Characteristics of Gliding Arc Discharge Plasma*

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Abstract A gliding arc discharge plasma and its characteristics are described. Analysis of the production principle of the plasma is presented. Some experimental results about two novel types of the gliding arc plasma generator have been obtained. These types of gliding arc plasma are potentially usable in the chemical industry and environmental engineering.

Keywords: gliding arc, non-equilibrium plasma at atmospheric pressure, non-thermal plasma

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1 Introduction

The gliding arc discharge plasma is a type of non-equilibrium plasma near atmospheric pressure, and has many applications in the chemical industry and environmental engineering. The non-equilibrium plasma near atmospheric pressure is the so-called non-thermal plasma in between the thermal plasma and cold plasma. The generation method of the non-equilibrium plasma has its inherent characteristics and differs from those of the conventional thermal plasma and cold plasma. Recently the subject of the non-equilibrium plasma at atmospheric pressure and its applications have attracted many researchers' attention and some papers on this area have been published [1~5]. The gliding arc discharge can be powered by a DC or AC power supply source [6,7]. In this paper, we will analyse the principle of the gliding arc discharge and present two novel types of gliding arc plasma generators: a DC gliding arc plasma generator and an AC three-phase gliding arc plasma generator. The DC gliding arc plasma generator is characterized by stability of discharge and a simple design. The main advantages of AC gliding arc discharge plasma generator are simplicity of the power supply system and its low cost.

2 The principle of gliding arc discharge

The gliding arc discharge is one of the main generation methods of non-equilibrium plasma near atmospheric pressure [8~10]. In general, the gliding arc plasma generator consists of two divergent electrodes, where the arc starts at the shortest distance between the electrodes, then moves with the gas flow and the length of the arc column increases together with the voltage. Presented in this paper are a DC gliding arc plasma generator driven by a gas flow with a circumferential velocity and an AC three-phase gliding arc plasma generator.

In the following we will discuss the force acting on the arc by the gas flow and the relationship between the velocity of the gas flow and the degree of non-equilibrium of the plasma.

The force acting on arc with unit length F is

$$F = \frac{1}{2} C_d \rho (V_g - V_a)^2 d, \tag{1}$$

where C_d is the resistance coefficient, ρ is the gas density, V_a is the arc velocity, V_g is the velocity of the gas flow, and d is the diameter of the arc.

As we know, a higher relative velocity between the arc and the gas flow is of advantage in increasing the degree of non-equilibrium of the plasma. Here we will discuss the relationship between the velocity of the gas flow and the degree of non-equilibrium of the plasma. A simplified two-temperature model of non-equilibrium plasma for the calculation of the relationship between the relative velocity and the degree of non-equilibrium of the plasma is adopted. The energy balance equations for electron and heavy particle are given as [11]

$$\rho_e C_{pe} \frac{\partial T_e}{\partial t} = \sigma E^2 - \gamma (T_e - T_h) + \nabla \lambda_e \nabla T_e - Q_r, \tag{2}$$

$$\rho_h C_{ph} \frac{\partial T_h}{\partial t} = \gamma (T_e - T_h) + \nabla \lambda_h \nabla T_h - \rho_h \nu C_{ph} \nabla T_h, \tag{3}$$

where ρ_e, ρ_h are the density of electron and heavy particle, T_e, T_h are the temperature of electron and heavy particle, C_{pe}, C_{ph} are the specific heat of electron and heavy particle, λ_e, λ_h are the thermal conductivity of the electron and heavy particle, respectively, σ is the electric conductivity, E is the electric field strength, γ is the coefficient of energy transfer between the electron and heavy particle, Q_r is the dissipated energy by radiation and ν is the velocity of the gas flow.

The degree of non-equilibrium of the plasma is defined as $(T_e - T_h)/T_e$. It can be expressed as [12]

$$\frac{T_e - T_h}{T_e} = \frac{m_h e^2 E^2}{3k T_e m_e^2 (\omega^2 + \nu_e^2)}, \tag{4}$$

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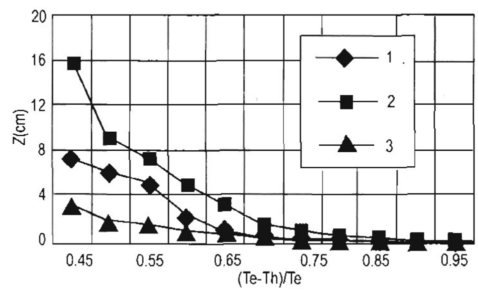


1 O_2, $\rho\nu = 1$ g/s·cm^2; 2 Ar, $\rho\nu = 1$ g/s·cm^2; 3 Ar, $\rho\nu = 0.2$ g/s·cm^2

Fig.1 Relationship between the degree of non-equilibrium and Z for different rates of gas flow

where ω is the frequency of the plasma, ν_e is the collision frequency of the plasma between the electron and heavy particle, k is the Boltzmann constant, e is the electric charge of the electron, and m_h is the mass of the heavy particle.

