Development of High Temperature Multi-Purpose Testing Furnace Using Gas Tunnel Type Plasma Jet †

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Abstract

In this paper, the development of a high temperature plasma furnace for multi-purpose applications is described. A high energy, high power plasma heat source: a gas tunnel type of plasma jet was used for the plasma furnace and the performance of this furnace was investigated. The efficiency of the plasma furnace was about 80 % at P = 21 kW. The temperature in the furnace was greater than 3000 K at the center axis under a low pressure of 40 hPa. The effects of experimental conditions on the temperature of this plasma furnace were investigated and the characteristics of the furnace are discussed.

KEY WORDS: (Plasma Furnace) (High Temperature) (Gas Tunnel Type Plasma Jet) (Vacuum) (Thermal Efficiency)

1. Introduction

As science and technology progress, demands on materials become more severe. Conventional metals are often not adequate for the performances needed. Functional materials, such as ceramics, have attracted the attention of many researchers. The preparation of such functional materials needs a higher technology than that used until now. Therefore, new type of high performance furnace has been developed.

The plasma jet is a heat source with a high energy, and is easy to operate. Therefore, the adoption of the plasma jet for a plasma furnace will offer big advantages for applications such as, the melting of materials, fabrication, processing, and high temperature chemical reactions. The availability of a high performance plasma furnace will help to expand the application fields.

The gas tunnel type plasma jet developed by the author is a high performance plasma jet, operating at a high voltage and with easy control of power[1,2,3]. The thermal efficiency of the gas tunnel type of plasma jet has been proved higher than of other conventional types of plasma jet[4].

The properties of the gas tunnel type plasma jet have been described in previous studies[1,2,3]. In particular, studies have shown that the gas tunnel type plasma jet is very useful in its application to thermal processing of materials. High quality coatings were obtained by a gas tunnel type plasma spraying method[5,6]; for example, one of the alumina coating produced had a high Vickers hardness of Hv =1200-1600[7]. Therefore, to apply this gas tunnel plasma jet to the furnace will be also offer the possibility of new application fields[8].

The development of a high temperature plasma furnace has therefore been started using the gas tunnel type plasma jet. In this study, performance tests on this new furnace were carried out, and its properties examined.

Thermal efficiency was measured, and the energy balance of the plasma furnace discussed.

2. Experimental

Figure 1 shows a block diagram of the total composition of the high temperature plasma furnace using the gas tunnel type plasma jet. The apparatus consisted of the plasma furnace, (which was formed by a water cooled chamber (300 mm diameter) with a gas tunnel type plasma torch), power supply units, a cooling water unit, a gas supply unit, and a gas exhaust unit.

The mechanism and properties of the gas tunnel type plasma torch which is shown in **Fig.2** have been described in previous papers[1,2,3]. The torch was located at the center of the side wall of the cylindrical chamber.

Performance tests of this plasma furnace were carried

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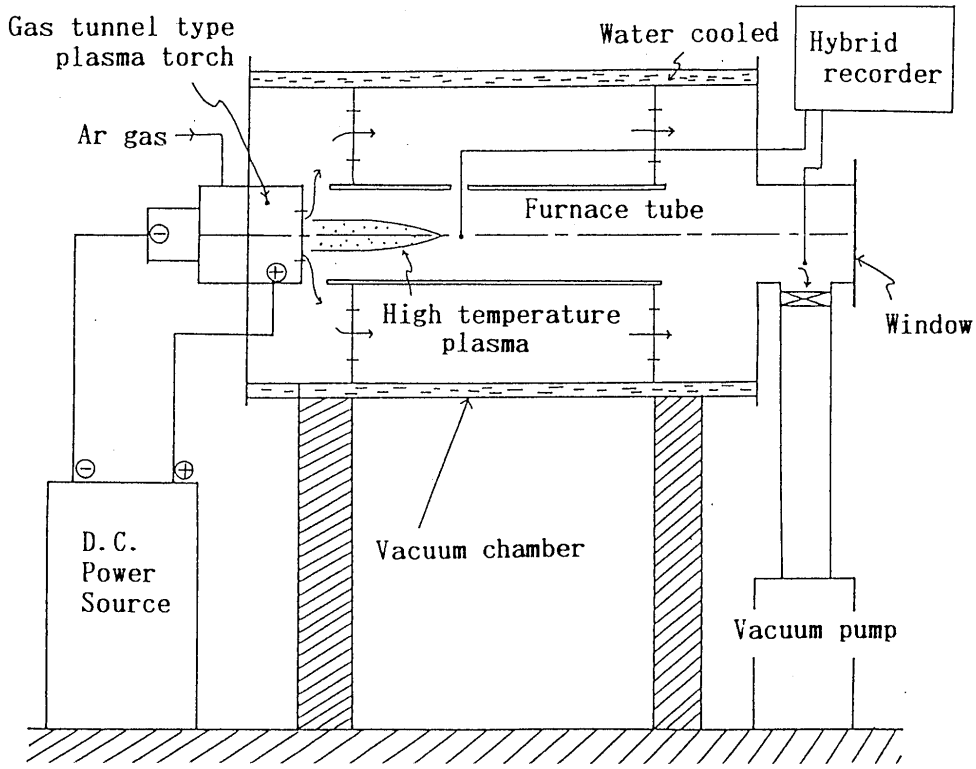

