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

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Abstract

The characteristics of a high temperature plasma furnace for multi-purpose applications are studied. A gas tunnel type plasma jet, used for the plasma furnace, was generated using nitrogen working gas as wel as argon gas, and performance tests were carried out. The efficiency of the nitrogen plasma furnace was about 82 % at P = 20 kW. The temperature in the nitrogen furnace was greater than 3500 K at the furnace center at 40 hPa. The results of this plasma furnace were discussed compared with argon plsma furnace.

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

1. Introduction

In this study, a new type of high performance furnace has been developed in order to produce various functional materials such as ceramics. The plasma jet was used as a heat source for this furnace, because of its high energy, and ease of operation.

The gas tunnel type of plasma jet is a high voltage type and has positive V-I characteristic due to a strong thermal pinch effect by the high speed vortex. Therefore high power can be easily obtained. The control of power is also easy[1,2,3]. Moreover, the thermal efficiency of the gas tunnel type plasma jet is higher than that of other conventional types of plasma jet[4].

Previous studies[1,2,3] have proved that the gas tunnel type plasma jet is very useful for the thermal processing of materials. For example, high quality coatings were obtained by gas tunnel type plasma spraying[5,6]; the alumina coating produced having a high Vickers hardness of Hv =1200-1600[7].

The development of a high temperature plasma furnace has therefore been based upon the gas tunnel type plasma jet in order to examine the possibility of new application fields[8] such as, the melting of materials, processing, and high temperature chemical reactions..

The following results were obtained during the performance testing of this plasma furnace using argon as a working gas[9].

Thermal efficiency of this plasma furnace increased as the pressure decreased. The value was about 80% at a pressure less than p = 100 hPa. The efficiency increased gradually with an increase in power input. It reached 84% at P = 30 kW.

In the pressure range below 200 hPa, the temperature in the plasma furnace at l = 100 mm on its axis, with P = 21 kW, was increased sharply as the pressure was decreased. Consequently, the temperature on the furnace axis reached 2000 K at p = 150 hPa. While, in the case of p = 39 hPa, the temperature was more than 3000K.

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

In this study, performance tests on this new furnace were carried out continuously, when the working gas was changed from argon to nitrogen. And its characteristics were examined especially in the case of nitrogen .

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Thermal efficiency of the furnace was measured and compared with the argon plasma furnace. The temperature in this plasma furnace was also measured and the distribution of the temperature was investigated.

2. Experimental

Figure 1 shows a photograph of the high temperature plasma furnace using the gas tunnel type plasma jet. The vacuum cylindrical chamber has a diameter of 300 mm.

Figure 2 shows a block diagram of the high temperature plasma furnace. The plasma furnace consisted of a water cooled chamber with a gas tunnel type plasma torch, which was connected to power supply units, a cooling water unit, a gas supply unit, and a vacuum pump. The gas tunnel type plasma torch was located at the center of the side wall of the cylindrical chamber. For the furnace tube, alumina or stainless steel pipe of 50 mm in diameter and 300 mm in length was used.

The performance tests of this plasma furnace were carried out under various experimental conditions which are shown in **Table1**. As the working gas of the gas tunnel type plasma jet, argon and/or nitrogen gas was used. The working gas flow rate, Q , was 150-200 l/min. The power input to plasma torch P was 18-21 kW. The pressure in the furnace was about 40 hPa.

The thermal efficiency of the furnace was calculated from the temperature increase of the cooling water of the torch.

The temperature in the furnace was measured during operation by using thermo couples, fine rods of high temperature materials such as titanium, molybdenum, tantalum, and small alumina pipes, whose diameters were 0.8-1.0 mm.

In these experiments, the main distance used as a furnace center was l = 100 mm, where l. is the distance from the torch.

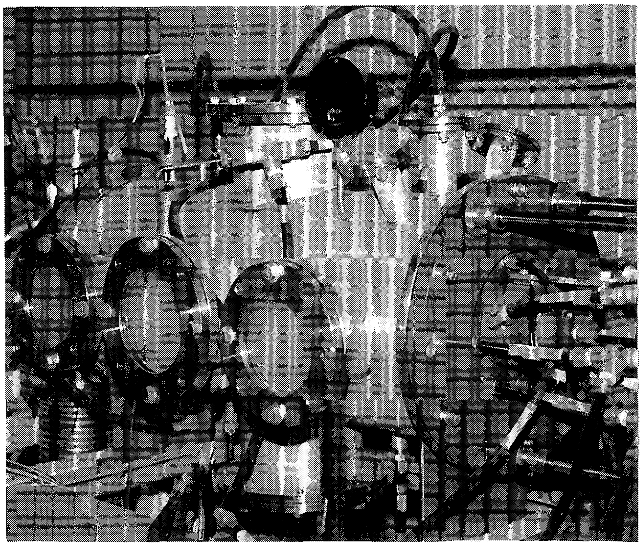

Fig.1 Photograph of a high temperature plasma furnace. The vacuum cylindrical chamber has a diameter of 300 mm.