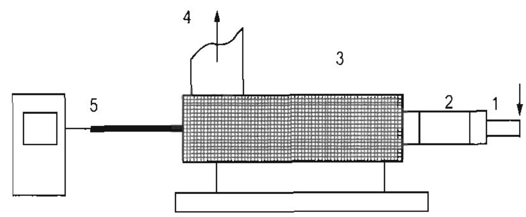
Here, the effect of the rate of the gas flow on the degree of non-equilibrium of the plasma will be studied with a simplified one-dimensional model. It is supposed that there is a half infinite plasma region with a certain electron temperature and some cold gas flows into the plasma region. The temperature of the cold gas will increase with the depth where the cold gas flows into the plasma region. Now let us study the variation in the temperature of the cold gas with the rate of the gas flow and the type of the gas. The calculation is based on the linear method in different sections of the temperature. The results of the calculation are shown in Fig. 1. It shows the relationship between the degree of non-equilibrium of the plasma and the depth Z for different rates of the gas flow. Z is the depth of the cold gas flowing into the plasma region. In Fig. 1, it can be seen that the degree of non-equilibrium of the plasma will increase with the increasing rate of the gas flow.

The results of the calculation show that a higher rate gas flow is of advantage in increasing the degree of non-equilibrium of the plasma.

3 DC gliding arc plasma generator

The DC gliding arc plasma generator consists of a central electrode, an outside electrode, a DC power supply system and a gas supply system. In general, the outside and the central electrodes are set as the anode and cathode, respectively. The shortest distance between the electrodes is 2~ 3 mm. When a voltage of 10000 volts is applied to the electrodes, an arc will be ignited at the place with shortest distance. The small plasma column is rotated by the gas flow and then the rotating arc is driven towards the exit of the setup by a gas flow. The experimental set-up of the DC gliding arc discharge is shown in Fig. 2. The photograph of the gliding arc discharge is shown in Fig. 3.

The temperature distribution of the DC gliding arc plasma in the axial direction is measured by a digital



1 Gas flow; 2 Plasma generator; 3 Experiment section; 4 Exhaust blower; 5 Digital thermometer

Fig.2 Experimental set-up of the DC gliding arc plasma

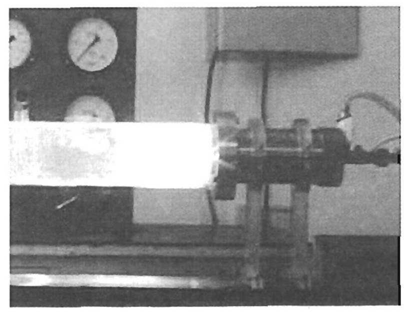


Fig.3 Photograph of the discharge for the DC gliding arc plasma generator

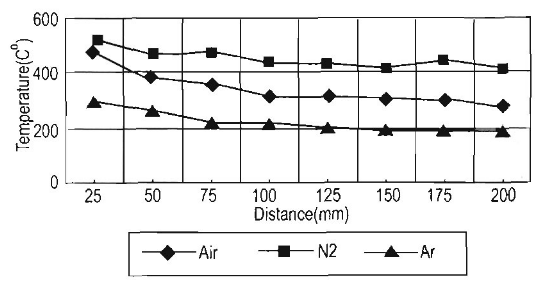


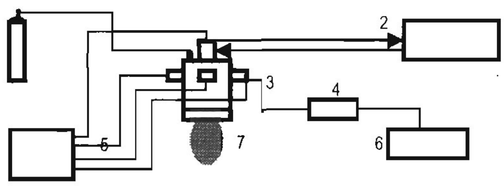
Fig.4 Distribution of temperature from the exit of the plasma generator in axial direction

thermometer. The measured results are presented in Fig. 4. The highest temperature at the exit of the plasma generator is near 530°C for N_2. The lowest temperature at the exit of the plasma generator is about 300°C for Ar.

