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FLUID DYNAMIC CONTROL OF HEAT TRANSFER TO TRANSFERRED ARC ANODE

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ABSTRACT

Fluid dynamic control of plasma flows is investigated experimentally. The fluid dynamic control with a blowing gas is able to sharpen the distribution of heat transfer from a plasma to a transferred arc anode. The blowing gas was injected from a circumference to the plasma. Thermal pinch effect and dynamic pressure of the blowing gas lead to higher concentration of the heat transfer. Higher concentration is obtained even at small flow rate of the blowing gas.

1. INTRODUCTION

Fluid dynamic control by use of a blowing gas is one of plasma-control-techniques. The blowing gas is injected from a circumference to the plasma. The fluid dynamic control is useful for concentration of plasma flows. The fluid dynamic control of plasma flows is investigated in this paper.

Control of energy flow density of plasma flows is important for various material treatments, such as plasma cutting, plasma spraying and plasma chemistry. High energy density of plasma flows is required for the plasma cutting; the high energy density results in precise cutting-surface. Broad high temperature region of plasma flows is desired for the plasma spraying and for the production of ultra-fine-particles; the broad high temperature region brings about the good production quality.

Plasma flows behave themselves like gas flows, but no other high temperature sources, such as laser, have this behavior. The advantage in plasma flows may be utilized for new material treatments. Therefore, fluid dynamic control is a key operation. The fluid dynamic control has been investigated in a few papers as follows:

An inward radial blowing gas is able to control a plasma jet [1,2]. The blowing gas was injected centripetally from a circumference to the plasma center. The blowing gas concentrates the plasma enthalpy flow and the heat transfer to a flat plate. The high concentration results from the control of outward radial flow of the plasma flow.

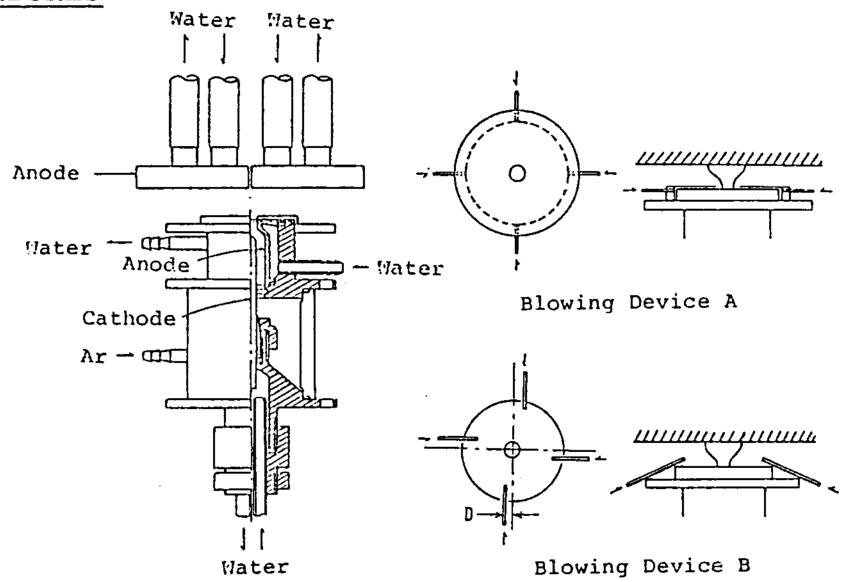
A constricting gas flow is capable of generating an extra fine arc, so-called "point arc" [3]. The constricting gas flow was blown centripetally and spirally against an arc column and electrode zone.

The purpose of this paper is to control the distribution of heat transfer to a transferred arc anode by use of a blowing gas. The blowing gas was injected tangentially or centripetally from a circumference to the plasma. Control procedures and control mechanism are investigated.

2. APPARATUS AND PROCEDURES

2.1 Plasma Generator

An argon plasma jet at atmospheric pressure was generated at a plasma generator. The plasma generator, shown in Fig.1(a), consisted of an anode and a cathode; the anode was a copper nozzle with 8 mm-i.d. and the cathode was a tungsten rod with 6 mm-diameter. These electrodes were prevented by water from melting.



(a) Plasma Generator (b) Blowing Device
Fig.1 Experimental Apparatus

The arc was transferred from the nozzle to a copper plate after the plasma was generated; the plate served as a new anode. The plate anode was located mainly at a distance of 16.5 mm from the cathode tip, i.e., 10 mm from the nozzle exit. The plate also served as equipment for heat transfer measurements.