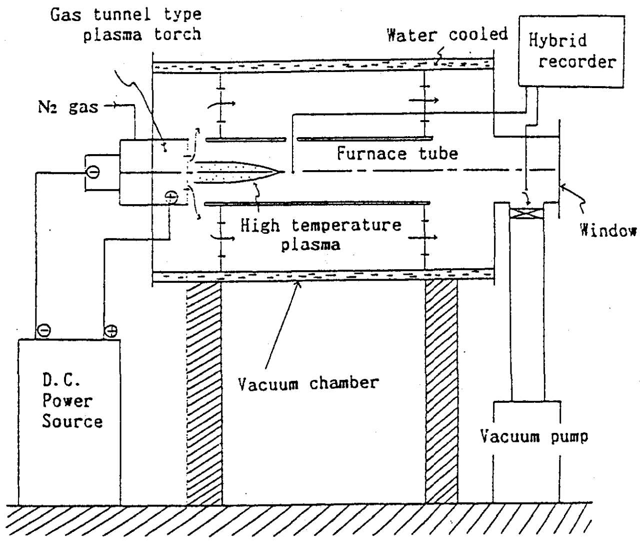

Fig.2 Block diagram of the experimental apparatus for the high temperature plasma furnace, consisting of a gas tunnel type plasma torch, power source, a cooling water unit, a gas supply unit, vacuum pump, etc.

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. In this case, the working gas was changed from argon (Ar) to nitrogen (N_2), and the thermal efficiency was measured at various nitrogen mixing rates R. Input power to the plasma torch changed from P = 21 kW to 18 kW. The working

Table 1 Experimental conditions

Power input	P = 20-30kW
working gas(N_2)	Q = 200l/min
Pressure	p = 39-1000hPa
Furnace tube	D = 50mm in dia
Gas divertor nozzle	d = 15mm

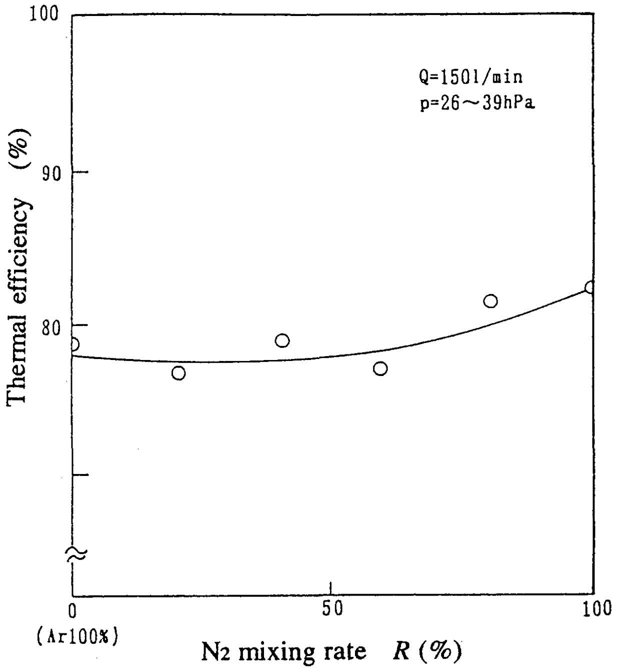

Fig.3 Dependence of thermal efficiency on N_2 mixing rate, for the conditions: P = 18-21 kW, Q = 150 l/min.,

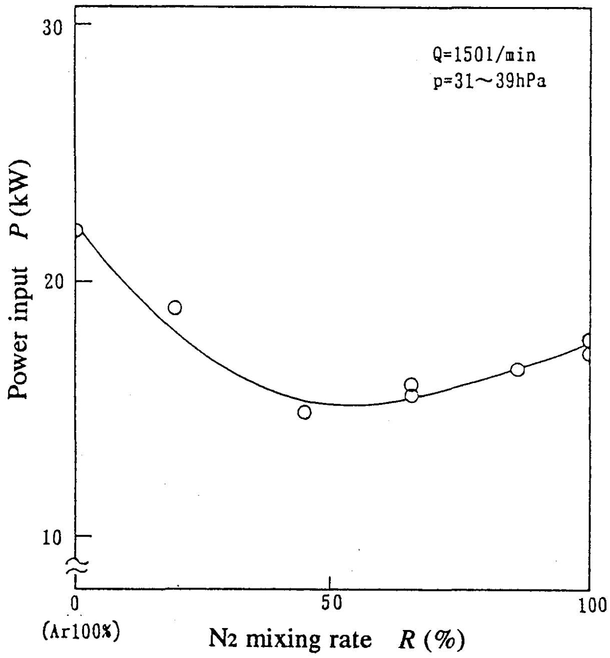

Fig.4 Dependence of power input on N_2 mixing rate, for the conditions:, Q =150 l/min.

gas flow rate was Q = 150 l/min, and the pressure in the furnace was p = 30-40 hPa.