4 AC three-phase gliding arc plasma generator

The experimental set-up of the AC three-phase gliding arc plasma generator is shown in Fig. 5. It consists of a gliding arc plasma generator, an AC three-phase main power supply system, a high voltage ignition power supply system and a gas supply system. The AC three-phase main power supply system includes a variable transformer, three inductors and a main transformer. The gliding arc plasma generator includes a water-cooled central electrode, three water-cooled outside electrodes, a gas injection device and an electric discharge chamber. The shortest distance between the central electrode and the outside electrodes is 2~ 3 mm.

When a high voltage of 10000 volts is applied between the central electrode and the outside electrodes, an arc will be ignited at the shortest distance and then



1 Gas supply; 2 System of cooling water; 3 AC three- phase plasma generator; 4 Sensor; 5 AC three-phase power supply; 6 TDS-2014-Oscillograph; 7 Flame of plasma

Fig.5 Experimental Set-up of the AC three-phase gliding arc plasma generator

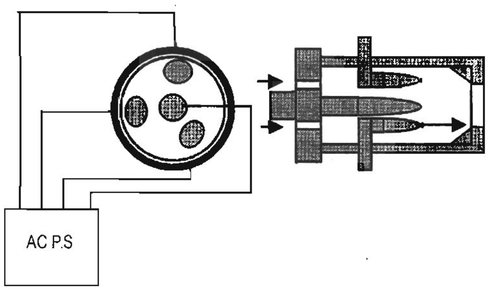


Fig.6 Schematic diagram of the AC three-phase gliding arc plasma generator

driven towards the exit of the setup by a gas flow and electromagnetic force produced by the arc current.

Parameters of the AC three-phase power supply system and the high voltage ignition power supply system are given in Table 1. The rate of the gas flow for the plasma generator is 8~10 m^3/h, and the gas medium is air.

Table 1. Parameters of the AC three-phase power supply and the ignition power supply

Type of P.S.	Voltage (V)	Current (A)
AC P.S.	1000	10
Ignition P.S.	10000	0.1

The configuration of the AC three-phase gliding arc plasma generator is shown in Fig. 6. The diameter and the length of the plasma generator are 120 mm and 220 mm respectively. Six holes, each with a diameter of 2 mm, for gas injection are made on the top of the generator.

The photograph of the AC three-phase gliding arc plasma generator is shown in Fig. 7.

The current of the discharge recorded with a digital oscilloscope is shown in Fig. 8. It can be seen in Fig. 8 that the discharge current has some oscillation when the instantaneous voltage is low. If the arc voltage is high enough, the oscillation in the arc current decreases.

5 Conclusions

We reported here two novel types of gliding arc plasma generator, a DC gliding arc plasma generator and an AC three-phase gliding arc plasma generator. Some results of the primary experiment for gliding arc discharge, including DC gliding arc and AC gliding arc, are presented. The AC three-phase gliding arc plasma generator has some advantages, for example, high

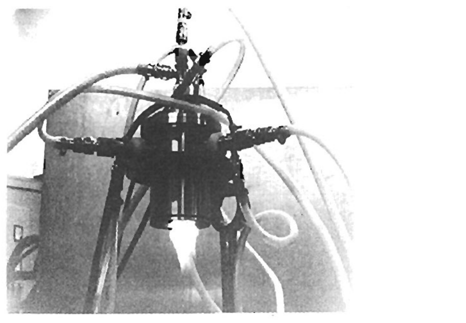


Fig.7 Photograph of the AC three-phase gliding Arc plasma generator in operation

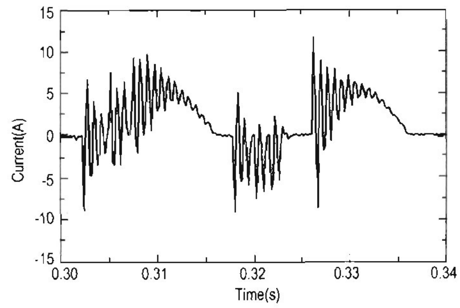


Fig.8 Current curve of the AC gliding arc discharge

power of the plasma generator, uniform temperature distribution of the plasma at the exit cross-section of the plasma generator, simplicity of the power supply system and a low cost. It offers good prospects of application in environmental engineering.

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