

# Experimental investigation of AC two-channel gliding arcs discharge plasma driven kerosene cracking

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**Abstract.** To improve the ignition and combustion performance of aviation kerosene, two-channel gliding arcs plasma was adopted to crack kerosene into active components, such as gaseous light hydrocarbons and H<sub>2</sub>. The influence of carrier gas flow rate on discharge characteristics and cracking effects were investigated. Experimental results indicate that, compared to single channel discharge, the power of two-channel gliding arcs discharge is greater while the arcs cover twice as much area as that of single channel discharge. The cracking rate of two-channel discharge plasma is greater than that of single channel discharge while it shows an upward trend with greater carrier gas flow rate. Among the main components of cracking gas, the molar percentage of hydrogen is the highest and exceeds 50%. Greater carrier gas flow rate would result in lower molar percentage of hydrogen. Interestingly, the ethyl group prefers to form C<sub>2</sub>H<sub>2</sub> as the carrier gas flow rate increases in the two-channel gliding arcs discharge while the molar percentage of C<sub>2</sub>H<sub>2</sub> and C<sub>2</sub>H<sub>4</sub> changes inconspicuously in the single channel discharge.

## 1 Introduction

As RP-3 aviation kerosene is composed of heavy hydrocarbons, it has problems of low chemical activity, poor evaporation and low flame propagation speed at high airflow speed and low temperature/pressure conditions, which would make negative effect on its combustion performance[1]. Therefore, cracking has become hotspots to increase the activity of kerosene recently. Kerosene cracking refers to the process of transform macromolecular compounds into light hydrocarbons and highly active substances through chemical reactions<sup>[2]</sup>.

Plasma is consisted of a partially ionized gas which contains active components, i.e. ions, electrons and reactive species that is able to perform reactions[3]. In hydrocarbon containing plasma reactors, free electrons (which have mean energy of 1–10 eV[4]) lose energy through collision with hydrocarbon molecules, and break the C-C bonds and C-H bonds (which have energy around 3–4eV[5]). Collisions between electrons and hydrocarbons results in the production of small activated free radicals, which can recombine and produce lighter hydrocarbons[3]. Gliding arc discharges (GAD) plasma can provide sufficient non-thermal plasmas due to their high energy efficiency[6], therefore, it is widely used in various industrial fields, such as assisted ignition, combustion enhancement and hydrocarbon cracking. Czemichowski et al.[7] found that gliding arc could not only reduce the defects of traditional gas processes but also bring controllable energy with low energy

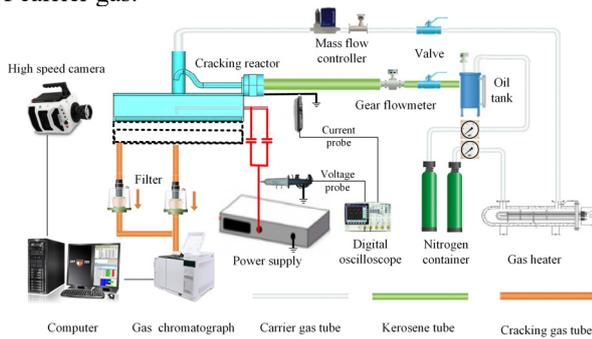
consumption in various applications. Bo et al.[8] cracked n-hexane with gliding arc discharge plasma generated by a knife-shaped electrode, the main cracking products were detected, and the influence of voltage and the initial concentration of n-hexane on the cracking rate was analyzed. Zhu[9] et al. developed a novel rotating gliding arc (RGA) discharge reactor for tar destruction and investigated the physical features of RGA discharge and its application to toluene destruction at different input concentrations and total gas flow rates. They found that the highest destruction efficiency could exceed 95%, with a toluene concentration of 10 g/Nm<sup>3</sup> and a total flow rate of 0.24 Nm<sup>3</sup>/h. Lin[10] et al. designed a gliding arc plasma fuel injector (GAPFI) using AC discharge, and found that the drop size of sprays from gliding arc plasma fuel injector decreased with low temperature kerosene and several light hydrocarbons with larger laminar flame propagation velocity such as CH<sub>4</sub>(1.26 SLM), C<sub>2</sub>H<sub>4</sub>(1.31 SLM) and C<sub>2</sub>H<sub>2</sub>(2.30 SLM) were produced.

