LASER DOPPLER ANEMOMETRY IN A TRANSFERRED ARC:

SOME PROBLEMS AND SOLUTIONS

P.A. Patterson and R.J. Munz
Department of Chemical Engineering, McGill University, Montreal

ABSTRACT

A laser doppler anemometer with a counter-microprocessor data treatment system was used in an attempt to measure gas and injected particle (5 μm) velocities in a transferred arc argon plasma operating in air. The plasma operated at 16 kW and had a length of 4 cm. Injected particle velocities were obtained successfully but problems with agglomeration, vaporization, and thermophoretic migration of tracer particles prevented the measurement of true gas velocities. The work is continuing.

1. INTRODUCTION

Of the many configurations of plasma torches described in the literature, the transferred arc torch, in which an arc is struck between a sheated thoriated tungsten cathode and an external anode is one which shows great promise for commercial application. The arc may be struck to multiple graphite anodes or plasma torches (to produce a powder product in a long tailflame[1,2], or to a molten bath to produce a consolidated product.[3] In applications where a powder feed is to be treated, the conical cathode is surrounded by either a continuous annulus or discrete orifices through which the powder is injected. These entry ports of powder are normally positioned so as to maximize the entrainment of powder into the arc by electromagnetic pumping. Information on the gas velocity and temperature profiles in such devices is of vital importance if optimum design and operation are to be achieved. Of equal importance is information on the velocity and concentration profiles of the injected particles so that the conditions for maximum conversion may be established. This work is centered on a transferred arc which simulates the conditions for operation to a molten bath. Temperature and velocity profiles have been measured in the absence of injected particles by Mehmetoglu.[4] The objectives of this work are to use laser doppler anemometry to measure velocity profiles of both plasma gas (via tracer particles) and larger injected particles as well as the concentrations of particles at various arc positions. The study is still in its early stages and only some preliminary results are presented here.

The plasma torch used in this work is shown in Figure 1. It is powered by a 45-kW d.c. welding power supply with current control. Full details on the auxiliary equipment used are given elsewhere.[4] The central orifice for plasma gas is 3.0 mm in diameter, and the cathode was adjusted to give an open area of 6.28 mm^2 for flow. The cathode is surrounded by four evenly-spaced cylindrical injection ports for powder and gas; these are 3.5 mm in diameter. The anode is a water-cooled circular copper plate 5.70 cm in diameter. The arc length is adjusted to the required length after ignition.

The tracer particles used were 5 μm micron alumina which were dispersed in a fluidized bed of silica particles and then injected with the plasma gas. Two types of injected particles of rutile (TiO_2) were used; these had mean number diameters of 106.2 µm and 0.5 µm. They were injected from a single feeder into a four-way tandem splitter which fed the four injection ports. The smaller particles were fed at a very low flow rate so that the splitter worked well even for these particles. All runs reported here were made at the following operating conditions:

Arc current 250 A
Arc voltage 63 V
Arc length 4.0 cm
Plasma gas flow rate 0.415 g/s argon
Injection gas flow rate 0.554 g/s argon

The LDA equipment used was very similar to that described by Lesinski et al.[5] It was mounted on an optical bench which allowed three-dimensional motion with an accuracy of ±0.1 mm. The laser axis was perpendicular to the arc axis and radial traverses were made by moving the optical system sideways. A beam spacing of 50 mm coupled with 250 mm transmitting and receiving lenses gain a scattering ellipsoid with axes of 4.6 and 0.32 mm. Measurements were made using 8 interference fringes. A narrow wave band filter (0.3 nm) centered on the laser wavelength was used to minimize interference between the scattered laser light and the intense plasma radiation.

The SWTPC 6800 microcomputer used to log and statistically treat data was able to treat up to 10000 points per velocity measurement. In this work, about 1000 points were used because of the short lifetime of the anode in the presence of molten oxides and the scarcity of particles at some plasma locations due to vaporization and thermophoresis.

