# SPECTROSCOPIC TEMPERATURE MEASUREMENTS IN A D.C. PLASMA JET

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## ABSTRACT

A study was made of the flow and temperature fields in an atmospheric pressure d.c. plasma jet under different operating conditions. The velocity field measurements carried out using laser doppler anemometry were reported earlier at the 4th International Symposium on plasma chemistry (1,2). In the present study, the work has been extended to include measurements of the temperature fields using emission spectroscopy for an argon and an argon/nitrogen plasma. The measurements were made using the absolute intensity technique for the ArI lines 4300.0 Å and 4259.0 Å. The parameters investigated were the current intensity and the plasma gas composition.

## INTRODUCTION

While d.c. plasma torches are presently used on a commercial basis for a variety of cuttings, welding and plasma spray-coating operations, they are still the subject of fundamental study aiming at improving our understanding of their caracteristics and the principal phenomena controlling their performance. A special attention has been given to the measurement of the velocity and temperature fields in the plasma jet which can have an important influence on the trajectories and temperature history of particles as they are injected in the flow.

Plasma velocity measurements has been reported in literature using transient total impact probes, water cooled probes and more recently using laser doppler anemometry. A number of techniques have been developed for temperature measurements under plasma conditions. The most commonly used are:

1- Enthalpy probes
2- Melting point determination using different materials
3- Radiation pyrometry combined with a moving screen
4- Emission spectroscopy

Each of these have obviously its advantages and limitations. In fact even emission spectroscopy which is the most widely accepted technique has the disadvantage of being limited to temperatures above 5000 or 6000K. This limitation, however, is more than compensated for by the fact that it is a non-perturbing technique and that it has a high special resolution and has vertually no upper limit.

In the present study, emission spectroscopy has been used for the measurement of the radial temperature profiles in a d.c. plasma jet under different operating conditions. The objectives of the work have been specifically to obtain temperature profile for the same torch and under the same conditions as those used previously in our velocity field measurements (1,2). This was particu-

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larly important in order to illucidate the dependence of the temperature field in the jet on the torch operating conditions. It also served to verify the validity of currently accepted similarity criteria between the velocity and temperature fields.

## EXPERIMENTAL SETUP

A schematic diagram of the experimental setup used in this investigation is shown in Figure 1. The d.c. torch was of a standard design with a water-cooled copper anode, 7.1 mm i.d, and a thoriated tungsten cathode. The plasma gas was either pure argon or an argon/nitrogen mixture. The total gas flow rate was maintained constant at 50 SCFH (23.6 $\ell$/min) while its composition and the current intensity were varied over the range 0-40% $N_2$ and 300-500 amps respectively.

The spectrometer used was a Jarrel-Ash, Czerny-turner type with a focal length of one meter. It was equiped with a grating blazed at 4800 Å giving rise to a first order dispersion of 10 Å/mm. The PM was an RCA 1P28.

Radial emission intensity profiles were obtained by forming an image of the plasma jet in a ratio of 1:1 on the entrance slit of the spectrometer. The plasma torch was then traversed in a plane parallel to that of the slit using an accurate traversing mecanism which allowed its position to be determained within $\pm$ 0.02 mm. For each profile measurements were made of the radiation intensity at the peak of the argon line as well as at its shoulder. The difference between the two values was then fitted using a spline subroutine and the specific radiation intensity profiles obtained by an Abel inversion. The absolute temperature profiles were computed using the spectrometer calibration curve which was obtained using a pyrometric Molarc lamp type 2371 placed in the position of the plasma jet. Since measurements made with the 4300.0 Å and the 4259.0 Å argon lines gave essentially identical results, only those obtained with the 4300.0 Å line will be reported in this paper.

## RESULTS AND DISCUSSION

Typical temperature profiles obtained for a pure argon plasma with a current intensity of 300 A and a power level of 7.5 kW are shown in Figure 2. As expected the maximum temperature observed on the centerline of the torch at a distance of 1.0 mm from the nozzle is about 12000K. The radial temperature profile is noted to drop rapidly in the radial direction reaching a temperature of 9000K less than 3 mm away from the axis. The overall temperature profile is also observed to drop with the increase of the axial distance from the nozzle ($1.0<z<14.0$ mm). The axial temperature profile, however, is less steep than the radial profile.

