EFFECTS OF REACTIVE GAS INJECTION ON RF THERMAL PLASMAS

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ABSTRACT

Numerical simulations of Ar-H_2 and Ar-N_2 RF thermal plasmas are performed to investigate the effective injection location of H_2 or N_2. The difference of the characteristics of plasmas among H_2 injection locations is small. The characteristics of Ar-N_2 plasmas are varied widely by N_2 injection locations.

1. INTRODUCTION

RF thermal plasmas have been used for a number of applications: chemical synthesis, plasma spraying and production of ultrafine powders. The temperature, flow and concentration fields in RF plasmas have been calculated to increase the efficiency of chemical reactions. The modeling of RF thermal plasmas with chemical reactions is rather scarce. Zhao et al. /1/ presented the modeling with reactions between $SiCl_4$ and H_2. McKelliget and El-Kaddah /2/ calculated the plasma fields only with dissociation of $SiCl_4$. Girshick and Yu /3/ reported the simulations of Ar plasmas with H_2, N_2 or H_2 on the assumption of chemical equilibrium. The authors /4/ presented the modeling of Ar-O_2 and Ar-N_2 plasmas in consideration of dissociation and recombination rates of the diatomic gas.

In the present work, numerical simulations of Ar-H_2 and Ar-N_2 RF thermal plasmas are performed to investigate the effective injection location of the diatomic gas.

2. NUMERICAL FORMULATION

The fields of flow, temperature and concentration in an RF thermal plasma were calculated by solving the two-dimensional continuity, momentum, energy and diffusion equations along with the one-dimensional electromagnetic equations /4,5/. The governing equations are solved using SIMPLER algorithm /6/. The torch is made of a quartz tube of 40 mm i.d. and 160 mm long, and the applied frequency is 4 MHz, the input power is 8 kW.

Six injection locations of H_2 or N_2 are considered in the numerical simulations (see Fig.2):

1) Type A; axial injection from the outer slit at the torch top.
2) Type B; axial injection from the inner slit at the torch top.
3) Type C; axial injection from a tube at x = 100 mm at the center.
4) Type D_1; radial injection at x = 60 mm (upstream from the coil).
5) Type D_2; radial injection at x = 90 mm (midpoint of the coil).
6) Type E; axial injection from the center of the torch top.

Argon issues at 20 liters/min, hydrogen or nitrogen issues at 5 liters/min from a slit of 2 mm-width except type E. The injection slit width in type E is 0.5 mm for H_2 injection, and 1 mm for N_2 injection, because the high injection velocity is necessary to overcome the recirculation eddy in RF thermal plasmas.

3. RESULTS AND DISCUSSION

3.1 Kinetic and Equilibrium Models

Comparisons of calculated results by kinetic and equilibrium models and measured results by a calorimetric method for the enthalpy distributions in an Ar-N_2 plasma are given in **Fig.1**. The better agreements between the results by the kinetic model and the measured results indicate the validity of the kinetic model. The kinetic model is used in the following simulations.

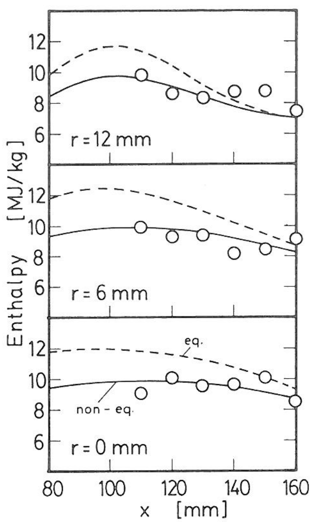

Fig.1 Calculated enthalpy profiles by kinetic and equilibrium model (Ar-N_2).

3.2 An Argon-Hydrogen Plasma

The calculated isotherms in an Ar-H_2 plasma are illustrated in **Fig.2**. The radial profiles of the temperature and the degree of dissociation of hydrogen at the torch exit are shown in **Figs.3 and 4**, respectively. The relatively low temperature and degree of dissociation at the center with type C results from the short residence time of H_2. However, the high temperature and high degree of dissociation are obtained with type E in spite of the short residence time. The low dissociation energy of hydrogen (432.1 kJ/mol) leads to the high degree of dissociation.

The distributions of conductive heat flux to the torch wall are presented in **Fig.5**. The high heat flux in the coil region is attributed to the high plasma temperature. The heat flux in the coil region with type A or B is relatively low because the plasma temperature near the wall is decreased by H_2 dissociation.