2.2 Experimental Conditions

Experimental conditions were as follows:
a) Applied electric power was in the range from 1.8 to 3.6 kW; the current was 75 to 150 A, the voltage was 24 V. (Standard electric power was 2.4 kW.)
b) Flow rate of argon plasma gas was in the range from 10 to 17.5 l/min. (Standard flow rate was 12.5 l/min.)
c) Flow rate of the blowing gas was in the range from 3 to 30 l/min.

2.3 Blowing Device

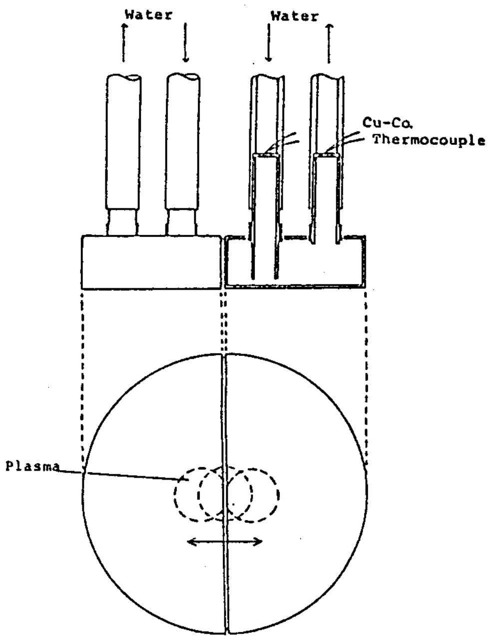
Blowing devices are shown in Fig.1(b). Argon as a blowing gas was injected horizontally and centripetally toward the plasma center at the nozzle exit by use of the blowing device A. The blowing gas was injected slantingly and tangentially toward the plate anode by use of the blowing device B. Argon, nitrogen or helium gas was used as the blowing gas. The offcentered distance which was indicated as D in Fig.1(b) was 5 mm.

2.4 Heat Transfer Measurements

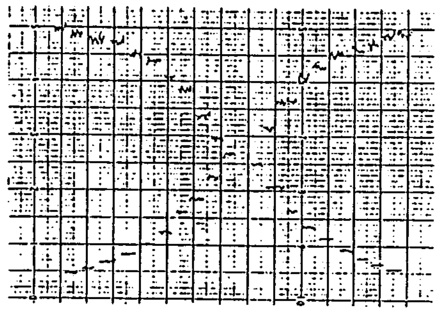
The heat transfer from the plasma flow to the plate anode was measured by calorimetric method.

The plate anode was used as the equipment for heat transfer measurements as shown in Fig.2(a). The plate anode consisted of two semicircle plates; these plates were insulated each other. The plates were made of copper with 150 mm-o.d. and with 10 mm-thickness. The plates were prevented by water from melting down.

The heat transfer to the plate anode was evaluated from the temperature risings of cooling water at each plate. The example data are shown in Fig.2(b); these data indicate the temperature risings of cooling water at each plate. These measurements were carried out at every 1 mm along the plasma arc diameter (measured axis). Directly obtained data were not pointwise values but were integrated values along the perpendicular to the measured axis. The radial distribution was obtained with the Abel inversion from the directly obtained data.



(a) Calorimetric Probe



(b) Example Data

Fig.2 Calorimetric Probe for Heat Transfer Distributions

3 RESULTS AND DISCUSSION

The experimental results are shown in Figs.3-8. Q-value is defined as a ratio of maximum heat transfer to half-value-width. Q-value is adopted as an indication for the sharpness of heat transfer distribution. The maximum heat transfer (W max) and the half-value-width (X half) are illustrated in each figure.

3.1 Experiments without Blowing Gas

The experimental apparatus was first operated without the blowing gas in order to establish basic characteristics. Q-value variations with input power are represented in Fig.3. Q-value increases as the input power increases; this increase in Q-value is ascribed to an increase in the maximum heat transfer. High energy density of plasma flows arises from high discharge power.