This result shows that the thermal efficiency of the plasma furnace increases slightly as the nitrogen mixing rate increases.

In the case of argon plasma, the value of the efficiency was about 80% at a pressure of p = 40 hPa with P = 20 kW. The efficiency was not changed at low nitrogen mixing rates, less than R = 50%

As the nitrogen mixing rate increased beyond R = 70%, the thermal efficiency was increased a little. In the case of a full nitrogen plasma, the value of the efficiency reached a high value of about 82% at a pressure of p = 40 hPa with P = 20 kw. The reason was thought to be that the thermal pinch effect of nitrogen gas increased as an increasing nitrogen mixing rate.

3.2 Dependence of power input on N2 mixing rate

The influence of the power input to the gas tunnel type plasma torch on the nitrogen mixing rate was also measured under the same coditions for Fig.3. The result is shown in **Fig.4**.

The power input decreased with an increase of nitrogen mixing rate in the range below R = 50 %. However, the input power increased as the nitrogen mixing rate rose beyond R = 50 %. This indicated that the thermal efficiency of the furnace increases gradually with an increase in power input.

3.3 Temperature distribution in the furnace

Figure 5 shows the distribution of temperature in the furnace. It was obtained by using the high temperature materials, whose melting points were respectively 1953 K for Ti, 2903 K for Mo, 3263 K for Ta, and 2323 K for alumina.

In this figure, (a) shows the result for the argon plasma furnace and (b) that for the nitrogen plasma fimace, in the case of pressures of p = 39 hPa. The power input was P = 21 kW for (a), 18 kW for (b).

For both cases, the temperature in the plasma furnace was more than 3000 K at l = 100 mm on the furnace central axis. (The temperature was more than the melting point of Mo.)

In the case of the nitrogen plasma furnace: (b), the temperature was much higher than for the argon plasma furnace. Consequently, the temperature at l = 150 mm on the furnace axis exceeded the melting point of Ta: 3263 K.

Moreover, in the case of the nitrogen plasma, the temperature was nearly 3000 K at l = 200 mm on the furnace central axis,. And the high temperature region was

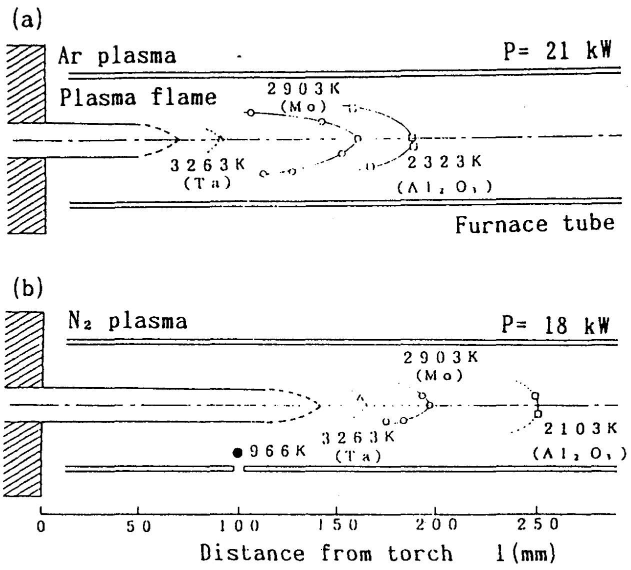

Fig.5 Distribution of temperature in the furnace, for the conditions: P = 18-21 kW, Q = 150 l/min., p = 39 hPa.
(a):argon plasma, (b):nitrogen plasma.

