APPLICATION FEASIBILITY AND CHARACTERISTICS OF A
GAS-STABILISED FREE-BURNING ARC REACTOR

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ABSTRACT

The feasibility of a new experimental reactor with a ring shaped anode has been investigated. The role of the convection-stabilization gas shroud is shown. Spectroscopic isotherms are given for parallel and convergent flow conditions, and the effect upon 10 micron tungsten powder penetration is considered.

1. INTRODUCTION

The principal objective of the present work is to demonstrate the feasibility of an experimental reactor and reveal its basic characteristics. This reactor is based on a free-burning arc drawn between a cathode and a ring shaped anode, used for the processing of refractory powders.

In conventional plasma reactors, reactive materials are frequently injected with a carrier gas of high flow rate, and very complicated phenomena (heat transfer, mass transfer, momentum transfer) arise inside the high temperature zone. This high flowrate is necessary to give the reactive material a sufficiently large inertia force to penetrate into the very high viscosity region of a high temperature plasma.

One of the advantages of the new reactor is that high melting point material powders can be easily introduced into the hot core of the plasma utilizing the cathode pumping effect (1). Optical access required for identification of the reaction mechanisms is another advantage. The arc, however, shows a tendency towards unsymmetry and non-uniform attachment at the anode surface. This tendency is further enhanced when powdered material penetrates into the plasma, disturbing the electric field distribution. However, this arc can be stabilized by a protective gas shroud leading to a symmetric current density distribution by cooling the arc fringes.

2. REACTOR DESIGN

Fig. 1 shows a schematic of the plasma reactor which is connected to a 50 kW D.C. power supply with current control.
The reactor itself is mounted in a water cooled chamber which provides control of the gas atmosphere (argon). Details of the main parts of the reactor are shown in Fig. 2.

The anode consists of high quality graphite (minimum I.D. 10mm, O.D. 40mm, thickness 8mm). The nozzle-shaped anode provides a smooth flow passage without stagnation. The radiation cooled anode reaches high temperatures (>1,500 K) during operation preventing injected materials from condensing and accumulating on the anode surface. The anode is supported by four thin tungsten rods serving also as current connectors. The cathode assembly consists of the cathode itself and a gas and powder feeding system around the cathode. The cathode is of standard design with a 60 degree conical tip (thoriated tungsten). Its base is water cooled. The inner gas injection port (1) provides gas necessary for maintaining the cathode jet. Powder with the carrier gas is injected through six evenly spaced holes (2) of 1.5 mm diameter placed on a 10 mm diameter circle concentric with the cathode tip.

Two types of concentric shrouding gas ports (3) and (3') are available for this experiment. The first port (3) produces a gas flow converging towards the arc (60 degree angle) from a 1 mm wide slot placed on a 19 mm diameter concentric circle. The second port (3') produces a parallel flow from a 30 mm diameter concentric circle (0.2 mm wide slot). Powder is entrained into the carrier gas via a fluidized bed from which the flow is directed into the powder distributor located at the top of the cathode assembly.

An important requirement for supplying fine powders uniformly is that the flow path of the powder carrying gas contains few and only smooth bends. Otherwise severe accumulation of powder in the duct will be experienced.

The feed rate of the powder depends on the carrier gas flow rate. It is thus impossible to change the powder feed rate without changing the carrier gas flow rate. A bypass gas line may be used to circumvent this problem allowing the powder feed rate and the total carrier flow rate to be changed separately. By using the previously described particle feeding system, powders in the size range from 10 to 20 μm can be injected almost axisymmetrically.

For visual observation, an imaging system consisting of a lens and a diaphragm projects the arc image on a screen as shown in Fig. 1. Further details of the reactor design may be found in (2,3).

3. RESULTS OF FEASIBILITY STUDIES

Experiments were performed with argon as operating gas and a current of 200 A. Both the converging and the straight gas shroud were used to determine their effect on the arc. The convergent flow tends to cool the arc fringes in the cathode region, and the parallel flow affects the downstream portion of the arc. Fig. 3 shows photographs indicating the stabilizing effects of gas shrouding (a: without, b: with shrouding). Convergent shrouding produces better results than the parallel shroud in the case of short arcs (less than 100 mm gap). As the arc gap is extended to 180 mm, it becomes
necessary to cool the downstream arc fringes employing the parallel shroud.