Q-value decreases with an increase in plasma flow rate, as shown in Fig.4. This decrease results mainly from an increase in the half-value-width. High flow rate brings about larger plasma arc spot at the plate anode because of hard impingement between the plasma flow and the plate anode. The maximum heat transfer decreases slightly with an increase in plasma flow rate, owing to a decrease in the energy density. The heat transfer distribution was able to be controlled by plasma flow rate. Higher Q-value was obtained at smaller flow rate of the plasma flow. The plasma arc, however, became unstable at small flow rate below 10 l/min.

Distance between the plate anode and the nozzle exit varied in the range from 7.5 to 12.5 mm, i.e., the discharge gap between the anode plate and the cathode tip varied in the range from 14 to 19 mm. Q-value increases as the distance increases as shown in Fig.5; this increase in Q-value is mainly attributed to a decrease in the half-value-width. The half-value-width decreases at soft impingement between the plasma flow and the plate anode. The heat transfer to the plate anode was able to be concentrated at larger discharge gap. However, the high concentration was limited by the unstability of the plasma arc at much longer distance.

3.2 Experiments with Blowing Gas

Argon gas was blown centripetally and horizontally at the nozzle exit by use of the blowing device A. Flow rate of the blowing gas varied in the range from 3 to 30 l/min. Q-value decreases largely by the blowing gas, as shown in Fig.6. Constricting the plasma flow at the nozzle exit results in the spread of the plasma flow at the plate anode. Q-value increases slightly at large flow rate above 20 l/min of the blowing gas. The blowing gas was able to reach the plate anode at large flow rate. The cooled down plasma arc periphery due to this cool blowing gas led to the sharp distribution of heat transfer. The blowing device A was capable of generating a uniform energy distribution.

The blowing gas was injected tangentially and slantingly toward the plate anode by use of the blowing device B. Argon, nitrogen or helium gas was blown in the flow rate range from 3 to 15 l/min. Q-value variations with blowing gas flow rate are shown in Fig.7. Q-value increases with an increase in flow rate of the blowing gas. Q-value is dependent on kind of gas as follows: 1) An argon blowing gas increases Q-value gradually. 2) A helium blowing gas has big effect on Q-value at small flow rate. High thermal conductivity of helium gas caused the plasma arc to be cooled down. High concentration of the heat transfer to the plate anode was obtained. 3) A nitrogen gas has also big effect at small flow rate. Dissociation energy of nitrogen gas caused the plasma flow to be cooled down. The heat transfer distribution was also sharpened. The blowing gas, especially nitrogen or helium, at larger flow rate made the plasma arc unstable.

Q-value variations with the blowing point are shown in Fig.8; the blowing point is an offcentered distance indicated as D in Fig.1. The value for D was 0 mm when the blowing gas was injected toward the plasma center. Higher Q-value was obtained at the use of heavier gas and at larger flow rate (argon at 5 l/min and nitrogen at 5 l/min). Dynamic pressure of the blowing gas mainly caused the heat transfer to be concentrated in this case. The value for D was 5 mm when the blowing gas was injected offcentered. Higher Q-value was obtained by use of a helium blowing gas or of a nitrogen blowing gas. The cooling effect was important in this case.

Sharpness of the distribution of heat transfer to the plate anode depends on the cooling effect, or thermal pinch effect, at smaller flow rate of the blowing gas. This effect is attributable to high thermal conductivity or dissociation energy of the blowing gas. A helium or a nitrogen blowing gas was able to concentrate the heat transfer to the plate anode even at small flow rate. Sharpness of the heat transfer at larger flow rate of the blowing gas depends on the dynamic pressure of the blowing gas.

4. CONCLUSIONS

Fluid dynamic control of plasma flows was investigated. Q-value is adopted as an indication for the sharpness of heat transfer to the plate anode. Q-value increases with an increase in discharge power, an increase in discharge gap or a decrease in plasma flow rate. Q-value decreases by use of the blowing device A. A uniform energy distribution is obtained. On the other hand, Q-value increases with an increase in flow rate of the blowing gas by use of the blowing device B. A helium or a nitrogen blowing gas concentrates the heat transfer to the plate anode even at small flow rate.

Plasma flows are able to be controlled with a suitable blowing device and blowing gas. Thermal pinch effect and dynamic pressure of the blowing gas lead to higher concentration of the heat transfer to the transferred anode.