Similar observations were made when operating at higher power levels as shown in Figure 3 (I=400 A, P=10.5 kW). It is interesting to note that for the same plasma gas flow rate, a 40% increase of the plasma power resulted in a relatively small increase of the temperature on the certerline at the exit of the torch. The temperature profile further downstream, at z=14 mm was slightly flatter at the higher power level than at lower powers.

The effect of changes in the plasma gas composition on the radial temperature profiles at the exit of the torch is shown on Figure 4. It should be pointed out, that these profiles were taken at the same current intensity. Since an increase in nitrogen concentration results in a substantial increase in the voltage drop across the torch, the power levels corresponding to these profiles are substantially higher than that for a pure argon plasma at the same current intensity. It is interesting to note, that the (30 Ar/20 $N_2$) profiles are lower than the other two profiles. The effect could be related to the substantially higher specific enthalpy of the argon/nitrogen plasma as compared with that for pure argon which seems to more than compensates for higher energy level in the plasma.

Since it has been commonly accepted that the temperature and velocity profiles in a d.c. plasma jet can be assumed to be similar, ie the non-dimensional velocity, U*, and temperature, T*, profiles coincides;

$$\frac{U}{U_o} = \frac{T-T_a}{T_o-T_a}$$

The temperature profiles obtained with the (40 Ar/10 $N_2$) plasma at 400 A have been plotted in non-dimensional form in Figure 5 superposed on the velocity profile data obtained earlier (1) under the same conditions it is noticed that the two profiles are rather close for z=10 mm. This is, however, not the case for z=5 and 20. Unfortunately the data are too few for a meaningful conclusion at this stage. More work is obviously needed to clarify this point.

## CONCLUSIONS

Measurements were made of the temperature profiles in a d.c. plasma jet under different operating conditions. The results indicate that the temperature at the exit of the torch is relatively insensitive variations in the current intensity. Variations in the gas composition at constant current intensity results in relatively little change in the temperature profile inspite of the associated substantial change in the torch power level.

## ACKNOWLEDGMENT

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## NOMENCLATURE

| | |
|---|---|
| r | distance in the radial direction, (mm) |
| T | temperature, (K) |
| $T_a$ | ambient temperature (K) |
| $T_o$ | centerline temperature at the exit of the jet (K) |
| T* | non-dimensional temperature ($T-T_a/T_o-T_a$) |
| U | axial velocity (m/s) |
| $U_o$ | centerline velocity at the exit of the jet (m/s) |
| U* | non-dimensional velocity ($U/U_o$) |
| z | distance in the axial direction (mm) |

## REFERENCES

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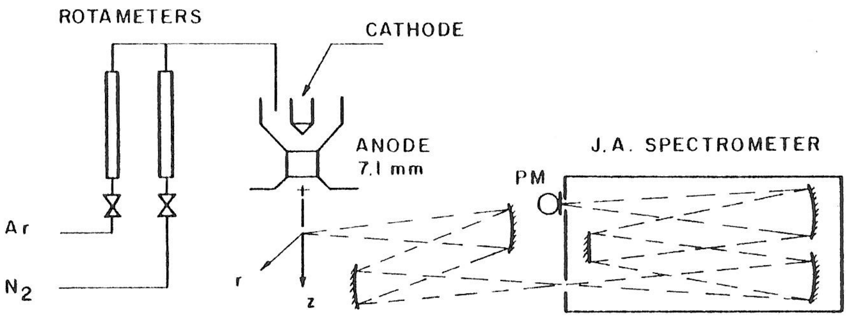