Fig.1 Block diagram of the experimental apparatus for a high temperature plasma furnace, consisting of the gas tunnel type plasma torch, power source, a cooling water unit, a gas supply unit, vacuum pump, etc. The vacuum cylindrical chamber has a diameter of 300 mm.

out under various conditions. The thermal efficiency of the furnace was determined from the efficiency of the gas tunnel plasma torch. The energy loss of the torch was calculated from the temperature of the cooling water of the torch.

The experimental conditions for the testing of the furnace are shown in **Table1**. Experiments were carried out between atmospheric pressure and a low pressure of about 40hPa using argon as a working gas. The working gas flow rate, Q , was kept at a constant value of 200 l/min. The power input to plasma torch P was 20-30 kW.

For the furnace tube, alumina or stainless steel pipe of 50 mm in diameter and 300 mm in length was used. The temperature in the furnace during operation was measured by thermo couple, fine rods of high temperature materials such as titanium, molybdenum, and tantalum, alumina small pipe, and a radiation thermometer.

A few detectors such as fine rods of those metals were located at certain positions away from the plasma torch; the distance between the torch and the detector is the distance: l. Then plasma jet was operating for a certain time until the pressure distribution was stable. In these experiments, the main distance as a furnace center was set as l =100 mm.

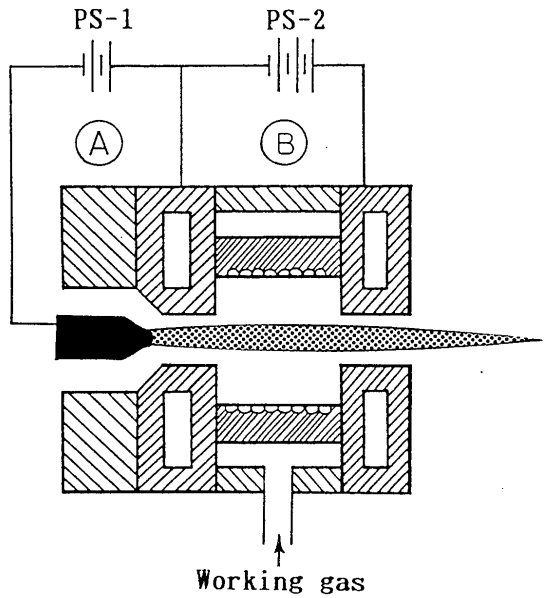

Fig.2 Schematic diagram of gas tunnel type plasma jet,
A: conventional type plasma torch
B: gas tunnel type plasma torch.
PS-1, PS-2: Power supplies.

Table 1 Experimental conditions

Power input	P = 20-30kW
working gas(Ar)	Q = 200l/min
Pressure	p = 39-1000hPa
Furnace tube	D = 50mm in dia
Gas divertor nozzle	d = 15mm

3. Results and Discussion

3.1 Thermal efficiency of the plasma furnace

Figure 3 shows the results of measurements of thermal efficiency of the plasma furnace. The experimental conditions were: input power to plasma torch P = 21 kW, working gas flow rate Q = 200 l/min. In this experiment, the pressure in the furnace was changed from atmospheric pressure to low vacuum (about 40 hPa).