The average enthalpy and degree of dissociation at the torch exit are shown in **Fig.6**. The high enthalpy and high degree of dissociation are obtained for all injection locations. Type E is the best injection location, but the differences of the enthalpy and degree of dissociation among H_2 injection locations are small.

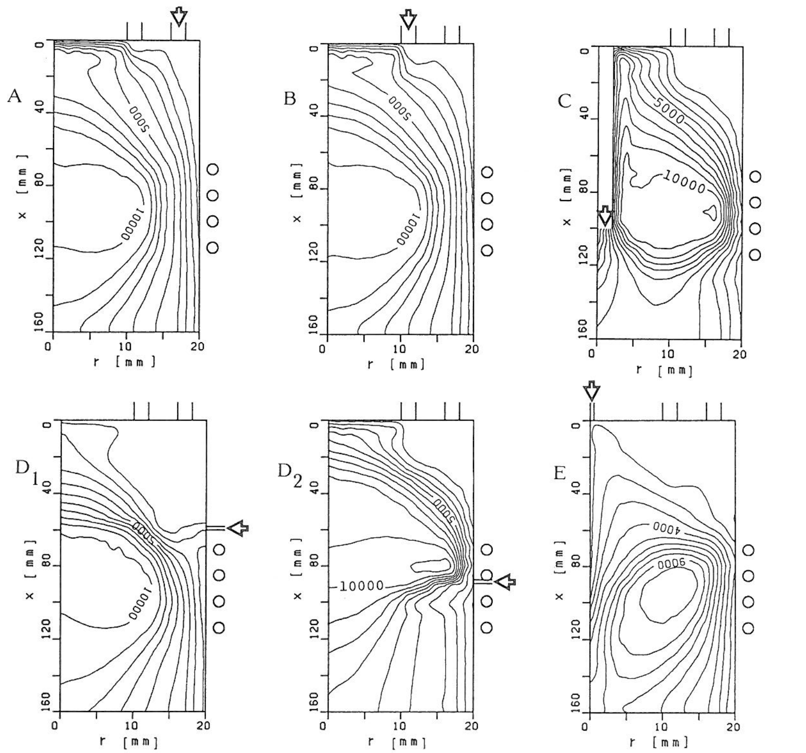

Fig.2 Isotherms (arrows indicate H_2 injection location).

3.3 An Argon-Nitrogen Plasma

The radial profiles of the temperature and the degree of dissociation of nitrogen at the torch exit are shown in **Figs.7 and 8**, respectively. The low temperature and degree of dissociation at the center with type C and E are attributable to the short residence time of nitrogen. The high dissociation energy of nitrogen (941.6 kJ/mol) brings about the low degree of dissociation for all injection locations.

The distributions of conductive heat flux to the torch wall are presented in **Fig.9**. The differences of the heat flux among N_2 injection locations are small.

The average enthalpy and degree of dissociation at the torch exit are shown in **Fig.10**. The highest enthalpy and the highest degree of dissociation can be obtained by use of type A. The long residence time of nitrogen is required for the high degree of dissociation owing to the high dissociation energy of nitrogen.

4. CONCLUSION

Numerical simulations of $Ar\text{-}H_2$ and $Ar\text{-}N_2$ RF thermal plasmas were performed to investigate the effective injection location of H_2 or N_2. The differences of the characteristics of the RF plasmas among H_2 injection locations are small. The characteristics of the $Ar\text{-}N_2$ RF plasma are varied widely by N_2 injection locations.

ACKNOWLEDGMENTS

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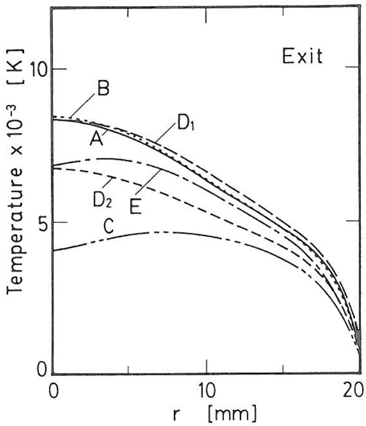

Fig.3 Profiles of temperature at torch exit with H_2 injection.

