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Thermal Plasma Characterization on Long DC Arc Discharge for Waste Treatment
廃棄物処理用のロングDCアーク放電における熱プラズマ特性

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Characteristics of thermal plasma generated by the long DC arc discharge system for waste treatment were numerically analyzed. Effects of arc current, gas flow rate, confinement tube diameter, and electrode gap distance on the thermal plasma were investigated. The numerical results reflect the experimental data well according to operating conditions. Uniformly high temperature distribution is predicted with large diameter of the plasma confinement tube, because less intrusion of cold gas into the center region leads broad current density profile in radial direction. Input power level is controllable precisely by adjusting electrode gap distance because of the linearity of arc voltage on the arc length.

1. Introduction

Thermal plasma has received a great attention for the waste treatment application, because it provides high energy density and control over the process chemistry with high decomposition efficiency [1]. In order to improve the thermal plasma waste treatment, novel long DC arc was studied in the present work.

Since long electrode gap distance of 400 mm and large plasma confinement tube diameter of 43 mm are employed in the experiment, larger plasma volume and longer waste residence time are achievable when compared with those in a conventional thermal plasma system. For a successive application, thermodynamic and electric properties of the long DC arc plasma were characterized by numerical analysis in various operation and design conditions.

2. Features of the Long DC Arc System

Photograph of the long DC arc system is shown in Fig. 1 (a). This system is constructed by Clean Technology Co., Ltd. to decompose global warming PFCs exhausted from the semiconductor industry. Arc channel is placed between tungsten imbedded rod-type cathode and copper-tungsten alloy used dome-type anode. Thermal plasma is confined by the quarts tube which has main diameter of 43 mm except anode region of 90 mm to avoid thermal damage. Auxiliary metal wire is used to breakdown in long electrode gap distance.

Computational domain for the thermal plasma region is illustrated in Fig. 1 (b). Nitrogen plasma forming gas is introduced with a swirl motion from the top of the confinement tube. Since the change of system geometry in the real experiments requires time and cost, effects of electrode gap distance and tube diameter on the thermal plasma characteristics were numerically analyzed in the range presented in Table 1. Influence of operating parameters of arc current and N_2 flow rate were also investigated.

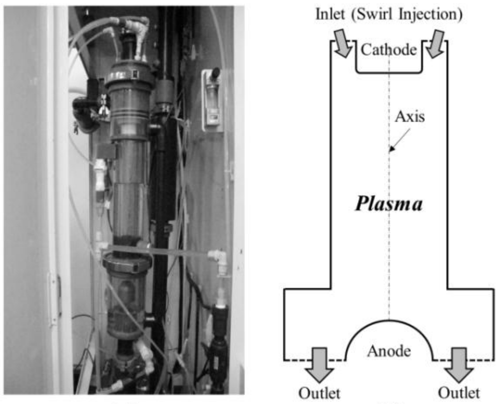

Fig.1. (a) photograph of the long DC arc system, and (b) computational domain on the plasma region.

Table 1. Design and operating parameters.

Electrode Gap Distance ***L*** (mm)	300, 350, 400, 450, 500
Tube Diameter ***D*** (mm)	30, 35, 40, 43, 45, 50
Arc Current ***I*** (A)	6, 7, 8, 9, 10
Gas Flow Rate ***G*** (lpm)	30, 40, 50, 60

3. Numerical Model

Axis symmetric 2-dimensional, steady state, laminar flow, and thermal plasma in LTE (local thermodynamic equilibrium) were assumed. Conservations of mass, momentum, energy, and current were used as governing equations where electromagnetic Lorentz force, joule heating, and radiation loss were also considered as the MHD (magnetohydrodynamics) fluid analysis method [2].