The thermal efficiency of the plasma furnace increases slightly as a pressure in the furnace is decreased. The value of the efficiency is about 80% at the pressure less than p = 100 hPa. This value is much higher than that of the conventional type of plasma jet which is about 50 %.

The dependence of the efficiency on the power input was also measured, and it was proved that the thermal efficiency of this furnace increased gradually with an increase in power input. It achieved a thermal efficiency of 84% at P = 30 kW.

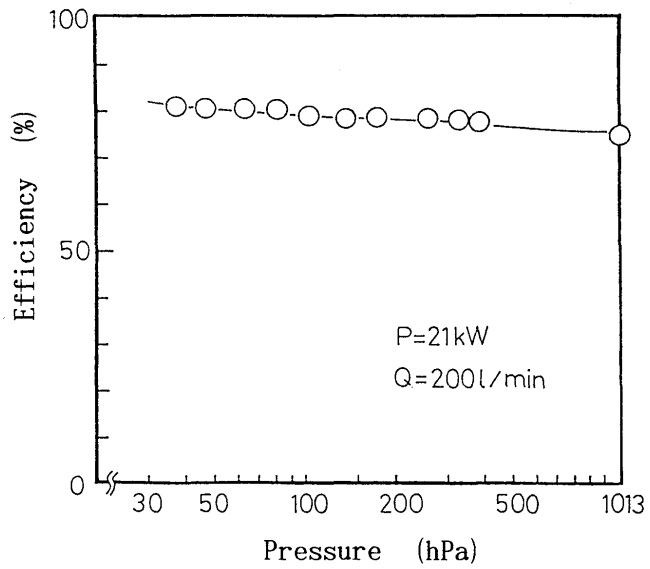

Fig.3 Dependence of thermal efficiency on the pressure, for the conditions: P = 21 kW, Q =200 l/min.,

3.2 Temperature in the furnace

Figure 4 shows the temperature in the plasma furnace when the power input was P = 21kW. The measurement positions were that the distance from the torch was l = 100 mm, on the center axis, and radial distances were r = 10 mm and 20 mm.

In the pressure range less than 200hPa (under vacuum conditions), the temperature in the furnace increases sharply as the furnace pressure is decreased. This is because the plasma length is increasing largely under vacuum condition. As a result, the temperature on the furnace axis reaches 2000 K at the pressure of 150 hPa.

In contrast, at a pressure between atmospheric pressure and 400 hPa, the temperature of furnace is almost constant of 1400-1500 K at the axis (r=0) and r=10 mm. This reason is thought to be that the plasma length does not change significantly in this pressure range.

3.3 Temperature distribution in the furnace

Figure 5 shows the distribution of temperature in the furnace, which was obtained by using the high temperature materials. In this case, the melting points of those high temperature materials were respectively 1953

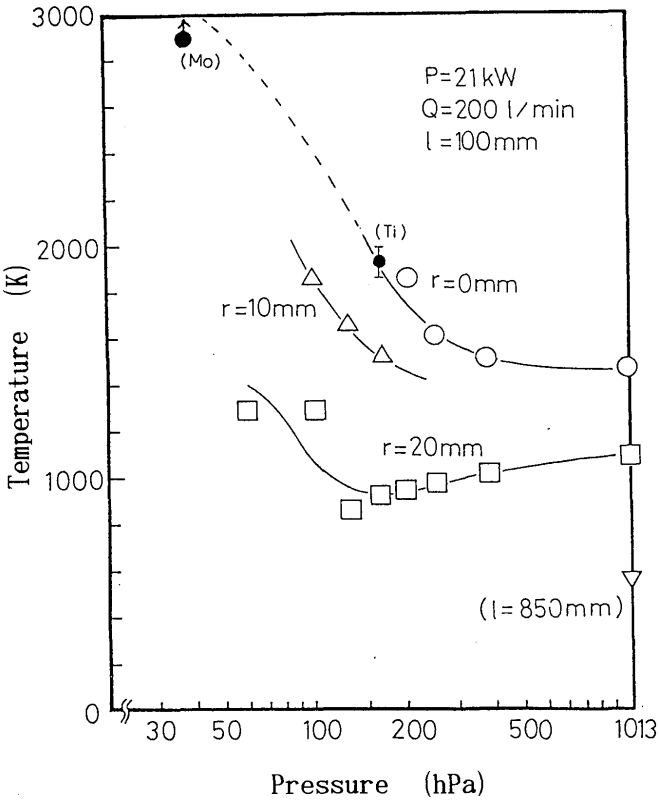

Fig.4 Dependence of temperature on the pressure at the various positions in the furnace, for the conditions: P = 21 kW, Q =200 l/min.