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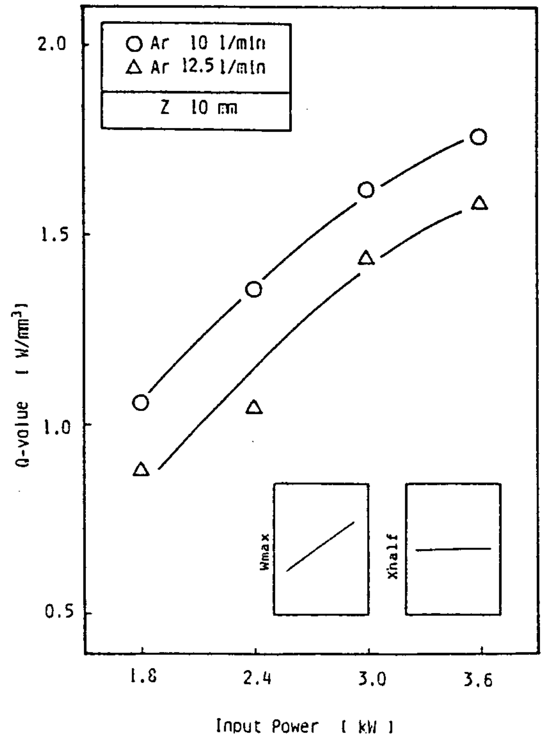

