

# APPLICATION FEASIBILITY OF GAS-STABILIZED FREE-BURNING ARC REACTOR

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## Introduction

The plasma reactors so far developed are not particularly suitable for the acquisition of basic data necessary to develop plasma technology.<sup>((e.g.2,3))</sup> The principle objective of the present work is to demonstrate the feasibility of a new experimental reactor. This reactor is a kind of free-burning arc drawn between a cathode and a ring-shaped anode. One of the greatest advantages of this reactor is that high-melting point material powders can be introduced easily into the plasma hot core, utilizing the cathode pumping effect. Another is that all conditions required for analysis of the reaction mechanism are measurable by use of proper optical instruments. This arc, however, tends to be drawn asymmetrically or unstably and jumps on the anode surface, because the anode is ring-shaped and the current chooses the easiest discharge path to the edge of the ring anode. This tendency increases when the powdered material penetrates into the plasma hot core and disturbs the electric field. However, the arc can indeed be stabilized if a protective gas shrouding flow is used. The cathode jet and the pumping effect are driven by the radial pressure gradient formed as a result of the interaction between the current and the self-magnetic field.<sup>1)</sup> This is expressed by the following equation.

$$\Delta p(r) = \mu_0 \int_r^{r_a} j_z \left( \frac{1}{r} \int_0^r j_z r dr \right) dr$$

Hence, in order to draw an axi-symmetric and stable arc, it is necessary to create a strong, symmetrical cathode jet due to the large pressure gradient. Using the shrouding gas flow and cooling the arc fringe enable the arc to create a narrow, symmetrical current density distribution for this purpose.

## Reactor Design

Figure 1 shows the plasma reactor designed in this

work. It is powered by a 50 kW D.C. power supply with current control. This reactor is placed inside a water-cooled chamber, which is vacuum purged and then filled with argon at atmospheric pressure before the starting of each experiment. Details of the main part are shown in Fig. 2.

The anode is made of high-quality graphite (minimum i.d. 20 mm, o.d. 40 mm, thickness 8 mm). The convergent throat shaping of the anode enables the flow to pass smoothly through it from top to bottom without flow stagnation. Though it possesses no cooling system, it can withstand thermal damage and still prevent the injected materials from condensing and accumulating on the anode surface. The anode is structurally supported and supplied electrically by four thin tungsten rods of 3.2 mm diameter.

The cathode parts consist of a cathode encircled by a gas and powder feeding device. The cathode is of standard design with a 60 degree conical tip made of tungsten with 2% thorium and a water cooling system. The inner gas injection port (1) is made to supply only gas. Powder with carrier gas is injected from six evenly spaced holes (2) (1.5 mm dia.) placed upon a 10 mm-diameter circle concentric with the cathode

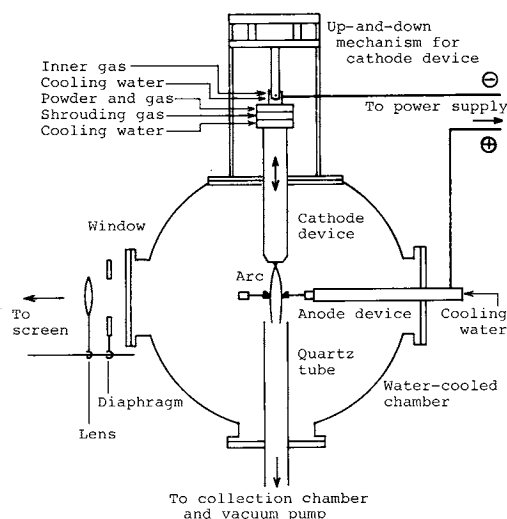


Fig. 1. Schematic of free burning arc reactor.

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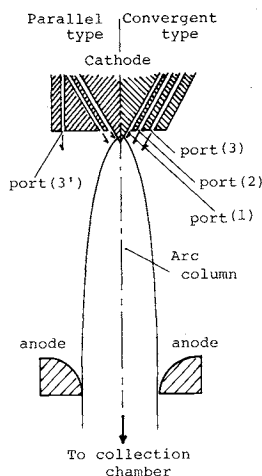


Fig. 2. Detail of main parts.

tip. Two types of concentric shrouding gas ports (3) and (3') are used in this work. The first (3) produces a gas flow which converges upon the arc at a 60-degree angle from a 1 mm-wide slot placed upon a 19 mm-diameter concentric circle. The second type (3') produces a parallel flow from a 30 mm-diameter 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 imaging system consisting of lens, diaphragm and screen is mounted to allow a projection of the arc image. This enables us to observe conditions with 10-fold magnification of the events occurring in the reaction zone.

## Results and Conclusions

The following experiments were performed by using argon gas and a 200 A current.

Experiments for shrouding flow were performed for both types of shrouding gas ports. The convergent-type shrouding gas flow cools the cathode side of the arc column, and the parallel-type cools the downstream portion. **Figure 3** shows the voltage variation for the case of the convergent shroud. Upon increasing the shroud flowrate the voltages becomes higher due to the cooling effect on the introduced gas. The photographs in **Fig. 4** show that this stabilizing effect exists (a: without shrouding gas; b: with it). Convergent shrouding gas flow is better at creating an axisymmetric arc than is the parallel shroud since the arc is a shorter one (less than 100 mm gap). According to our observations, in which the arc gap was extended up to 180 mm, it is necessary to cool the farther fringes of the arc by the parallel shroud.

