ROTATING ARC OF COAXIAL DESIGN FOR PLASMA SYNTHESIS
AT INTERMEDIATE TEMPERATURES

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ABSTRACT

A magnetically rotating electric arc of coaxial design was produced in \( \text{N}_2 \) and air at 1 atm and 7-9 A. The axial temperatures decreased with distance from the cathode tip, for example, from 1400 K at 5 mm to 500 K at 5 cm, and depended both on the arc current and the gas flow. Spectral analysis of the arc indicated \( \sim 12\% \) conversion of \( \text{N}_2 \) to NO in air.

1. INTRODUCTION

Depending upon gas pressure and the mode of excitation the gas temperature in glow discharges varies in the range 350-700 K. For a number of inorganic syntheses higher gas temperatures and greater mass throughputs are desirable (1). Although thermal plasmas produced by the various types of electric torches operate under normal pressure, they have temperatures in the range 3000-15,000 K (2). The range of intermediate pressures and temperatures is especially interesting, since in this region the reactions are quite vigorous, while excitation of the molecules is known to be a thermodynamically nonequilibrium process (3).

In an effort to achieve the intermediate range of temperatures we have constructed a magnetically rotating electric arc which operates below 10 A at atmospheric pressure. Preliminary spectroscopic studies (4) of the arc in helium at 8-9 A indicated a radial distribution of temperature from 2800 K at 1 mm from the cathode to 2200 K at 1 mm from the anode for a 4 mm gap. The evaluation was made using the Saha equation and the relative intensities for several pairs of lines in the range 361.3 - 501.6 nm. This paper reports the temperature measurements at various axial distances from the cathode tip and a spectral analysis of the light emission from such an arc in nitrogen and air. The axial, rather than radial, temperatures are meaningful in flow systems used for plasma synthesis.
Fig. 1. Schematic of the rotating arc.

2. EXPERIMENTAL

A schematic diagram of the apparatus is shown in Fig. 1. It consisted of a water-cooled tubular reactor made from 24 mm i.d. stainless steel pipe. The arc chamber was constructed inside the central portion of this tube which functioned as the anode, by fitting a 14 mm i.d. stainless steel tube with 5 mm wall thickness. The cathode was a 6 mm tungsten rod which was positioned coaxially inside the arc chamber by means of a stainless steel holder inside a ceramic plug with a 3 mm gas inlet at one end of the reactor. The gas inlet was connected to a manifold consisting of flowmeters, pressure gauges and supply tanks with metering valves for the desired gases. At the other end of the reactor a sealed quartz window allowed visual observation of the arc as well as its spectral analysis. A 8 mm port located near the window was designed for insertion of a thermocouple for temperature measurement in the spatial afterglow region.

The arc region was centered inside two water-cooled 62 ohm solenoids consisting of 3400 turns of 18 gauge copper wire. These solenoids were connected in parallel and operated in the current range of 1-4 A to produce field strengths in the range of 0-480 G, which were sufficient to rotate the arc. The magnetic field strengths were measured using a calibrated axial probe and a Bell 240 gaussmeter. The arc was ignited in the desired gas flow by an rf high voltage across the 4 mm gap and then maintained by a Jarrel-Ash Varisource constant current power supply rated for 0-30 A at a voltage upto 120 V.
The power supply included the A.C. high voltage section in the form of a 24 kV neon transformer coupled by relays to the D.C. output. When the arc ignited, the relays opened, isolating the high voltage section from the arc chamber. The voltage drop across the electrodes increased with magnetic field and rapidly reached a plateau.

The rotational speed of the arc was measured using a coil consisting of 5 turns of 24 gauge copper wire located in the arc chamber and connected to an oscilloscope (not shown in Fig. 1). The passing of the arc column induced a current in the coil that was displayed on an oscilloscope as a sinusoidal wave. At arc currents of 6-9 A the rotations increased linearly with magnetic field in the range 80-250 G and varied from 70 to 360 ± 3 per second in flowing nitrogen/air slightly above 1 atm. The rotational velocity of the arc remained independent of the gas flow rate up to 900 ml/min.

For direct temperature measurement a calibrated Pt-10% Rh/Pt thermocouple was used together with a battery operated 0-64 mV Leeds and Northrup potentiometer. Both radial and axial temperature measurements could be made by replacing the window with a slotted aluminum plug through which the thermocouple could be positioned at different locations (not shown in Fig. 1).

For spectral analysis of the light from the arc it was focused using a system of quartz lenses onto a scanning F/4 Bausch and Lomb monochromator equipped with an RCA 1P 28 photomultiplier tube operated at -900 V. An adjustable iris permitted the light from a selected region of the arc to be analyzed. The output of the photomultiplier was fed by way of a voltage divider and a 60 Hz notch filter to a AI 13 analog to digital converter module (Interactive Structures) and interfaced with an Apple IIe microcomputer. The monochromator was calibrated using a mercury vapor lamp.

3. RESULTS AND DISCUSSION

Figure 2 shows the temperature T as a function of the axial distance x from the cathode tip. The data could be well fitted by a computer using the equation

\[ T = m \log(x) + b \]

where m and b are constants. The dotted lines represent this least squares fit of the data. Besides the arc current, gas flow rate was a factor in determining the axial temperature in the nitrogen arc at 1 atm.

In a representative set of observations at 8 A, spectral bands in each of the following systems were observed (5):

First positive system \((A^3\pi_u + B^3\pi_g)\)

Second positive system \((C^3\pi_u + B^3\pi_g)\)

First negative system of \(N_2^+ (B^2\Sigma_u^+ + X^2\Pi_g)\)
Fig. 2. Gas temperature $T$ as a function of the axial distance $x$ from cathode in nitrogen arc at 1 atm pressure. The dotted lines represent a least squares fit of the data using the equation $T = m \times \log(x) + b$.

Vegard-Kaplan system ($A^2_l_u^+ + X^1\Sigma_g^+$)

Goldstein-Kaplan system ($C^{13}\Pi_u + B^{3}\Pi_g$)

Gaydon's Green system ($H^3\phi_u + G^3\Delta_g$)

The three most intense bands were: 426.9 nm (2nd positive) > 423.6 (1st negative) > 586.4 (1st positive) and contributed to 20% of the total luminosity. Bands that belonged to the $\beta$ system ($B^{2}\Pi + X^{2}\Pi$) of NO were observed. Unlike the strong $N_2$-bands which were triple-headed and degrading to shorter wavelengths, the NO-bands were double-headed and degraded to the red. The most intense of the NO bands was at 457.4-459.0 nm and contributed to ~2% of the optical emission. In the 389-587 nm region $\Sigma I(\text{NO})/\Sigma I(\text{total})$ indicated ~12% as a lower limit for the conversion of nitrogen into nitric oxide. Work is in progress for the analysis of the effluent gases by in situ gas chromatography.
REFERENCES