4. Results and Discussion

Numerically calculated arc voltages are compared with experimental data in Fig. 2 by changing the arc current. The voltage difference from 7% to 18% is thought to come from the LTE assumption and steep increase of electric conductivity of N_2 gas around 7,000 K which is corresponding to the center area temperature [3]. However, present numerical simulates suitably the voltage decrease by increasing arc current due to the enhancement of plasma temperature and electric conductivity, especially in the high arc current where energies of electron and heavy particles are closer than in the low arc current condition. Numerical results on the plasma gas flow effects are also in good agreement with experimentally measured data. The higher arc voltage was obtained by increasing flow rate, because increased cold plasma forming gas reduces temperature and electric conductivity.

Since the operating conditions are usually predetermined and have the limitation in the individual treatment process, design variables are important to control thermal plasma characteristics. Temperature distributions are presented in Fig. 3 for different confinement tube diameters. Relatively uniform high temperature distribution in radial direction is achieved with a large tube diameter owing to uniform Joule heating by current density profiles in large diameter as shown in Fig. 4.

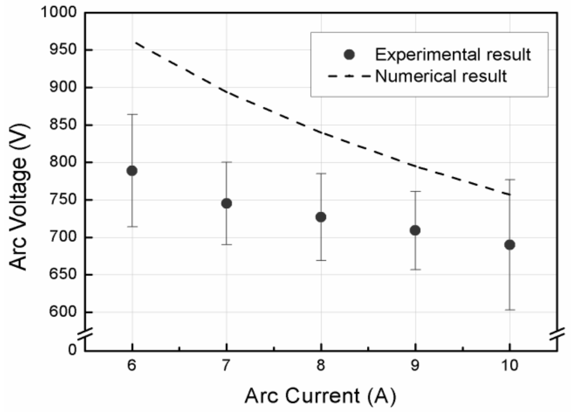

Fig.2. Arc voltage comparison between experimental and numerical results according to arc current.

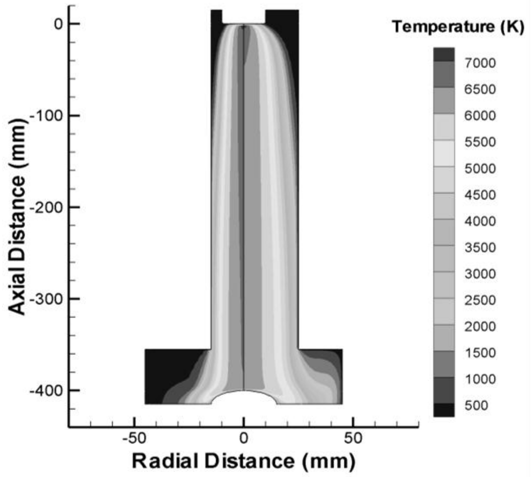

Fig.3. Comparison of temperature distributions between ***D***=30 and 50 at operating conditions of 10 A and 30 lpm.

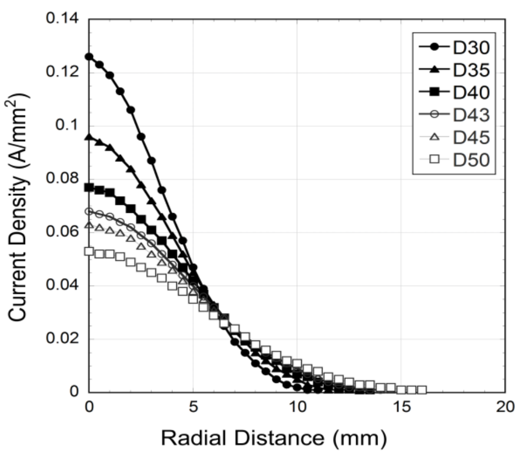

Fig.4. Radial profiles of arc current density on the middle of the arc channel (z=200) for different tube diameters.

The arc voltage is linearly increased by 1.61 V/mm with lengthening the electrode gap distance. Therefore, the electrode gap distance can be utilized to control the input power level precisely at fixed operating conditions and power requirement.

5. Conclusion

Thermal plasma generated by the long DC arc discharge has been characterized by numerical analysis. The numerical results are in good agreement with the experimental data. Temperature field and input power level required in the thermal plasma waste treatment can be predicted and controlled by the design variables.

References

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