Streamer Corona Plasmas and NO Removal

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Abstract: This paper reports experimental studies on the discharge modes with AC/DC and DC power sources and different electrode configurations. Very uniform streamer coronas can be generated by using AC/DC source. The energy cost for NO oxidation in air is about 30 eV/NO.

Keywords: Streamer corona, Non-thermal plasma, AC/DC power source, Denitrification

1 INTRODUCTION

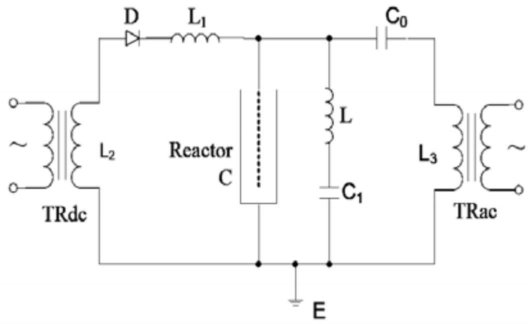
Within the last 20 years, various kinds of corona-induced non-thermal plasmas have been investigated in order to remove gaseous pollutants, such as NO_x, SO_2, VOCs, Hg, H_2S from exhaust gases and tar from biomass-derived fuel gas. Electrical corona discharge methods can be implemented in many ways, depending on the geometry of the plasma reactor and the electrical power supplies, such as pulsed corona, dielectric-barrier discharge, surface discharge, radical shower, AC/DC streamer discharge etc. Up to now, more than 50 kinds of pollution emission control with corona plasma techniques have been investigated. Both laboratory and pilot scale tests have indicated significant technical and economical advantages of the non-thermal plasma process compared to the electron beam process and other conventional methods. Primary streamer leads to an higher energy efficiency than the secondary streamers[1].

The active electrons generated in streamers induce chemical radicals, such as OH, O, N, O_3 etc.[1] According to Yan's early work, the produced initial radicals are mainly OH, O and H radicals in air like mixtures. N radical generation is negligible when the O_2 concentration is larger than 3.6%[2]. In the development of a streamer, electric field near the streamer head can accelerate upto an energy of 10-12 eV[3], which is enough to break the bonds of $H_2O$and O_2.

As we know, positive streamer corona can lead to good chemical effects. However, DC power source can not generate a uniform streamer corona in a large plasma reactor. In this work, we use a so-called AC/DC power source to energize the reactor. The stable streamer coronas can be generated and have fairly good denitrification and tar removal effects[4,,5]. Both pulsed corona and AC/DC streamer corona generation systems have almost the same chemical efficiencies. Research also confirms that AC/DC source has given a very good effect in flue gas desulfurization[6,7]. In this paper the AC/DC streamer characteristics are explored on the basis of the existing research, its denitrification effect is further verified, the chemical effects and the discharge properties are examined under the conditions of high-velocity gas flow.

2 EXPERIMENTAL SET-UP

Fig. 1 shows a schematic diagram of the test setup. A AC/DC source is composed of a DC and an high frequency AC sources via a coupling capacitor. In the experiments the DC voltage ranges from 0 to 50 kV, the frequency of AC is 10 kHz-35 kHz and its peak-peak voltage is 0-20 kV. Reactors are point-plate type, wire-plate type, and wire-cylinder types. The electrical parameters are measured with a Tektronix TDS3014 oscilloscope. A Vario Plus flue gas analyzer is used to analyze NO_x and other components in the simulation gas.



TRdc - transformer. TRac - transformer AC; D - High-voltage diode; C - Reactor capacitance; L - AC air-core inductor; C_0 - High-voltage coupling capacitor; L_1 - Resonant inductor; C_1 - Resonant capacitor.