However, in the process of plasma cracking, most reactants are treated around the gliding arc, where the limited plasma area is one of the defects of the technology. In this paper, a parallel two-channel gliding arcs discharge circuit was adopted to produce more plasma to crack kerosene. The discharge characteristics of the two-channel gliding arcs discharge, including discharge power and gliding process of arcs were researched. Besides, the influence of carrier gas flow rate and the quantity of discharge channels on cracking rate and the distribution of main components in cracking gas were studied.

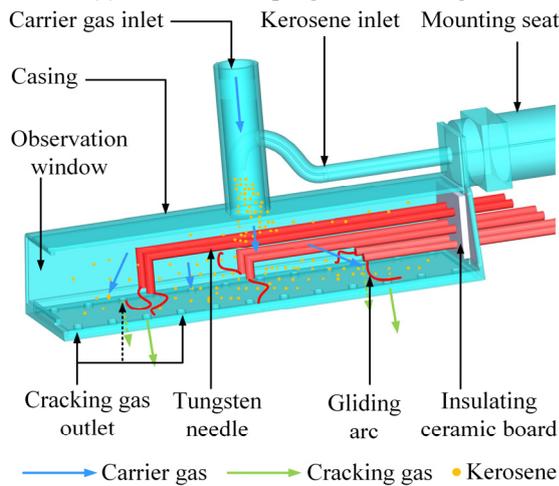
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## 2 Experimental setups and methods

Fig.1 shows the schematic diagram of the experimental set-up and gliding arc plasma cracking reactor. The plasma cracking reactor was consisted of a plasma reaction zone generated between tungsten needles (anode) and a trapezoidal shell which was grounded (cathode). The observation window was sealed with quartz glasses while the electrodes were fixed and insulated by a ceramic board. Besides, the tungsten needle was coated with insulating ceramic tube to make sure the arcs were generated in different positions. The arcs were ignited initially at the narrowest gap (5 mm) between the electrodes and then glided and extended under the blowing of carrier gas.



(a) Plasma cracking experimental setup



(b) Cracking reactor

Fig.1. Schematic diagram of plasma cracking experimental setup (a) and cracking reactor (b).

The carrier gas (N<sub>2</sub>, 99.99%) was heated up to 450K by the gas heater and then injected into the cracking reactor through a round tube with a diameter of 10mm. Kerosene (RP-3) was injected into the round tube through a thin tube with an inner diameter of 0.7mm and mixed with nitrogen, then, the mixture would flow into the plasma area and be cracked. The flow rate of the carrier gas and kerosene were controlled and recorded through a mass flow controller (D07-9E, range 0–300 L/min, accuracy 2%) and a gear flow meter (CX-M2, range 0.5–150 mL/min, accuracy 0.5%), respectively. In this experiment, the mass flow rate of kerosene kept at 30g/min and the carrier gas flow varied from 25L/min to 200L/min. The cracking gas was detected by a gas

chromatograph (Agilent 7890B), equipped with one flame ionization detector (FID) and two thermal conductivity detectors (TCD). Sample collection and analysis were repeated three times for each experimental condition to acquire the concentration data with an error of less than 3%.

The schematic circuit diagram of multi-channel discharge is shown in Fig.2. A high voltage AC power (CTD-1000z, discharge frequency was 23kHz, max output voltage was 20kV output voltage waveform was sine wave) was used to drive the two-channel discharge through a constant output voltage and current. The principle of multi-channel discharge was as follows: as one of the electrode gaps (take electrode gap 1 for example) occurred breakdown, the capacitor 1 would keep the high electric potential difference between point a and b, which would result in the breakdown in other electrode gaps.