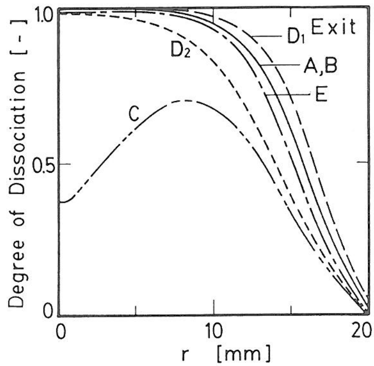

Fig.4 Profiles of degree of dissociation at torch exit with H_2 injection.

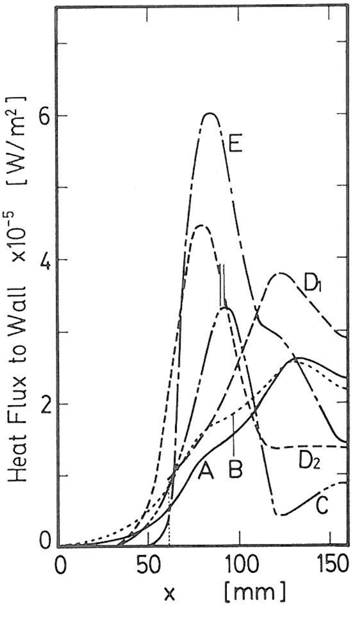

Fig.5 Heat flux to torch wall with H_2 injection.

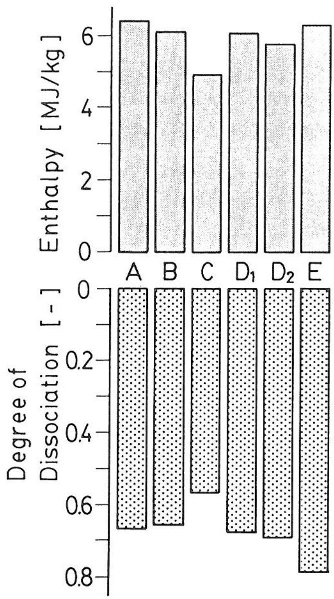

Fig.6 Average enthalpy and degree of dissociation at torch exit with H_2 injection.

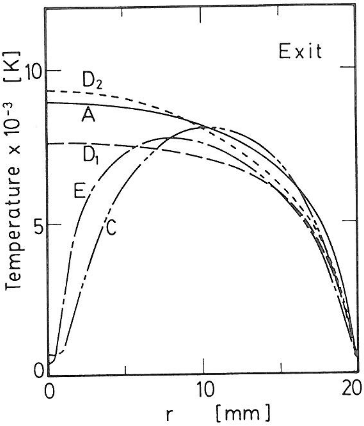

Fig.7 Profiles of temperature at torch exit with N_2 injection.

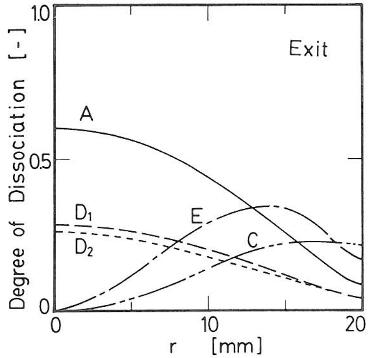

Fig.8 Profiles of degree of dissociation at torch exit with N_2 injection.

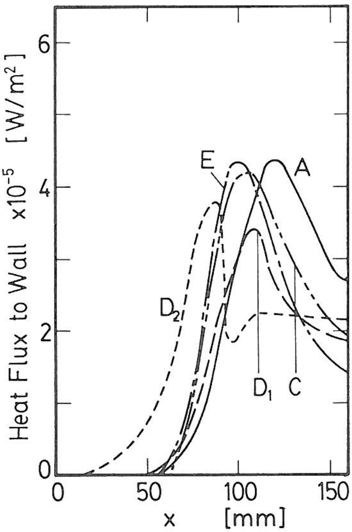

Fig.9 Heat flux to torch wall with N_2 injection.

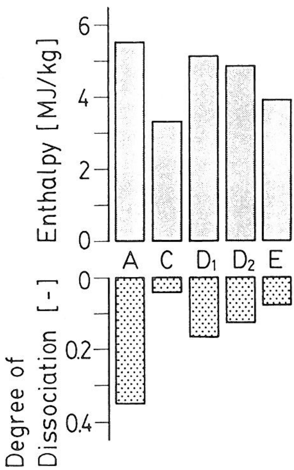

Fig.10 Average enthalpy and degree of dissociation at torch exit with N_2 injection.