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Decomposition of CO_2 Gas by Gas Tunnel Type Plasma Jet and Its Recycling System†

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Abstract

The rise of atmosphere temperature by the "greenhouse effect" effect is thought to result from the increase of CO_2 gas, NOx gas, etc. Therefore, the decomposition treatment of CO_2 gas is an important research subject in order to solve global environmental problems. In this study, gas tunnel type plasma jet, which is a high energy plasma process, was used to decompose CO_2 gas, and the decomposition mechanism was clarified by varying the plasma operation conditions. In addition, the possibility of recycling systems of CO_2 gas is also discussed. Firstly, the performance test of the gas tunnel type plasma jet used for decomposition of CO_2 was conducted and the efficiency of CO_2 decomposition by using the high-energetic plasma jet was determined under various conditions. Secondly, the improvement of operating conditions of the plasma to enhance its performance was discussed. The decomposition ratio of CO_2 was about 30%, with a power of 8kW, and a CO_2 content of 10% in argon. Then the possibility for the gas tunnel type plasma jet to be a high efficiency CO_2 decomposition process was discussed.

KEY WORDS: (High energy plasma process), (Gas tunnel type plasma jet), (Decomposition of CO_2 gas), (Environmental problems), (Resources)

1. Introduction

Environmental problems, such as chemical materials called environmental pollutants, are serious for human life and have become a most important problem for all of us. For example, the environmental pollutant dioxin is very hazardous, and is generated by home and industrial furnaces. A similar problem arises from an increase of CO_2 gas, NOx gas, etc. These are called warm-room gas which is one of the reasons of the warm-room effect for the global environment. This causes a rise of atmosphere temperature of the earth and exerts a bad influence on ecological systems. Therefore, the decomposition treatment of CO_2 gas is an important research subject in order to solve the global environmental problem. The decrease of CO_2 should be a global task for scientists related to this research field.

Generally, there are many applications of plasma to the environmental problems such as: (1) High temperature treatment of hazardous materials, like dissociation of toxic materials such as PCB, dioxin, etc., (2) Convert waste to resources, like reformation by dissociation and recombination of materials. (3) Formation of high performance energy transfer materials for high efficiency of energy systems. (4) Environmental tolerance materials like heat resistance materials, erosion resistant materials, etc.

Regarding the plasma sources for plasma application to environmental problems, the authors developed a high power plasma jet, which was called gas tunnel type plasma jet, and its performances were clarified in previous studies [1-3]. For example, the gas tunnel type plasma jet, which is in the 200 kW class, has a high temperature of more than 20,000K and a high energy density, also it has high thermal density of 80%. It is superior to the properties of other conventional type plasma jets [4]. Therefore this plasma has great possibilities for various applications to thermal processing [5]. As to the formation of high performance materials, high quality ceramic coatings were obtained by the gas tunnel type plasma spraying method [6,7], for example, typical alumina coating produced had a Vickers hardness of Hv =1200-1600 [8]. As another application, the gas tunnel type plasma jet was applied to the surface nitridation of titanium. This experiment also investigated the possibility of the speedy formation of a high functionally thick TiN coating [9,10].

The study of the applications of high-energy type

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plasma jet to the environmental problem was started in 2000. The fundamental characteristics of the method using this plasma jet were clarified, as one example for the treatment of carbon dioxide gas by this gas tunnel type plasma jet. [11,12]

In this study, the gas tunnel type of plasma jet was improved to a high-energy type and the fundamental characteristics of the method for the treatment of carbon dioxide gas using this plasma jet were discussed by the experiment. The performance test of the gas tunnel type plasma jet was carried out in order to decompose CO_2 gas, and determine the efficiency of CO_2 decomposition at various conditions. Also, the decomposition mechanism was clarified by varying the plasma operation conditions. Secondly, the improvement of operating conditions of the plasma to enhance its performance was discussed. In addition, the possibility of transforming CO_2 gas to other compounds was also discussed to find out the most effective reaction at high temperature in order to treat the CO_2 gas. The effect of the high energy type plasma jet on the transformation of CO_2 into other compounds as a recycling system for CO_2 are also discussed.

2. Experimental Procedure

Figure 1 shows a block diagram of the gas tunnel type plasma torch experimental apparatus used for the decomposition of carbon dioxide (CO_2). An improvement was made in the ignition system. A W cathode was inserted through the hollow cathode of a gas tunnel type plasma torch to the anode of the gas divertor nozzle, and pulled out after the plasma generation. The mechanism of the gas tunnel type plasma torch has been described in previous papers [2-4]. In this case, CO_2 gas is mixed with the working gas (argon) after the formation of plasma jet.