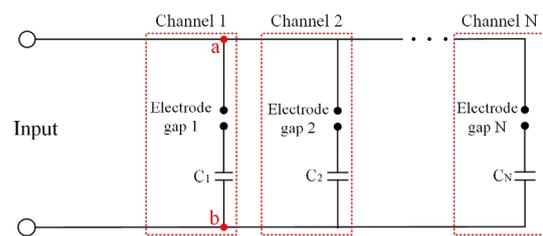


Fig. 2. The schematic diagram of the multi-channel discharge circuit.

## 3 Results and discussion

### 3.1 Discharge characteristic

The power input into the cracking system was defined as formula 1.

$$P(W) = \frac{\int_{t_2}^{t_1} U(t)I(t)d(t)}{t_1 - t_2} \quad (1)$$

The average power of single channel and two-channel discharge are shown in Fig.3. The data in Fig.3 shows that the average discharge power increase with greater carrier gas flow rate. Besides, the discharge power of two-channel gliding arcs is greater than that of single channel discharge.

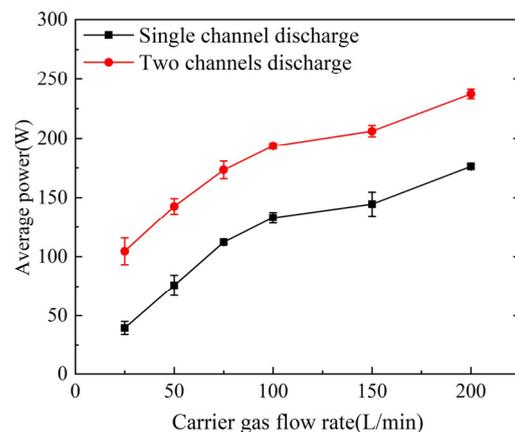


Fig.3. Variation of discharge power with carrier gas flow rate.

The gliding process of arcs is shown in Fig.4 where the carrier gas flow rate was 100L/min. As can be seen from Fig.4, the arcs generate at the narrowest electrode gap, then glide and extend due to the blowing of carrier gas, eventually disappeared and re-generated at the narrowest electrode gap. However, in the gliding process of single channel discharge, the arc gliding area is only half of the area that two-channels discharge arcs gliding. Meanwhile, the gliding speed of single channel discharge arc is twice that of two-channel discharge.

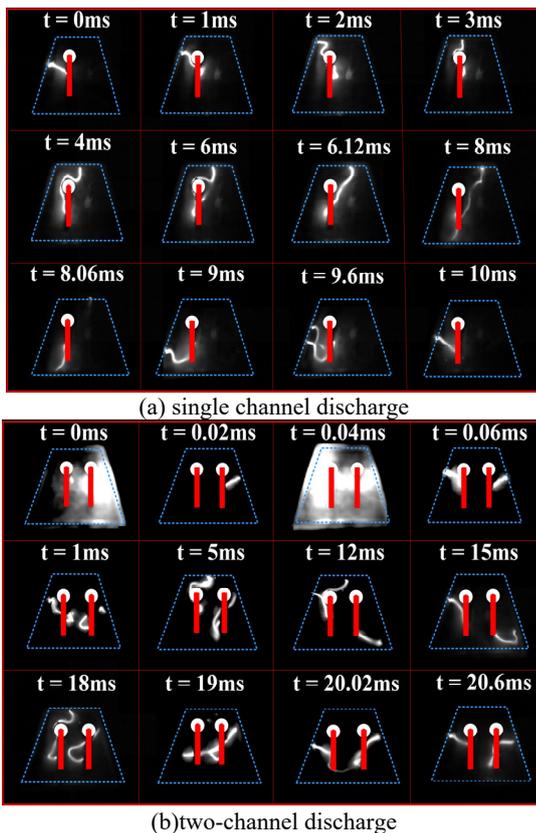


Fig.4. Gliding process of the arcs.