4. INFLUENCE OF SHROUDING GAS ON THE ARC

It is expected that the shrouding gas flow will have two effects on the arc. The first is a fluid dynamic effect that should lessen the input energy, due to a reduction in the steep velocity gradients which exist about the arc column, minimizing the momentum transfer in the boundary. The second effect is associated with convective cooling of the arc fringes. Any accidental excursion of the arc column will lead to enhanced convective cooling of the arc at the location of the excursion, forcing the arc back to its equilibrium position.

Though some experiments were carried out to investigate these two expected effects, a significant reduction of the input energy could not be recognized, as the power change was too small. However, it is confirmed that the shrouding gas is indispensable to create a long stable and symmetric arc column.

Results of temperature measurements using a computer controlled spectroscopic technique (4) are shown in Fig. 5, in which the right half of the temperature distribution refers to the case of the converging shroud and the left to the parallel shroud. This figure indicates that the shrouding gas cools the cathode region constricting the arc in the case of the convergent flow, and in the case of the parallel flow the cathode region is not affected, resulting in a wider arc column. The temperatures in the core region of the arc exceed 12000 K, and there seems to be little effect on this temperature regardless of the type of shrouding.

Experimental isotherms for other flows can be found in (2,3). Numerically determined isotherms and flow fields may be found in (2,5). In the case of the converging flow, the average flow velocity is relatively low (0.3 m/sec) because of the larger slot. In spite of this fact, the flow appears to properly cool the cathode region of the arc. Further downstream, this flow is entrained by the strong arc flow towards the anode. For the parallel flow, the smaller slot width produces an average velocity of 1.7 m/sec. The higher velocity is necessary for cooling the arc fringes downstream close to the anode.

5. INFLUENCE OF SHROUDING GAS FLOW ON ARC STABILITY DURING POWDER INJECTION

Arc stability during powder feeding is affected by the type of gas shroud used. After a stable arc is established by supplying the proper amount of shrouding gas, particulate matter is injected into the arc. In the case of the convergent shroud the arc seems to be less sensitive to particle injection although its shape may substantially change. For the parallel flow case however, the arc becomes unstable and may even extinguish.

The previously described observations refer to experiments
with tungsten powder (10 μm) as feeding material. Fig. 4 shows photographs of the arc during feeding. The arc shown in Fig. 4-a is no longer symmetric due to the relatively large amount of powder penetrating into the arc. Fig. 4-b shows a photograph for a situation with less powder feeding and additional gas feeding along the cathode. In this case, the shrouding gas works very well keeping the arc symmetric.

The analysis of products collected in the collection chamber showed that the majority of the product consists of fine tungsten particles (< 1 μm). This result indicates that the 10 μm powder reaches the hot core of the arc. The very fine particles collected downstream are probably formed from the vapour phase.

6. CONCLUSION

The shrouding gas is indispensable for producing a stable and axi-symmetric arc column for the reactor described in this paper. Spectroscopic isotherms confirm this finding. Powder penetration into the high temperature core region is also dependent upon insuring a symmetric, stable arc. Shroud stabilization assures this situation. The described reactor is a convenient tool for basic studies in the field of thermal plasma processing.

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Fig. 1. Schematic of free burning arc reactor.

Fig. 2. Details of main parts.

Fig. 3. Typical arcs. Arc gap, 60 mm; carrier gas, 0.16 g/s. 
(A) Unstable arc (no shroud); 
(B) Arc stabilized by shroud of 0.48 g/s.

Fig. 4. Arcs with injected W powder. Arc gap, 35 mm; carrier gas, 0.16 g/s; shrouding gas 0.63 g/s. 
(A) overfeeding of the arc (cathode flow, 0); 
(B) proper feeding of the arc (cathode flow, 0.08 g/s).
Fig. 5. Measured Isotherms for both of shrouding types. (right) convergent type; (left) parallel type.