Fig.3 Q-value Variations with Input Power

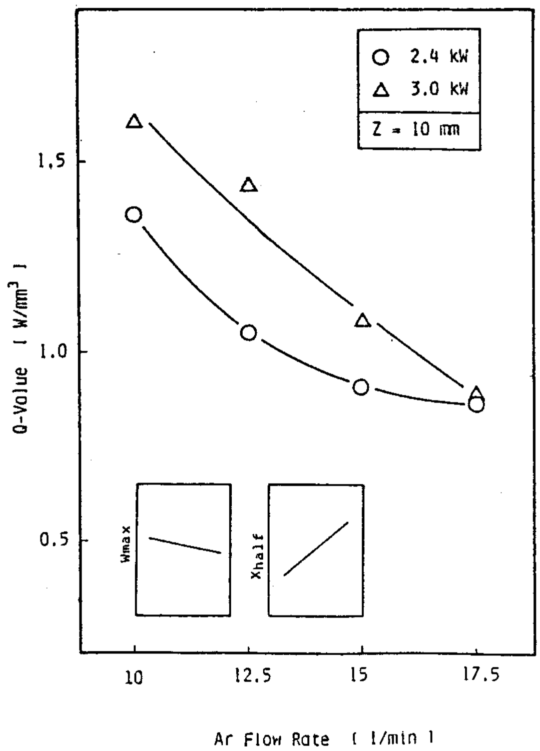

Fig.4 Q-value Variations with Plasma Gas Flow Rate

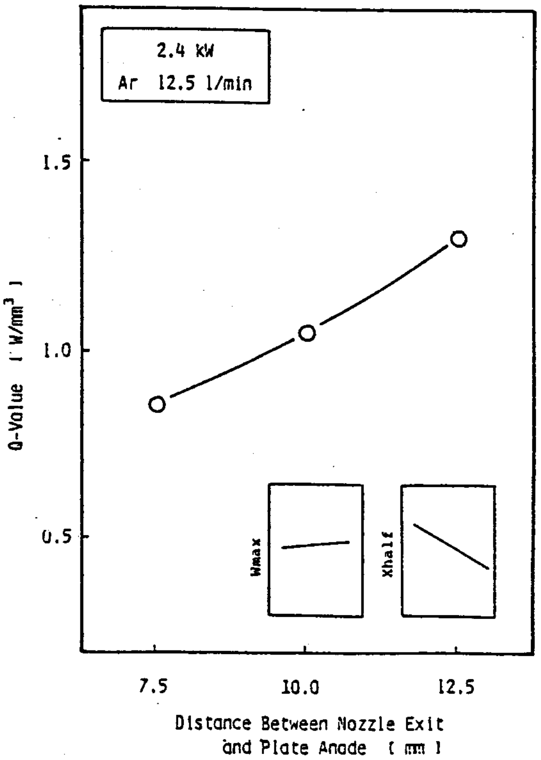

Fig.5 Q-value Variations with Distance between Nozzle Exit and Plate Anode

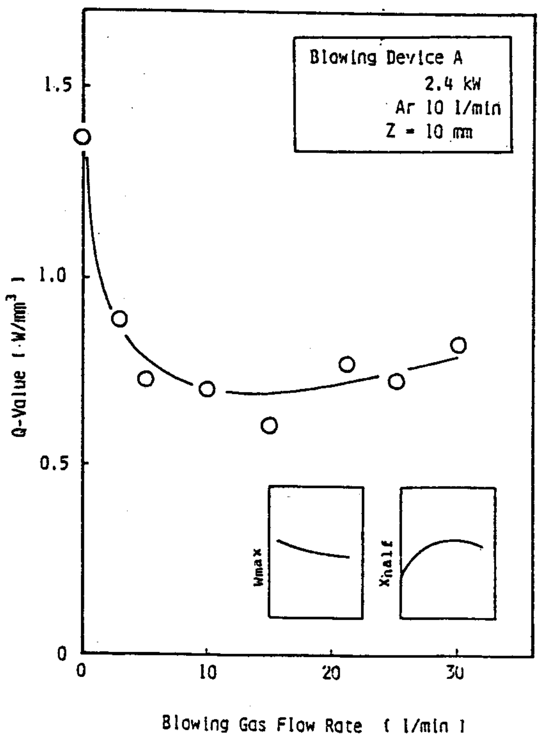

Fig.6 Q-value Variations with Blowing Gas Flow Rate (Blowing Device A)

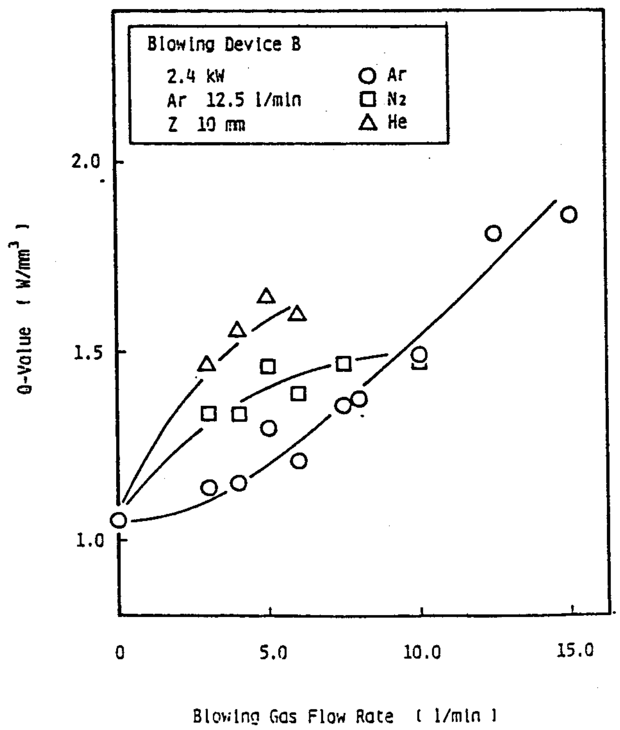

Fig.7 Q-value Variations with Blowing Gas Flow Rate (Blowing Device B)

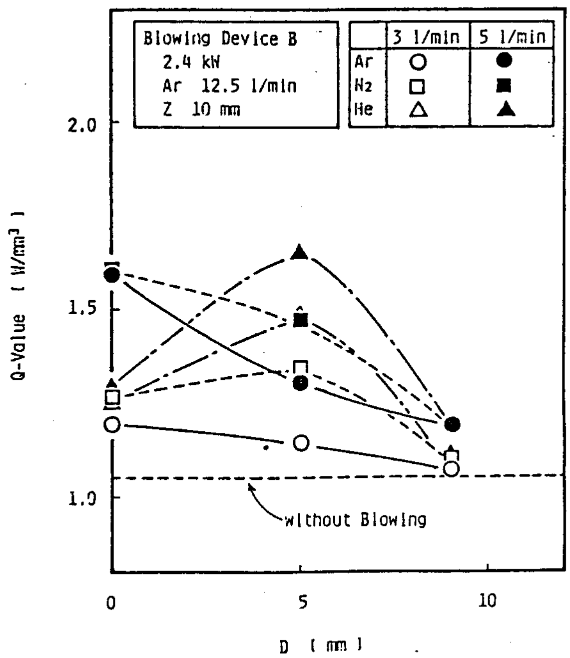

Fig.8 Q-value Variations with D; D was indicated in Fig.1