### 3.2 Plasma cracking effect

The cracking effect is evaluated through cracking rate and the molar percentage of main components. Cracking rate and molar percentage are defined as follows.

$$\text{Cracking rate} = \frac{\sum \frac{P_{C_xH_y \text{ or } H_2} \times F_{N_2}}{P_{N_2} \times V_m} \times N_{C_xH_y \text{ or } H_2}}{m_H} \times 100\% \quad (2)$$

$$\text{Molar percentage} = \frac{P_{C_xH_y \text{ or } H_2}}{\sum_i P_{C_xH_y \text{ or } H_2}} \times 100\% \quad (3)$$

In formula, where F and P represent volume flow rate (L/min) and volume percentage (%). N is hydrogen atoms number in  $C_xH_y$  and  $H_2$ ,  $V_m$  is gas molar volume (L/mol),  $m_H$  is hydrogen atoms mass flow rate (g/s) in kerosene.

The cracking rate in different experiment conditions is shown in Fig. 5.

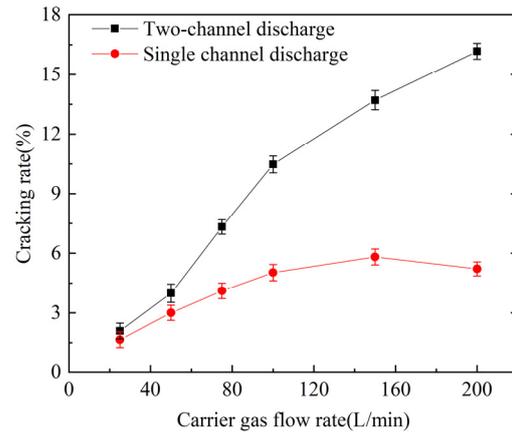
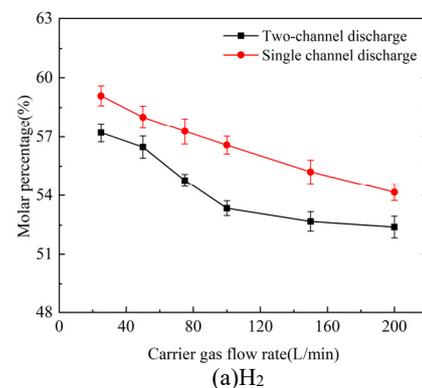


Fig.5. The change laws of cracking rate with carrier gas flow rate.

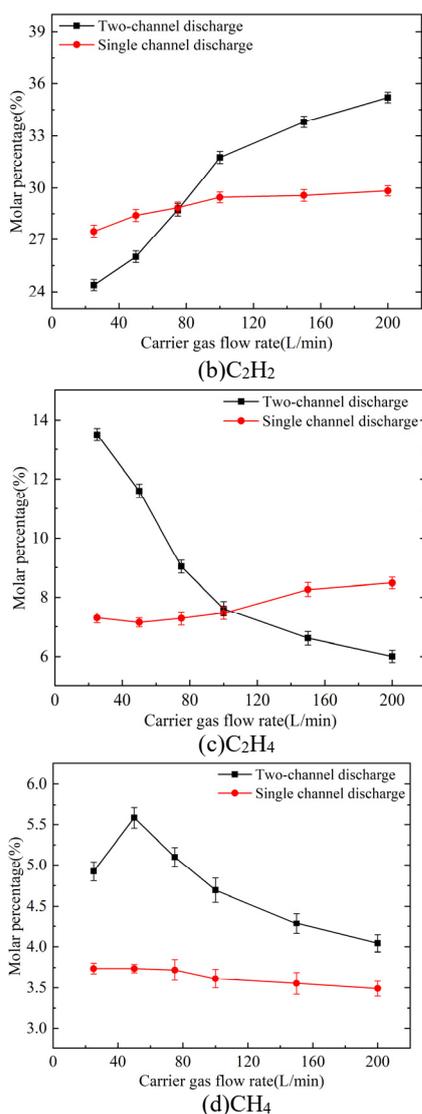
As the carrier gas flow rate increases, the cracking rate of two-channel gliding arcs discharge plasma shows an upward trend. However, that of single channel discharge plasma increases at first and then falls. It reaches the maximum when the carrier gas flow rate is 150L/min and the maximum cracking rate is 5.8%. As the carrier gas flow rate increases from 25L/min to 200L/min, the cracking rate of two-channel discharge plasma rises from 2.1% to 17.3%.