The experimental apparatus is shown in **Fig. 2**. The plasma torch is located at the center of the sidewall of the cylindrical chamber. For the generation of the gas tunnel type plasma jet, a DC power supply was used, and argon was used as a plasma forming gas. Additionally, CO_2 and nitrogen gas were added with the working gas.

The experiment was carried out under vacuum pressure condition, are shown in **Table 1**. The efficiency of the plasma torch using mixed gases was measured calorimetrically. At the same time, the parameters of plasma jet, temperature and electron density, etc., were measured by an optical monochrometer. The control of the plasma parameter was possible by changing experimental conditions.

The exhaust gas from the plasma jet was collected by the gas collector and analyzed by gas chromatography. This enabled the efficiency of decomposition of CO_2 by the plasma jet was calculated. Also, the materials created by the reaction were investigated. The efficiency of the transformation of CO_2 into synthesis fuel gas such as methane, acetylene, and the most effective reaction of CO_2 gas at high temperature is discussed.

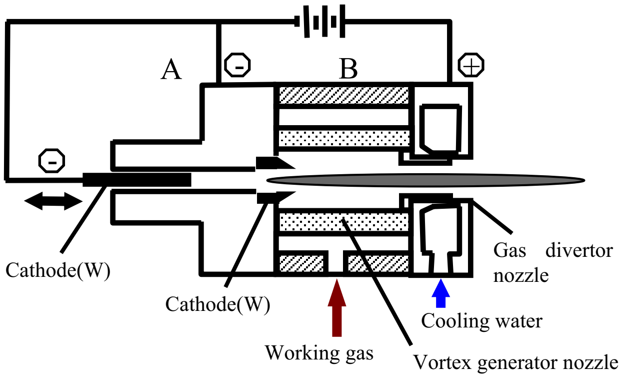

Fig. 1 Diagram of gas tunnel type plasma torch.

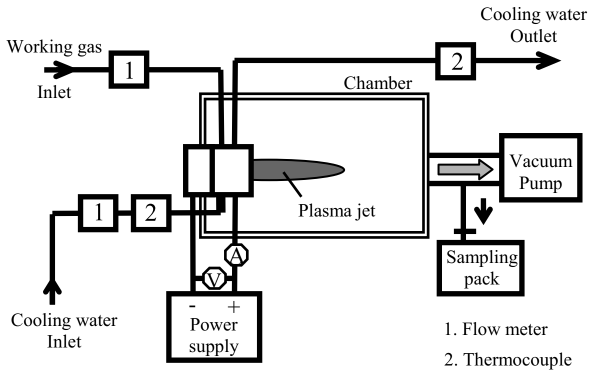

Fig.2 Experimental arrangement for measuring decomposition of CO_2 by gas tunnel type plasma jet.
The vacuum cylindrical chamber has a diameter of 300 mm.
1: Flow meter with regulator, 2: Thermometer.

Table 1 Experimental conditions.

Power input:	P	=	5 - 11 kW
Arc current:	I	=	80-100 A
Working gas (Ar+CO2)			
flow rate:	Q	=	100 l/min
CO2 gas flow rate:	Qad	=	10-30 l/min
Pressure:	p	=	50 hPa
Chamber length:	L	=	80 cm
Sampling time:	t	=	30 s

3. Experimental Results and Discussion

Figure 3 shows the dependence of discharge voltage on the mixing ratio of CO_2 in the working gas for the gas tunnel type plasma torch. The voltage was 53V in the case of pure Ar gas. The voltage increased markedly as the mixing ratio of CO_2 was increased up to X=30%, and voltage became V=110V. This means that the thermal pinch effect of CO_2 gas is very strong for this plasma jet. But the effect would be weak at the CO_2 mixing ratio of more than 30%.