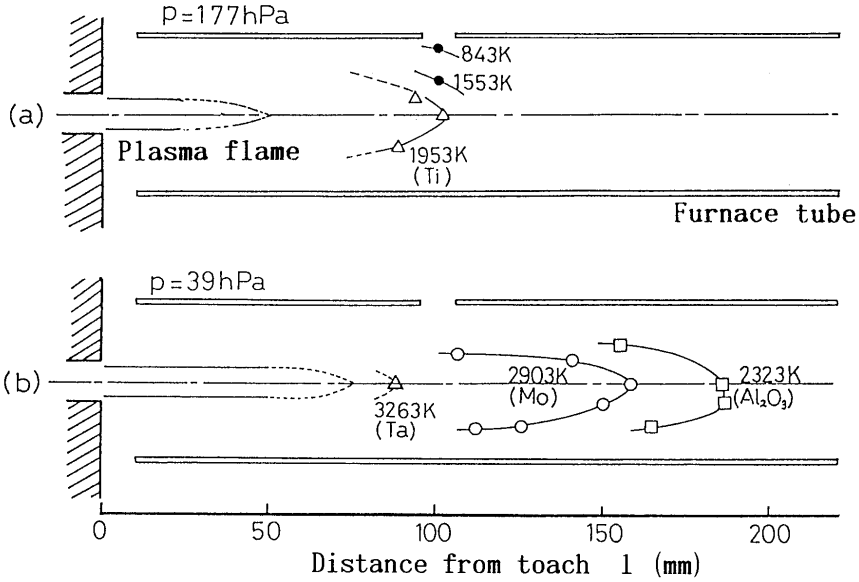

Fig.5 Distribution of temperature in the furnace at the different pressures, for the conditions: P = 21 kW, Q =200 l/min.
(a):p=177 hPa, (b): p=39 hPa.

K for Ti, 2903 K for Mo, 3263 K for Ta, and 2323 K for alumina.

In this figure, (a) shows the result at p=177 hPa and (b) shows, p=39 hPa. The power input was constant at P= 21 kW. The diameter of furnace tube was 50 mm.

In the case of (a): p=177hPa, the furnace temperature was about T = 2000 K at the axis of l = 100mm judged from the melting point of Ti. Moreover, in the case of (b): p= 39 hPa, it was found that the furnace temperature at the center is more than 3000 K. For the comparison this value is indicated as a black circle in Fig.4.

At p=39 hPa, even the temperature at l = 200 mm is more than 2000 K. In this case, the high temperature region is expanded to much longer distance. The estimated plasma flame is shown in the same figure.

At the distance l=100mm, r=10mm, the temperature is 1500 K in the case of p=177 hPa, but T= 2900 K in the case of 39hPa. This confirms that, the high temperature region also expands in the radial direction.

3.4 Dependence of furnace temperature on power input

Figure 6 shows the results of temperature measurement by means of a radiation thermometer on the surface of tungsten rod which was inserted at the furnace center (l =100 mm, r = 0 mm) under vacuum condition (p=39hPa). This figure shows the dependence of temperature in the furnace on plasma current which is related to power input.