Figure 1:- Experimental setup

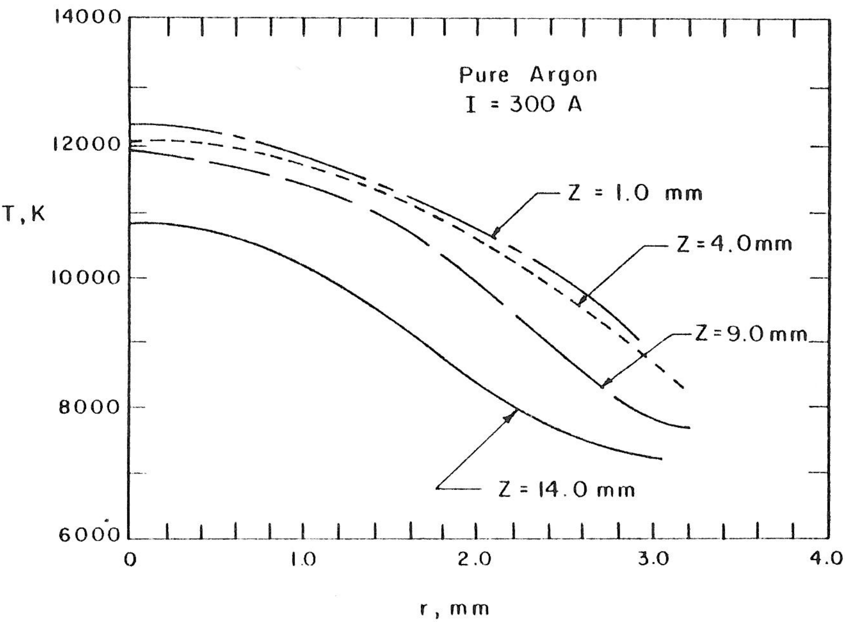


Figure 2:- Temperature profiles for a pure argon plasma
I=300 A, P=7.5 kW

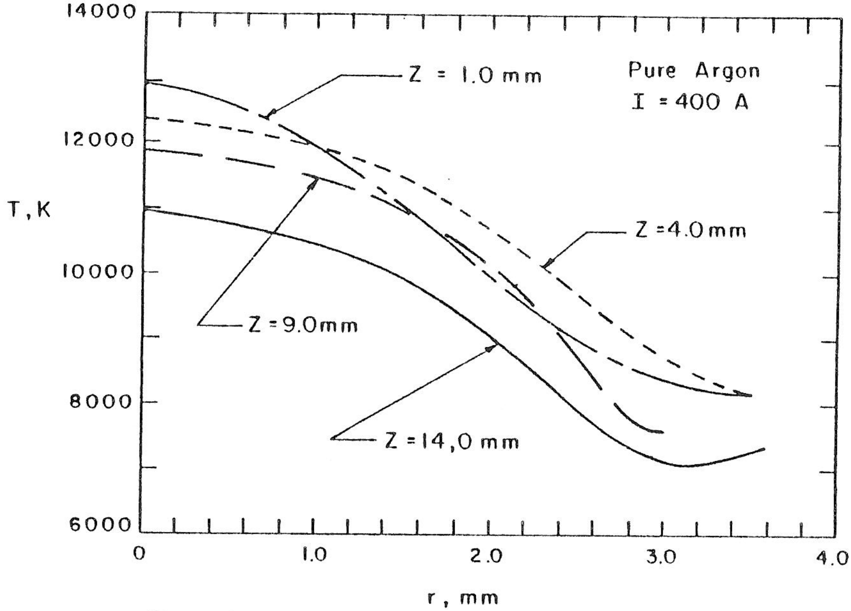


Figure 3:- Temperature profiles for a pure argon plasma
I=400 A, P=10.5 kW