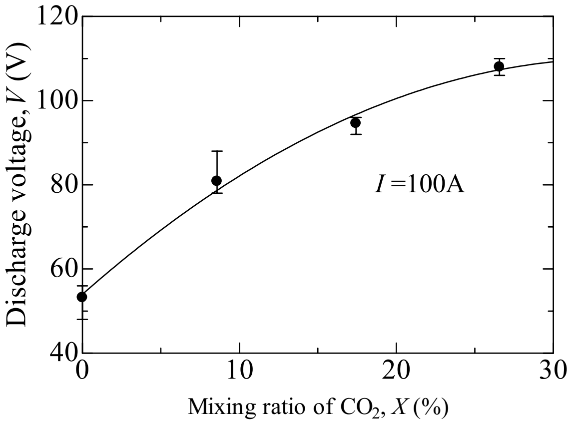

Fig. 3 Relation between discharge voltage and mixing ratio of CO_2. I=100A

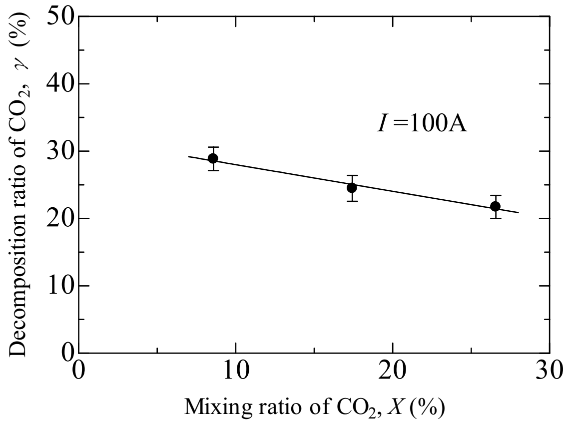

Fig. 5 Relation between decomposition ratio and mixing ratio of CO_2.

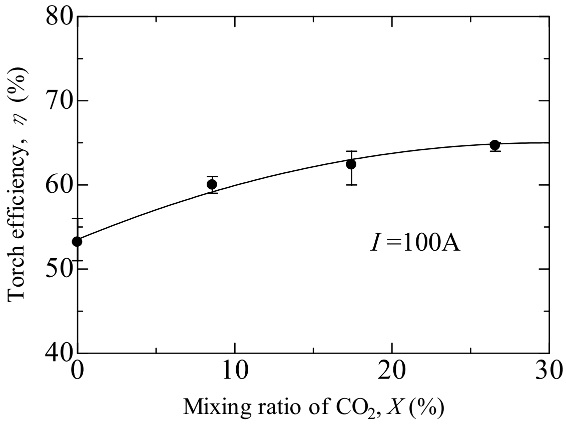

Fig. 4 Relation between torch efficiency and mixingratio of CO_2.

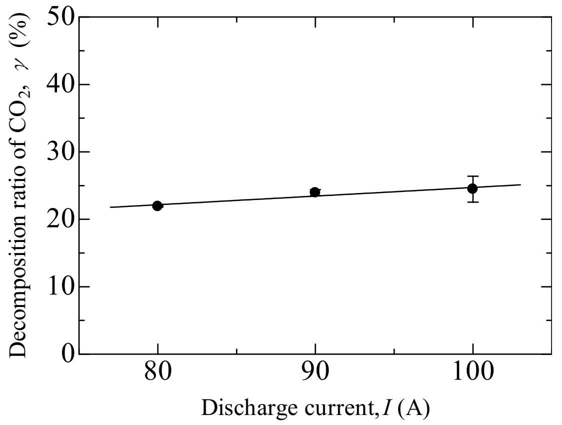

Fig. 6 Relation between decomposition ratio of CO_2 and discharge current.

Figure 4 shows that the relation between torch efficiency and mixing ratio of CO_2. In this case the discharge current was I=100A. The change of torch efficiency with the CO_2 mixing ratio was similar to that of the discharge voltage. Namely, the efficiency increased with mixing ratio of CO_2 is as shown in this figure. However the value would be constant at about η =65% at a CO_2 mixing ratio of more than X=30%. This value was a little smaller than the value of the previous one, because, the working gas flow rate was much less than that of the previous one.

The dependence of the decomposition ratio of CO_2 on different mixing ratios of CO_2 is shown in **Fig.5**. In this case the discharge current was I =100A, the same as in Fig.4. The decomposition ratio of CO_2: γ decreased with an increase in mixing ratio of CO_2. The decomposition ratio was about γ =30% when the mixing ratio of CO_2 was 10%. At 30% mixing ratio of CO_2, the decomposition ratio of CO_2 was still more than 20%. These values were calculated by the ratio of CO content to CO_2 content within the exhaust gas.