As the plasma current is increased, it is found that

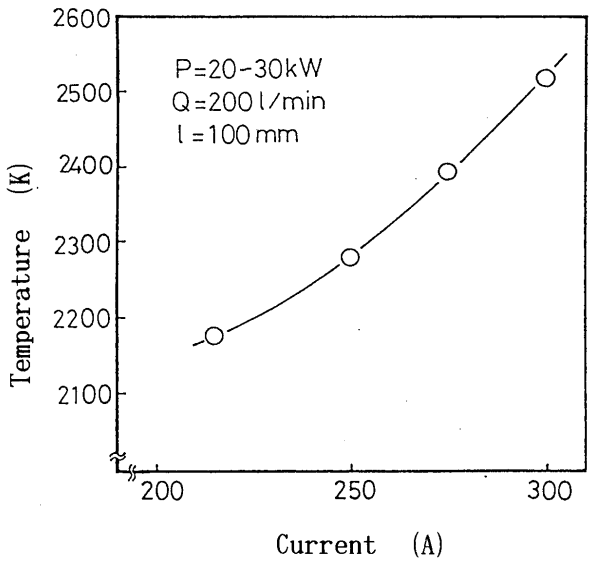

Fig.6 Dependence of temperature at center axis in the furnace on the plasma current, for the conditions: l = 100 mm, Q =200 l/min.

the furnace temperature also increases. While the temperature is 2150 K at P = 20 kW, it is more than 2500 K at P= 30kW. The absolute value of this measurement is different from the results in Fig.5. This reason is thought to be that calibration of the radiation thermometer is not correct.

From above results, high temperatures of 3000-5000 K could be achieved in the furnace, by increasing power input under vacuum conditions.

4. Conclusion

A high temperature plasma furnace was developed by using the gas tunnel type plasma jet. The following results were obtained during performance testing of this plasma furnace.

(1) The thermal efficiency of the plasma furnace using the gas tunnel type plasma jet increased as the pressure decreased. The value of the efficiency was about 80% at a pressure less than p = 100 hPa. This is much higher than that of the conventional type plasma jet which is about 50 %.

The thermal efficiency of this furnace increased gradually with the increase in power input. The efficiency was achieved 84% at P = 30 kW.

(2) The temperature in the plasma furnace was measured at l = 100 mm on the furnace central axis, when P = 21kW. In the pressure range less than 200 hPa (under vacuum condition), the temperature was increased sharply as the pressure was decreased. Consequently, the temperature on the furnace axis reached 2000 K at the pressure of 150 hPa.

(3) The temperature distribution in the furnace was measured by using high melting point materials. When P= 21 kW, the furnace temperature was T = 2000K on the axis at l = 100mm in the case of p=177 hPa, while, in the case of p= 39 hPa, the furnace temperature at the center was more than 3000K.

Moreover, in the case of 39hPa. the high temperature region expanded to longer distances, and also expanded in the radial direction. The temperature at l = 200 mm is more than 2000 K.

(4) The temperature measurement by the radiation thermometer at the furnace center (l =100 mm) under vacuum condition showed that the temperature was increased with plasma current, which was related to power input.

Acknowledgements

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References

1) Y.Arata and A.Kobayashi,"Development of Gas Tunnel Type High Power Plasma Jet (in Japanese)", *J.High Temp.Soc.,* Vol.**11**, No.3, 1985, p124-131
2) Y.Arata and A.Kobayashi," Application of gas tunnel to high-energy-density plasma beams", *J.Appl.Phys.*, Vol.**59**, No.9, 1986, p3038-3044
3) Y.Arata, A.Kobayashi, and Y.Habara," Basic Characteristics of Gas Tunnel Type Plasma Jet Torch", *Jpn.J.Appl.Phys.,* Vol.**25**, No.11, 1986, p1697-1701
4) M.Okada and Y.Arata," *Plasma Engineering* (in Japanese)", Pub. Nikkan Kogyo Shinbun-sha, Tokyo,1965
5) Y.Arata, A.Kobayashi, and Y.Habara," Ceramic coatings produced by means of a gas tunnel type plasma jet",*J.Appl.Phys.*, Vol.**62**, No.12,1987, p4884-4889
6) Y.Arata, A.Kobayashi, and S.Kurihara," Effects of Spraying Conditions in Gas Tunnel Type Plasma Spraying(in Japanese)", *J.High Temp.Soc.,* Vol.**15**, No.5, 1989, p210-216
7) A.Kobayashi," Property of an Alumina Coating Sprayed with a Gas Tunnel Plasma Spraying", *Proc.of ITSC.*, 1992, p57-62
8) A.Kobayashi," New Applied Technology of Plasma Heat Source",Weld.International,Vol.**4**,No.4,1990 p276-282