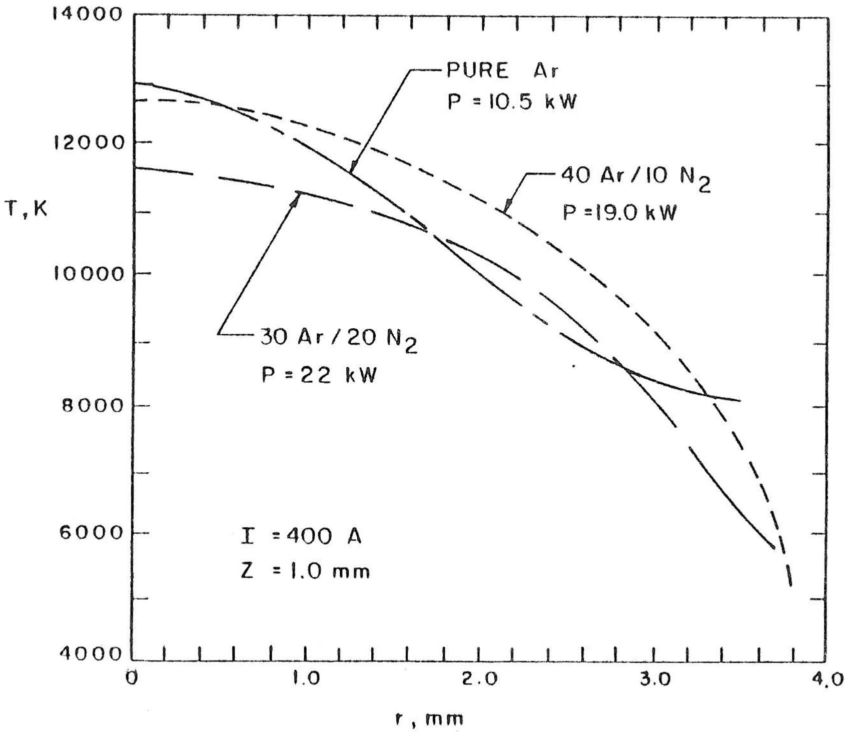


Figure 4:- Temperature profiles for an Argon/Nitrogen plasma
I=400 A, z=1.0 mm

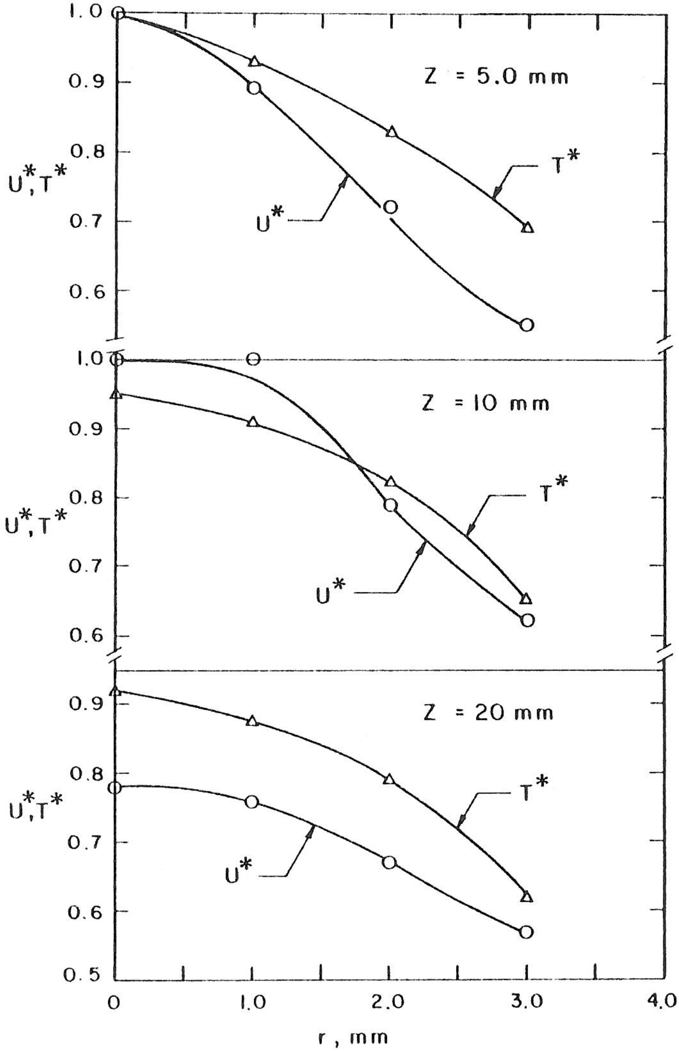


Figure 5:- Non-dimensional velocity and temperature profiles for a 40 Ar/10 $N_2$ plasma, I=400 A ($U_o$=218 m/s and $T_o$=12085 K, Ta=300 K)