RESULTS

Fine Particles in Plasma Gas

We initially intended to measure the plasma velocity distribution in the absence of large particles to compare these results with those reported by Mehmetoglu[4] based on pitot tube traverses and spectroscopically measured temperature distributions. For this study, alumina particles were injected directly into the plasma gas; this led to a rather unstable operation of the torch. Non-uniform particle feeding caused a particle build-up in the cathode annulus which in the worst case led to cathode failure by arcing to the sheath and at best caused considerable perturbation of the arc. The perturbation was evident in both the electrical characteristics (increased and unstable voltage) and in the spatial stability of the arc. Velocity measurements were almost meaningless since both the temperature and velocity gradients are very steep, and the location of the anodic arc root was only known to about 5 mm.

Some data were obtained showing that the LDA technique can in fact be applied in a transferred arc. Measurements of velocity could not be obtained on the far side of the arc axis if a radial traverse was made in a direction parallel to the laser beams; this showed that some plasma radiation interference was present. All further traverses were thus made in a plane perpendicular to the laser beams. The velocity data obtained were all about an order of magnitude less than expected although the maximum values obtained agreed fairly well with the expected results. A great deal of alumina fume was produced in these experiments sugesting that penetration of the particles into the arc was good. Only a few runs were made with injection directly into the plasma gas.

Coarse Particles Through Injection Ports

The second series of experiments were to investigate the velocities of larger particles injected into the four injection ports surrounding the cathode. Rutile (TiO_2) particles were used and some typical results are shown in Figure 2 which shows the geometry as well as the axial velocity profiles taken at four levels. The curves are simply smooth lines drawn through the data taken at 2 mm intervals. The profiles have off centre maxima and are similar in form to those reported by Lesinski et al[5] for a cold flow. Again, the velocities are well below the expected gas velocities as would be expected for such large particles. Maximum velocities of about 200 m/s were obtained presumably for the smallest particles. A statistical analysis of 1000 point samples suggests that the 95% confidence limits for the mean velocities is about ±4%.

Fine Particles Through Injection Ports

In these experiments, fine futile was injected into the injection ports in an attempt to map the arc velocity field. Surprisingly, these curves also showed off-centre maxima and mean velocities much lower than expected. One problem is that the velocity at a single point is averaged over the length of the scattering volume which is about 4 mm; this can distort the velocity profile. Figure 3 shows the radial profile of Mehmetoglu[4], the profile measured using fine rutile, the data acquisition rate for rutile and the velocity profile calculated by using Mehmetoglu's data averaged over 4 mm sections and weighted according to the data acquisition rate. It is clear that the averaging can distort the expected profile but it cannot account for the measured results. It must be concluded that either the measured profile is correct (which is highly unlikely on physical grounds) or that the fine rutile particles behave as much larger agglomerates which do not follow the gas flow. The fine alumina particles used in the first experiments have also been injected through the ports. These give higher apparent velocities but also result in off-centre maxima.

CONCLUSIONS

It must be concluded from these preliminary results that the application of laser doppler anemometry to the study of velocities in a transferred arc is far from simple. Some useful measurements have been made with larger particles and these appear to be reliable. A simple model is being developed to compare these results to prediction based on calculated trajectories. Improvements can be made by using short focal lenses and thus shortening the scattering volume. It is felt that gas velocity measurements made to date are unreliable since although some of the injected particles attain the gas velocity, most do not. The work will be continued using finer, more refractory particles which are better dispersed.

ACKNOWLEDGEMENT

We are grateful to the plasma technology group of Prof. M.I. Boulos (U. of Sherbrooke) and Prof. K. Ananthan (Dept. of Computer Science, McGill U.) for development of the microprocessor data treatment system, and to Dr. Y. Sahai (Dept. of Metallurgical Engineering, McGill U.) for initially setting up the LDA system. Financial assistance was obtained from the Ministry of Education of Quebec and from Guyana Mining Enterprise Ltd. in the form of a scholarship to P.A. Patterson.

REFERENCES

(1) C. Sheer et al, "Arc gasification of coal", Proceedings of International Symp. on Plasma Chem., Vol. 1 p 277, Zurich Switzerland (August 1979).

