 50 mm and 100 mm from the exit of the electric arc heater.

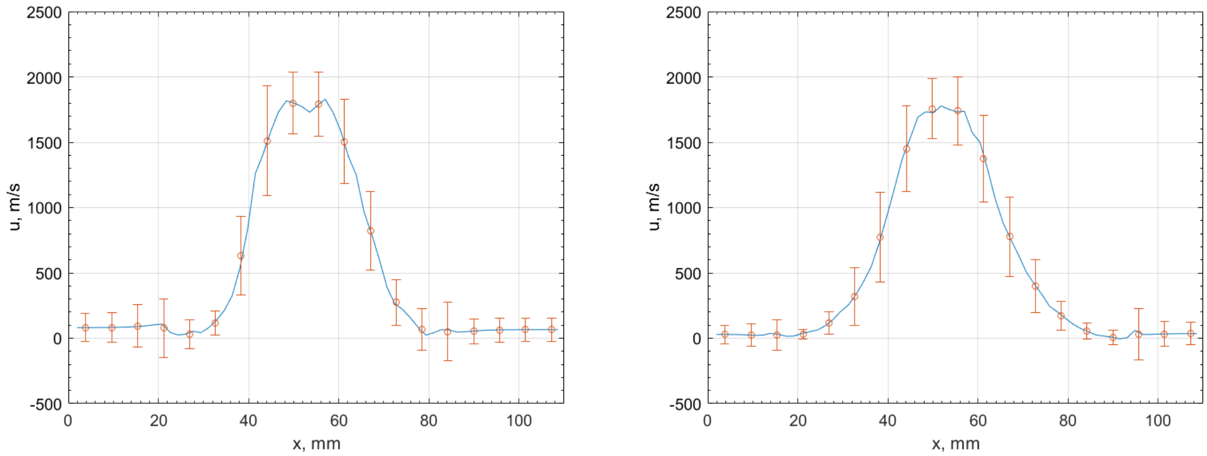

Fig 8. The distribution of the u velocity in the cross sections at a distance of 50 mm (left) and 100 mm (right) from the plasmatron exit.

Figure 9 shows the variation of the averaged particle velocity on the axis of the plasma flow. The confidence interval corresponds the standard deviation values of the velocity measurements.

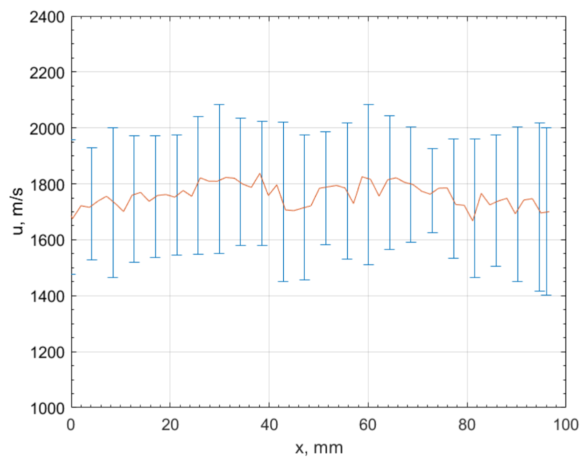

Fig 9. Variation of the dispersed phase velocity along the axis of the plasma flow.

Conclusion

During the experiments, the dispersed phase velocity measurements were performed for the supersonic mode of the electric arc gas heater operation. This mode of operation corresponds to the marginal functional conditions for such model of plasmatron. In this case, the electric power of the plasma torch reaches a value of 1.5 MW. The results of the velocity measurements of SiO_2 particles in high-temperature supersonic plasma flow are presented. The results show that the time-averaged velocity of the particles reaches the value of ~1800 m/s in the observed region of the heterogeneous flow. The flow is essentially non-uniform and the magnitude of the root-mean-square deviation for the u component of the velocity reaches 30% of its maximum value.

References

[1] Dubreus T, Sheeley J, Stewart J. Development of a Mid-Pressure Arc-Heated Facility for Hypersonic Vehicle Testing. American Institute of Aeronautics and Astronautics, 2010.
[2] Mayeaux B, Olivas J, Melroy P, Cone D. Study of Ti Alloy Combustion Susceptibility in Simulated Entry Environments. American Institute of Aeronautics and Astronautics, 2009.
[3] Ritt PJ, Williams PA, Splinter SC, Perepezko JH. Arc jet testing and evaluation of Mo–Si–B coated Mo and SiC–ZrB2 ceramics *J. Eur. Ceram. Soc.* Vol. 34, No. 15, pp 3521–3533, 2014.
[4] Carandente V, Savino R, Esposito A, Zuppardi G, Caso V. Experimental and numerical simulation, by an arc-jet facility, of hypersonic flow in Titan's atmosphere *Exp. Therm. Fluid Sci.* Vol. 48, pp 97–101, 2013.
[5] Chuprasov VV, Tret'yak MS, Klishin AF. Characteristic features of diagnostics of supersonic high-temperature jet parameters *J. Eng. Phys. Thermophys.* Vol. 84, No. 5, pp 1120–1125, 2011.
[6] Raffel M, Kompenhans J, Wereley ST, Willert CE. *Particle Image Velocimetry a Practical Guide*. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg, 2007.

Copyright Statement