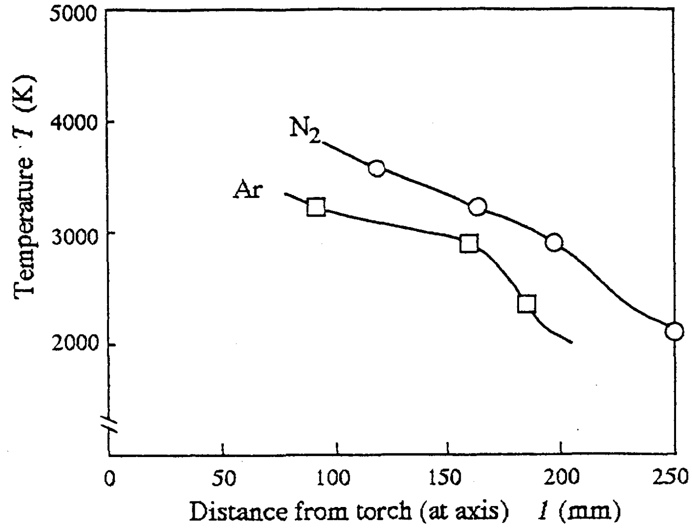

Fig.6 Dependence of temperature at center axis in the furnace on the distance from torch, for the conditions: P = 18-21 kW, Q = 150 l/min in both cases of Ar and N_2.

expanded to longer distances. The plasma flame of nitrogen appeared to become longer as is shown in this figure.

Figure 6 shows the temperature distribution on the central axis of the furnace for both argon and nitrogen, measured under the same conditions as Fig.5.

The temperature of the nitrogen plasma furnace was 400-500 K higher than the temperature of the argon plasma furnace. Consequently, the temperature of nitrogen plasma furnace was assumed to reach to 3700 K at the furnace center (l = 100 mm).

As the high temperature region expanded to longer distances in the case of nitrogen plasma, even the temperature at l = 250 mm was more than 2000 K.

The radial distribution of the temperature in the furnace at l = 120 mm is shown in **Fig. 7**, measured under the same conditions as Fig.5.

At the axis, the temperature was more than 3000 K for both argon and nitrogen. The temperature of the nitrogen plasma was about 3500 K, which was 400 K higher than the argon plasma (T = 3100 K).

However the diameter of temperature distribution of the nitrogen plasma was much smaller than for the argon plasma. For instance, in the case of argon plasma the diameter of the region of T = 2000 K in argon was 48 mm, which was 25% larger than in the case of nitrogen plasma.

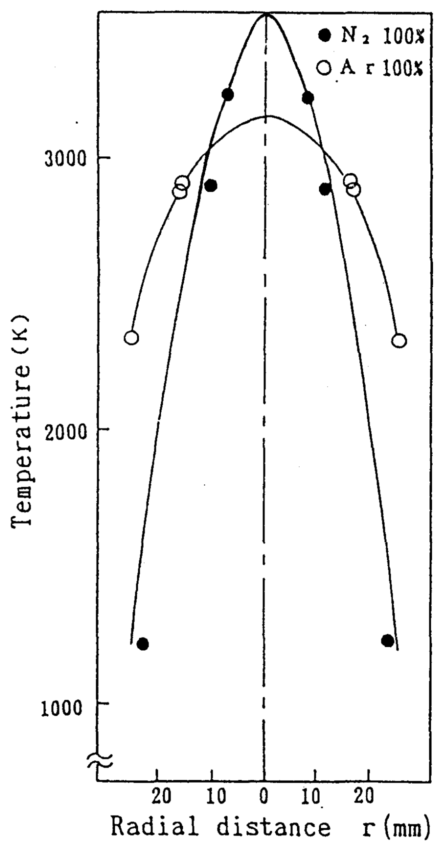

Fig.7 Radial distribution of temperature in the furnace, for the conditions: P = 18-21 kW, Q = 150 l/min.

4. Conclusion

The characteristics of a high temperature plasma furnace using a gas tunnel type plasma jet were investigated, with the following results.

(1) The thermal efficiency of the plasma furnace using the gas tunnel type plasma jet increased slightly with increases in the nitrogen mixing rate.

In the case of argon plasma, the value of the efficiency was about 80% at a pressure of p = 40 hPa when P = 20 kW. In the case of nitrogen plasma, the efficiency was a little higher value of about 82% at p = 40 hPa when P = 20 kW.

(2) The temperature in the plasma furnace was 3000 K at l = 100 mm on the furnace central axis, when P = 20 kW and at the pressure of 40 hPa.

In the case of the nitrogen plasma furnace, the temperature was much higher than for the argon plasma. Consequently, the temperature on the furnace axis reached 3700 K at the furnace center.

(3) In the case of the nitrogen plasma, the high temperature region extended to longer distances.

When P = 18 kW, the axis temperature in the plasma furnace was nearly 3000 K at l = 200 mm, and even the temperature at l = 250 mm was more than 2000 K.

(4) The radial distribution of the temperature in the furnace at 1 =120 mm showed that the temperature of the furnace center was about 3500 K in the case of nitrogen plasma, but the diameter of this region was much smaller than in the case of an argon plasma.

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