Figure 6 shows the relation between the decomposition ratio of CO_2 and the discharge current, I. In this case, the decomposition ratio of CO_2 linearly increased as the discharge current was increased from I =80A to 100A when the mixing ratio of CO_2 was about X=20%. But the increasing rate was not so large, and the decomposition ratio of CO_2 was about γ =25%, at I =100 A. Therefore the high power plasma jet will be effective for obtaining a high decomposition ratio of CO_2.

4. Reaction of Carbon Dioxide in Plasma and Its Recycling

Figure 7 shows an example of the recycling system of CO_2 by high energy plasma for a power station. The amount of CO_2 gas, which is exhausted from the power station, is very large and a reduction of CO_2 is important in order to decrease the environmental effect. Here a reduction rate of CO_2 gas is assumed to be 6% according to the Kyoto Conference relating to the protection of the

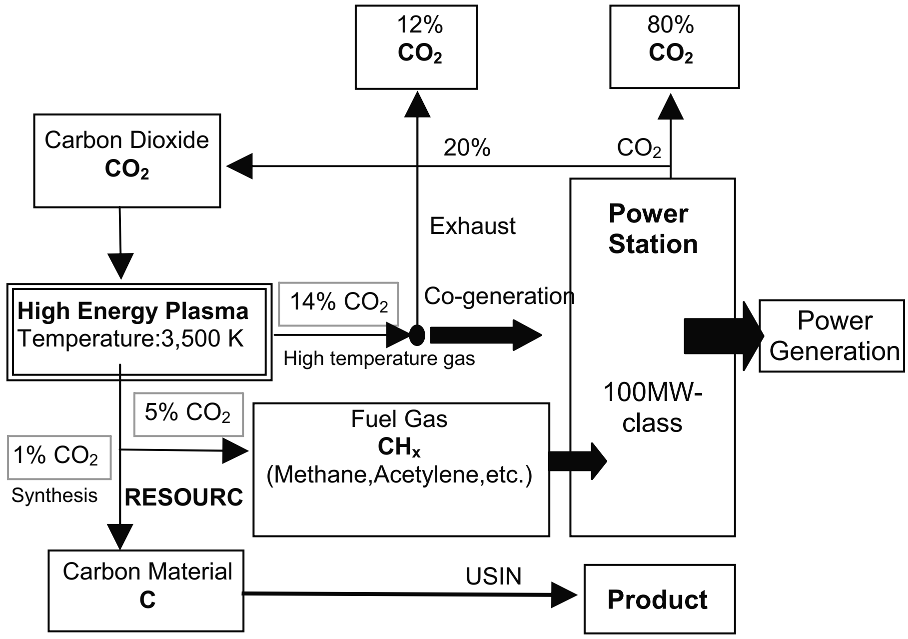

Fig. 7 Recycling system of CO_2 from a power station using a high energy plasma.
Flow of CO_2
Flow of energy

environment.

The 20% of carbon dioxide, which is collected from the exhaust gas of a power station, is introduced into the plasma. Then, CO_2 reacts by various chemical processes under high temperature conditions. In this case the decomposition rate is estimated at about 30%. Some of these constitute new materials and potential fuel resources. These resources are generated by hydrogenation of carbon dioxide, synthesis by the hydrogen, and so on. This process will also form carbon materials. The transformation to such resources from CO_2 gas will be more than 6 % as shown in Fig.7.

One problem of this system for the transformation of CO_2 to other resource is the economical balance for actual manufacturing use. Therefore the development of more effective and stable high temperature, high energy density plasma sources are expected in the industrial fields.

5. Conclusion

The gas tunnel type plasma jet as a high energy plasma process was used to decompose CO_2 and the characteristics of this method were clarified by varying the plasma operation conditions. In addition, the possibility of transforming CO_2 gas to other various resources was also discussed.

(1) The performance test of the gas tunnel type plasma jet for decomposition of CO_2 was conducted and the thermal efficiency of gas tunnel type plasma using mixing gas was about 65% when the working gas flow rate of 100 l/min with CO_2 contents of 30%.

(2) The efficiency of CO_2 decomposition by the high-energetic plasma jet was determined at various conditions. The efficiency of CO_2 decomposition was about γ=30%, when P=8kW, and the CO_2 content was X=10% in argon.

(3) The improvement in operation conditions of the gas tunnel type plasma jet to enhance its performance was discussed. A high efficiency CO_2 decomposition process would be possible at low CO_2 contents when a high power plasma was used.

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