The gas flow introduced from the port (2) not only plays the role of transporting the powdered material, but also increases arc stability by supplying enough gas to satisfy the cathode pumping requirements. In

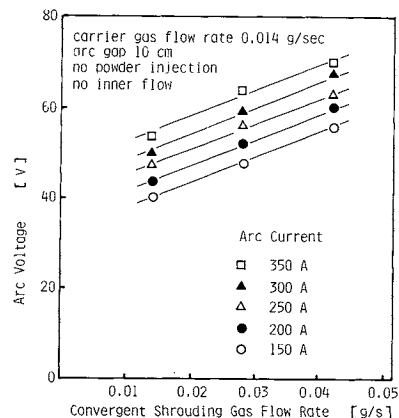


Fig. 3. Effect of convergent shrouding gas flow on arc voltage.

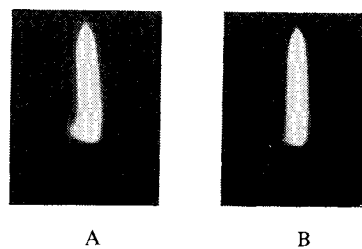


Fig. 4. Typical arcs. Arc gap, 60 mm; carrier gas, 0.014 g/s. (a) Unstable arc (no shroud); (b) Arc stabilized by shroud of 0.042 g/s.

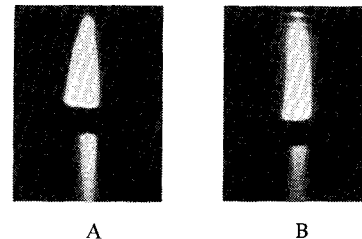


Fig. 5. Tungsten powder injected arcs. Arc gap, 35 mm; carrier gas, 0.014 g/s; shrouding gas, 0.056 g/s. (a) Too great injected arc (inner gas, 0); (b) Proper injected arc (inner gas, 0.007 g/s).

the case of small flowrates, 0.01 g/s down to 0, the arc becomes unstable and jumps on the anode surface. It may be considered that the cathode pumping rate is on the order of 0.01 g/s in this condition ( $I=200$  A). From this result, it is possible to control powder penetration ratio from port (2) into the cathode jet by changing the flow rate of the inner gas flow from port (1) in the range of 0 to 0.01 g/s. In the present experiments tungsten powder of 10-micron size was used as the feed material. **Figure 5** shows photographs of the arc into which powder has been introduced. It is readily recognized that the arc shape in Fig. 5a is no longer symmetrical, due to too much powder penetrating into the arc, although shrouding gas is injected. Figure 5b shows a situation with less powder

feed, controlled by inner gas injection. In this case, the shrouding gas is very effective in making the arc symmetrical.

The analysis of product from the collection chamber showed that major one is fine particles of tungsten (less than 1-micron size). This may be proof that 10-micron powder injected into the plasma hot core melts, evaporates and condenses downstream.

It is confirmed that the shrouding gas is indispensable in creating a stable arc column that is axisymmetric. Thus, this reactor will be a strong tool for experimental research in the field of plasma chemistry.

#### Acknowledgment

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#### Nomenclature

$j_z$	= axial current density component	[A/m <sup>2</sup> ]
$p$	= pressure	[Pa]
$r$	= radial coordinate	
$r_a$	= distance to arc fringe from arc center	[m]
$z$	= axial coordinate	
$\mu_0$	= permeability of vacuum	[H/m]

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## MASS TRANSFER BETWEEN PARTICLES AND LIQUID IN DILUTE FLUIDIZED BEDS IN THE LOW REYNOLDS NUMBER REGION

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Recent work on liquid fluidized beds<sup>5-10)</sup> has revealed an unexpected phenomenon in which mass transfer coefficients between particles and liquid decrease rapidly with a decrease in Reynolds number. One of the explanations for this peculiar phenomenon is neglect of the effect of axial liquid dispersion, as pointed out for the case of fixed beds by Wakao and Funazkri.<sup>11)</sup> For example, the results reported by Koloini *et al.*,<sup>5)</sup> originally analyzed by the plug-flow model, should be treated with due attention to liquid dispersion. As for estimating the axial dispersion coefficient of liquid, a new correlation equation has recently been proposed for the low Reynolds number region,<sup>4)</sup> usable for many mass transfer systems in liquid fluidized beds. However, it is intrinsically desirable to conduct mass-transfer experiments with least affect of liquid mixing to determine mass transfer

coefficients. Two methods have been considered to neglect the effect of axial liquid dispersion: that using shallow beds, and that using dilute beds. The former is doubtful because of the inevitable effect of the turbulence generated in the distributor.<sup>9)</sup> The latter requires a skillful technique for dispersing both active and inert particles homogeneously.

In this work, liquid-side mass transfer coefficients were measured in the low Reynolds number region by the use of dilute fluidized beds with cation and anion exchange resins. The experimental results were compared with the published correlation equations, and with data originally reported by Koloini *et al.*<sup>5)</sup> and reanalyzed on the basis of the dispersion model, with axial dispersion coefficients estimated by the authors' correlation.<sup>4)</sup>

### 1. Experimental Apparatus and Procedure

The experimental apparatus was the same as that

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