Characteristics of Gliding Arc Discharge Plasma

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

1. Introduction

The gliding arc discharge plasma is a type of non-equilibrium plasma near atmospheric pressure, and has many applications in chemical industry and environment 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 the conventional thermal plasma and cold plasma. Recently the subject of the non-equilibrium plasma at atmospheric pressure and its applications attracts many researchers` attentions and some papers on this study area were published [1-5]. The gliding arc discharge can be powered by a DC or AC power source supply [6,7]. In this paper, we analyze 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. Characteristics of the DC gliding arc plasma generator are stability of discharge and simplicity of the plasma generator. The main advantages of AC gliding arc discharge plasma 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, 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. In this paper a DC gliding arc plasma generator driven by gas flow with circumferential velocity and an AC three-phase gliding arc plasma generator are presented.

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

The force acting on the per unit length of arc F is

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

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

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

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

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

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, σ is the electric conductivity , E is the electric field strength, γ is the coefficient of energy transfer between the electron and heavy particle , λ_e, λ_h are the thermal conductivity of the electron and heavy particle , Q_r is the dissipated energy by radiation, v is the velocity of gas flow.

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

$$\frac{T_e - T_h}{T_e} = \frac{m_h e^2 E^2}{3kT_e m_e^2(\omega^2 + v_e^2)} \quad (4)$$

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

In the following, we calculate the effect of the rate of gas flow on the degree of non-equilibrium of plasma with a simplified one-dimensional model. We suppose that there is a half infinite plasma region with a certain electron temperature, some cold gas flows into the plasma region. The temperature of the cold gas will increase together with the depth for the cold gas flowing into the plasma region. Now we study the variation of the temperature of cold gas with the rate of gas flow and the type of gas. The calculation is based on the linear method in different sections of temperature. The results of calculation are shown in Fig. 1. It shows the relationship between the degree of non-equilibrium of plasma and the depth Z for different rate of gas flow. Z is the depth for the cold gas flowing into the plasma region. In Fig.1, we can see that the degree of non-equilibrium of plasma will increase with the increasing of the rate of the gas flow.
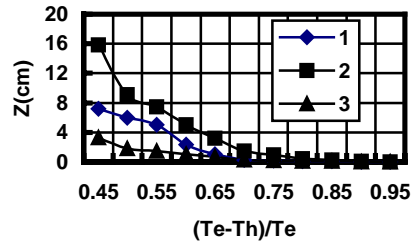

Fig. 1 Relationship between the degree of non-equilibrium and Z for different rate of gas flow
1 O_2 , v= 1g/s.cm^2 ; 2   Ar, v= 1g/s.cm^2 ;
3 Ar , v= 0.2g/s.cm^2

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

3. A DC gliding arc plasma generator

The DC gliding arc plasma generator consists of a center electrode, an outside electrode, a DC power supply and a gas supply. In general, the outside electrode is positive and the center electrode is negative. The shortest distance between the electrodes is 2-3 mm. When a power supply with 10000 volts is attached to the electrodes, the arc will be ignited at the shortest distance. The small plasma column is rotated by the gas flow and then the rotating arc is driven towards exit of the setup by gas flow. The experimental set-up of the DC gliding arc discharge is shown in Fig.2. The photograph of gliding arc discharge is shown in Fig.3.
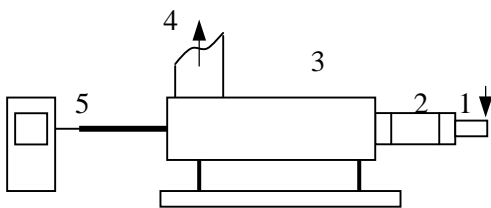

Fig.2. Experimental set-up of
the DC gliding arc plasma
1 Gas flow;   2 Plasma generator;
3 Experiment section; 4 Exhaust blower;
5 Digital thermometer

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

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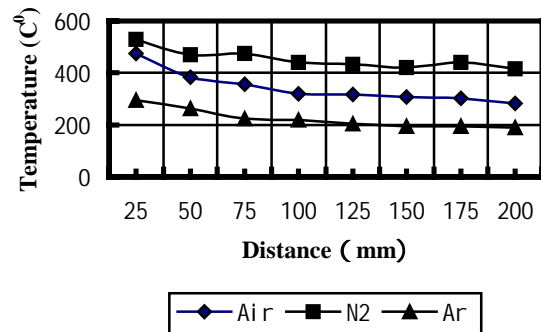

Fig.4 Distribution of temperature from the
exit of the plasma generator in axial
direction.

4. An 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, a high voltage ignition power supply and a gas supply. The AC three-phase main power supply included a variable transformer, three inductors and a main transformer. The gliding arc plasma generator included a water-cooling center electrode, three water-cooling outside electrodes, a gas injection device and an electric discharge chamber. The shortest distance between the center electrode and outside electrodes is 2-3 mm.
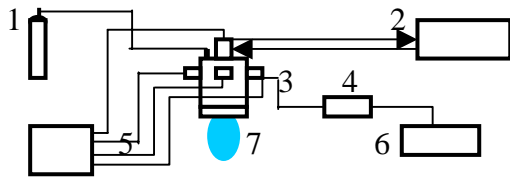
Fig.5 Experimental Set-up of the AC three-phase gliding arc plasma generator

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

When a high voltage ignition power supply of 10000 volts is attached to the center electrode and the outside electrodes, the arc will be ignited at the shortest distance and then driven towards the exit of the setup by the gas flow and electromagnetic force created by own arc current.

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

Table1. 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 of the plasma generator is

120mm, and length is 220mm. Six holes for gas injection with 2mm diameter are set on the top of the generator.
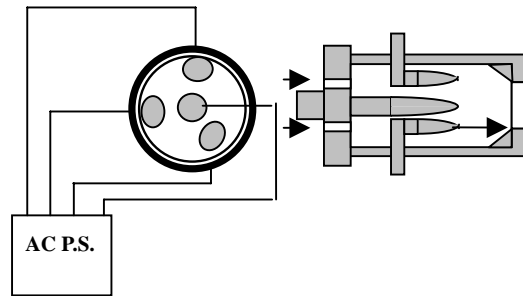

Fig.6 Schematic diagram of the AC three-phase gliding arc plasma generator

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

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

The current curve of the discharge recorded with a digital oscilloscope is shown in Fig.8. We can see that the discharge current has some oscillation when the instantaneous voltage is low in Fig.8. If the arc voltage is high enough, the oscillation of the arc current will decrease.
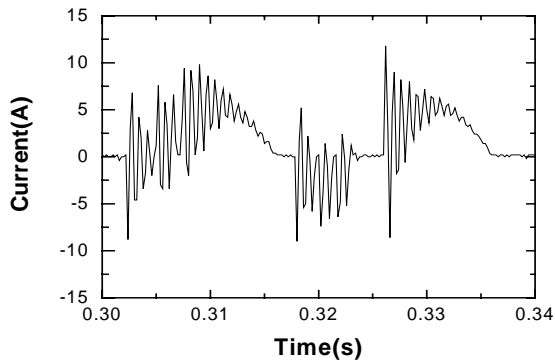
Fig.8 Current curve for the AC gliding arc discharge

5. Conclusions

We report 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 experiment for gliding arc discharge (include DC gliding arc and AC gliding arc) are presented. The AC three-phase gliding arc plasma generator has some advantages (for example, high 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 its low cost.) and offer good application prospect in environment engineering.

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