Fig. 1 Schematic circuit diagram of the AC/DC power source

3 RESULTS AND DISCUSSIONS

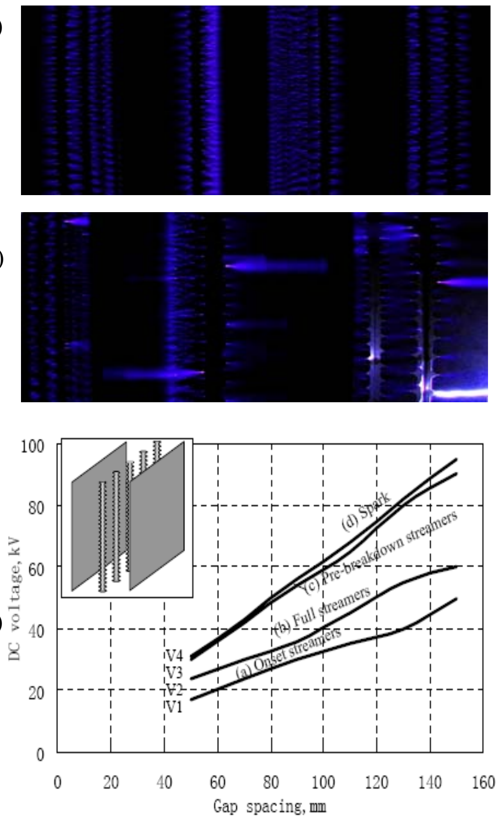
The corona modes refer to streamer, glow and sparkover discharges. The streamer can effectively initiate chemical reactions but the effects initiated by glow are insignificant. The aim to optimize the electrode configuration is to seek an electrode system for industrialization, which shows a wide votage range for streamer generation, high energy efficiency and good mechanical strength.

Fig. 2 shows experimental results of corona discharge for a multi-tip saw-tooth wire-plate electrode system with tips radius of 0.25 mm under the DC power supply. With increase of the DC voltage, the discharge occur as onset streamer, glow, pre-breakdown streamer and, finally, spark breakdown. Because of the difference of the tip size, the onset streamer usually appears at some tips when the applied voltage is lower. With increase of the applied voltage, streamer numbers and their intensity rise continuously. For a electrode gap of 80 mm, at 33 kV, over 95% of tips show streamer discharge. With a voltage of around 33 kV-48 kV, very uniform streamer discharge can be maintained with a well spatial distribution, as shown in Fig. 2(a). When the voltage becomes higher than 50 kV, streamers begin to cross the gap and the spark discharge may occur due to the pre-breakdown streamer, see in Fig. 2(b). Fig. 2(c) shows the threshold curves for the various modes under DC power source.

(a)

(b)

(c)



a) A discharge photo at 45 kV, b) A discharge photo 50 kV,
c) Threshold curves for various modes under DC power supply

Fig. 2 Various modes of positive corona discharge for a multi-channel saw-tooth wire-plate reactor with tips of 0.25 mm curvature radius

It is found that after superposing the AC, the streamer region is enlarged. According to Yan's work a source with the peak-to-peak AC voltage of greater than 1.0 kV and an rise rate of larger than 0.2 kV/μs can lead to change the glow to the streamer.[8]

Fig. 3 plots the relation of power density to the voltage under AC/DC for a reactor with 100 mm gap at normal temperature and pressure. Under DC condition, the peak-to-peak voltage of AC equals 0. In the plot, V_1 is the critical value from no discharge to the onset streamer. From V_1 to V_2 the scattered onset streamer gradually transform to uniform streamer. Within V_2-V_3 is the full streamer region. In the range of V_3-V_4 pre-break-down streamers occur and very easily turn to spark-over. It is hardly observe pure glow mode in multi-tip plate configuration under DC power supply. The most important advantage of using AC/DC energization lies in increase of uniformity streamer distribution. In addition with the same average voltage higher AC component gives higher power output.

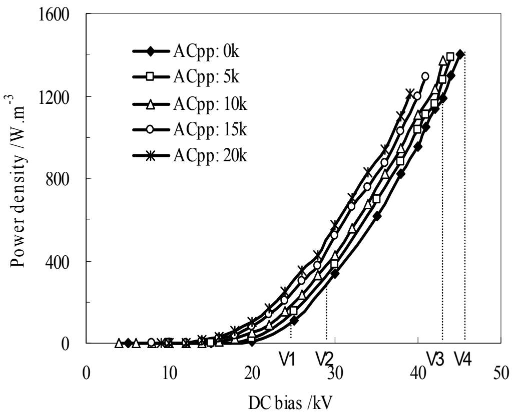


Fig. 3 AC/DC corona power via the voltage

Fig. 4 shows electric discharge characteristics of a wire-cylinder reactor. As the positive electrode a saw-tooth wire with a length of 800 mm is set coaxially. The cylinder has an inner diameter of 100 mm and is grounded. The gap from the saw-tooth to the inner surface of the cylinder is 40 mm. At 10 kV, an observable onset streamers emerge and within 18 kV-24 kV well-distributed streamer is generated steadily. Fig.5 is the picture of the streamer in a wire-cylinder reactor at 20 kV DC and 4 kV AC.

