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THE ARC DIAMETER AND RATE OF ROTATION OF A MAGNETICALLY ROTATED ARC WITH SUPERIMPOSED GAS FLOW

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Abstract

A magnetically rotated arc heater producing a uniformly heated and highly turbulent hydrogen plasma is briefly described. The effect of nozzle geometry and parameters affecting the diameter of the arc and its rate of rotation are discussed and some results are presented. It is shown that steady rotation of the arc can occur when the externally applied magnetic field is zero. The drag coefficient was determined.

1. Introduction

A magnetically rotated arc heater with hydrogen as the plasma working fluid has been developed for use in chemical processing (1, 2). A highly turbulent plasma is necessary to obtain good mixing of the reactants and, in order to satisfactorily control the rate and direction of the chemical reactions, a uniformly heated plasma is required. Both the level of turbulence and the uniformity of heating (3) depend upon the rate of rotation of the arc and the arc diameter. It has been shown (4) that cathode erosion is negligible and that anode lifetime is dependent upon the rotation rate; a high arc rotation rate being required to give an acceptable lifetime. Thus, the effect of arc current, gas flow rate, cathode setback, cathode shape, nozzle geometry and magnetic flux density upon the rate of rotation of the arc have been investigated. The arc diameter, velocity, anode root velocity and the drag coefficient have also been determined.

2. Apparatus and procedure

The arc heater (Figure 1) consisted of a non-transferred d.c. plasma torch mounted on the axis of a magnetic field coil. The torch had a cylindrical outer jacket which terminated in a water cooled nozzle (anode). A water cooled rod, tipped with thoriated tungsten served as the cathode. The plasma working fluid was heated by passage through an arc generated between the electrodes which was rotated by means of a magnetic field. The gas was introduced tangentially to the plenum chamber so that the direction of swirl was in the same sense as the rotation produced by the externally applied magnetic field. The arc rotation rate was measured using differential magnetic search coils (1, 4), the resonant frequency of which was \( \approx 20 \text{ MHz} \). The probe output was monitored oscillographically and on a frequency counter.

A mirror immersed in the plasma and screened with a jet of argon was used to take high speed cine photographs of the arc. The combination of camera aperture and optical filters was chosen so that the diameter of the arc recorded photographically was not reduced by further reductions in the amount of light collected. Synchronised photographs of the arc and the probe output were obtained using a pulse circuit to trigger the camera and a pre-framing pulse from the camera to trigger the oscilloscope.
It can be seen from Figure 2 that increasing the arc velocity and rotation rate produced an increase in the convective losses from the arc and thus a reduced arc diameter. Similarly, increasing the gas flow rate or decreasing the nozzle diameter increased the convective losses and reduced the arc diameter. As the arc current increased the diameter increased approximately as $r^{2/3}$. The low viscosity and density in hydrogen lead to high convective losses as compared to argon. For example, average values of arc diameter in the range 0.65mm-1.1mm were measured for $I = 90A$ and $20 \text{ l/min.}$ of hydrogen compared to a typical diameter of 2.5mm under similar conditions in argon. The diameter was found to be insensitive to the applied magnetic field.

Frame by frame analysis of the high speed cine films (an example is given in Figure 3) confirmed the magnetic probe readings. The rate of rotation of the arc varied from one revolution to the next but the rate, averaged over a period long compared with the period of revolution, was found to be constant. The rate of rotation increased with increasing gas flow rate (Figure 4). This is attributed to the increased thermal pinch, produced by the increased gas flow, which gives a narrower arc that is subject to smaller aerodynamic drag opposing rotation.

The rotation rate in hydrogen as a function of magnetic flux density is compared with that in argon in Figure 5. The rotation rate $(n)$ increased with increasing magnetic flux density ($B$ Tesla) and for hydrogen $(nkHz) = 35 + 5400B$ when $0 < B \leq 0.003$ Tesla and $(nkHz) = 56 + 62B$ when $B > 0.02$ Tesla with a transition region in between. The curve for argon exhibited a similar step but the transition region extended over a greater range of $B$, the slopes were smaller and the rate of rotation was approximately an order of magnitude less. The rate of rotation decreased with increasing nozzle diameter (Figure 6) and increased with increasing throat length (Figure 7). It was approximately independent of nozzle angle, setback and the angle of the cathode tip. However, for an arc current of 100A and 0.088 Tesla (other conditions as for Figure 5), the rotation rate increased from 53 to 68 kHz as the radius of curvature of the cathode tip was reduced from 6mm to 4mm. The drag coefficient for the arc for the range of Reynolds number investigated (640-1530) was found to be 0.95 and was in good agreement with results published for other arcs(6, 7, 8).

The very high rates of rotation obtained in hydrogen were such as to give a uniformly heated plasma despite the small arc diameter(3) and a highly turbulent plasma. The latter was demonstrated by injecting fine carbon particles into the flame. It was noted that the direction of rotation in hydrogen could be with or against the direction of swirl for magnetic flux densities $< 0.01$ Tesla applied in the sense which produce rotation in the swirl direction. The self magnetic field of the arc is not negligible and this effect, which was not observed in argon, is thought to originate in a spatial arc instability, the growth of which is encouraged by the resulting self-field. Depending upon the swirl direction, the spatial instability may be enhanced or suppressed by the swirl. The effect was strong enough in hydrogen to produce steady rotation rates as high as 35 kHz for zero applied field and is the explanation of the rapid initial increase in rotation rate at low magnetic flux density - the higher aerodynamic drag in argon resulting from the higher density viscosity and diameter suppresses the effect.

5. Conclusions

Very high rotation rates ($\approx 80$ kHz for $B = 0.08$ Tesla) have been obtained in hydrogen producing a uniformly heated and highly turbulent plasma and long electrode lifetimes. It is possible to obtain a steady and high rate of rotation in hydrogen with no externally applied magnetic field.

6. References


7. Acknowledgement

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