Greater gas flow rate would bring greater discharge power which would generate more hard-electron to collision with C-C bonds and C-H bonds and produce more active groups as well as more hydrogen atoms. The increase of active groups and hydrogen atoms would result in more gaseous light hydrocarbons and hydrogen. Therefore, the cracking rate rise. Greater power that two-channel discharge would bring to cracking reactor as well as the larger arcs gliding area would promote more kerosene cracking and elevate cracking rate.

The molar percentage represents the distribution of the main components in cracking gas. It is an important parameter to evaluate the quality of cracking gas. With the increase of carrier gas flow rate, the change rule of the molar percentage is shown in Fig.6.



(a)H<sub>2</sub>



**Fig.6.** Change laws of molar percentage of main components in cracking gas.

In the cracking gas, the molar percentage of hydrogen is the highest and exceeds 50% in all experimental conditions. Greater carrier gas flow rate would result in lower molar percentage of hydrogen. As the carrier gas flow rate increases from 25L/min to 200L/min, the molar percentage of hydrogen decreases from 59.08% and 57.21% to 54.15% and 53.30% in the single channel discharge conditions and two-channel discharge conditions, respectively.

Different from hydrogen, the molar percentage of  $C_2H_2$  appears an upward trend with greater carrier gas flow rate. However, the rising velocity of  $C_2H_2$  in two-channel discharge is much faster than that in single channel discharge. Interestingly, the variation tendency of molar percentage of  $C_2H_4$  and  $CH_4$  in two-channel discharge shows downward trends with greater carrier gas flow rate while that in single channel discharge remains basically unchanged. Analysis, greater flow rate would reduce the heat loss during the carrier gas flow into cracking reactor, which would result in higher temperature

in cracking reactor. As the formation of acetylene by ethyl group is an endothermic reaction, the ethyl group prefers to form  $C_2H_2$  as the carrier gas flow rate increases. However, in the single channel discharge, the number of ethyl groups is less, so that the molar percentage of  $C_2H_2$  and  $C_2H_4$  changes inconspicuously.

## 4 Conclusions

In this paper, two-channel gliding arcs discharge plasma is adopted to crack kerosene. The influence of carrier gas flow rate on cracking effect and discharge characteristic is studied. The conclusions are as follows.

(1) Compared to single channel discharge, the discharge power of two-channel gliding arcs plasma is greater. Besides, in the gliding process of two-channel gliding arcs, the arcs cover twice as much area as that of single channel discharge.

(2) With the carrier gas flow rate increases, the cracking rate of two-channel discharge plasma shows an upward trend. However, that of single channel discharge plasma increases at first and then falls.

(3) In the cracking gas, the molar percentage of hydrogen is the highest and exceeds 50% in each condition. Greater carrier gas flow rate would result in lower molar percentage of hydrogen.

(4) The ethyl group prefers to form  $C_2H_2$  as the carrier gas flow rate increases in the two-channel discharge. However, in the single channel discharge, the number of ethyl groups is less, so that the molar percentage of  $C_2H_2$  and  $C_2H_4$  changes inconspicuously.

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