(2) Humphreys Corporation U.K. Patents 1 317 918 and 1 317 919 (1973) (See also I.G. Sayce, Pure and Applied Chem. Vol 48 pp 215-228 1976).

(3) W.H. Gauvin et al, Journal of Metals 33 (1) pp 42-46 (1981).

(4) M.T. Mehmetoglu, "Characteristics of a Transferred Arc Plasma", Ph.D. Thesis, McGill U., Department of Chemical Engineering (1980).

(5) J. Lesinski et al,"Laser doppler anemometry in gas-solid flows", Proceedings of 2nd Multi-phase Flow and Heat Trans. Symp., Florida, U.S.A. (April 1979).

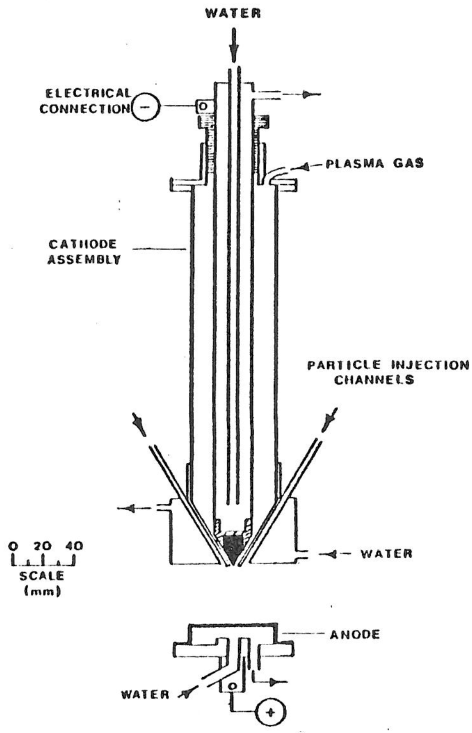

Figure 1: Schematic Diagram of Transferred Arc Plasma Torch

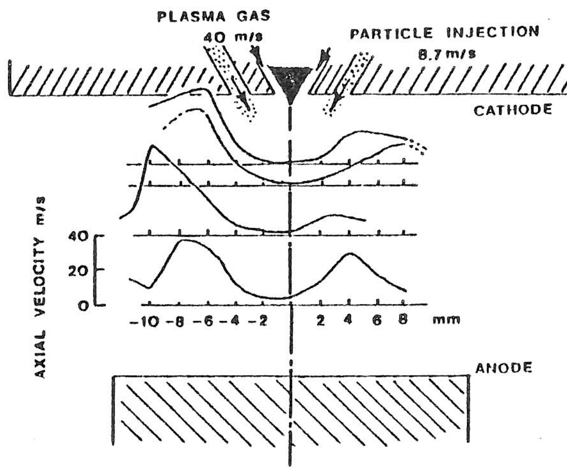

Figure 2: Radial Profiles of Axial Velocity of Injected 106 μm T_iO_2 Particles

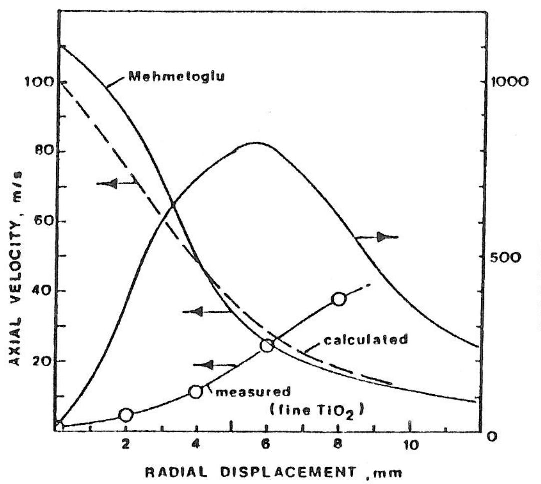

Figure 3: Radial Profile of Plasma Gas Axial Velocity at a Position 2 cm below the Cathode