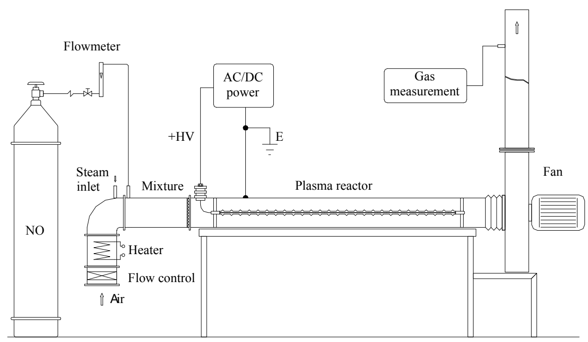


Fig. 4 Flowchart of streamer plasma reactor with a saw-tooth wire-cylinder electrode configuration

It is observed that the breakdown voltage depends on the gas velocity inside the reactor. Fig. 6 plots the discharge power via the gas flow speeds. Fig. 7 shows the maximum injected power at different gas flow speed. The maximum injected power at flow speed 52 m·s^{-1} is 5-6 times of that at zero speed. It can be found that with increase of the gas flow speed there are two different regions. Below the speed of 30 m·s^{-1} the tendency of increase of the power is relatively slow, but when the flow speed is higher than 30 m·s^{-1} the maximum injected power increases twice faster than that in the former region. It is obvious that the existence of this turning point seems due to the ionic flow initiated by the gas discharge leading to gas movement toward the reactor wall (so-called electric wind).

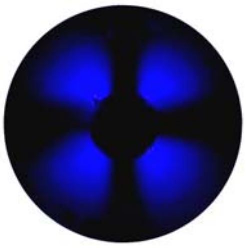


Fig. 5 A time integral picture of streamer discharge in a saw-tooth wire-cylinder reactor

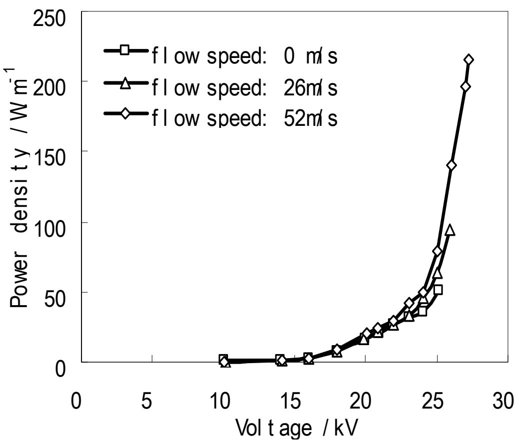


Fig. 6 Power density against the high-voltage

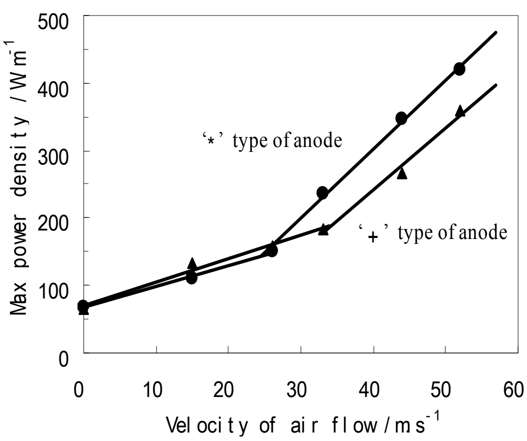


Fig. 7 Max power density viat the velocity of air flow

NO removal is performed with the experimental set-up shown as Fig. 4. Stimulated gas is composed of air, water vapor and NO. Flow rate of the air is adjusted with a valve. The air is firstly heated to a controlled temperature, mixed with other components and then be injected into the reactor. The concentration of NO of the gas is measured with a gas analyzer. Then the gas is discharged by fan.

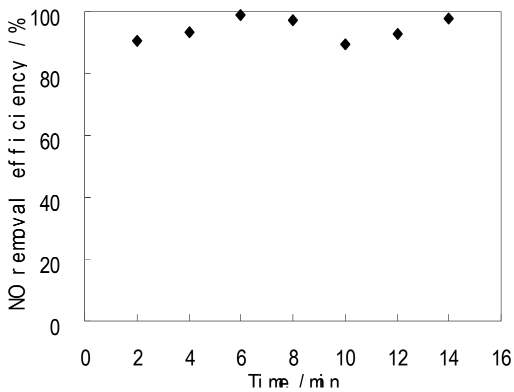


Fig. 8 Streamer plasma induced NO removal efficiency

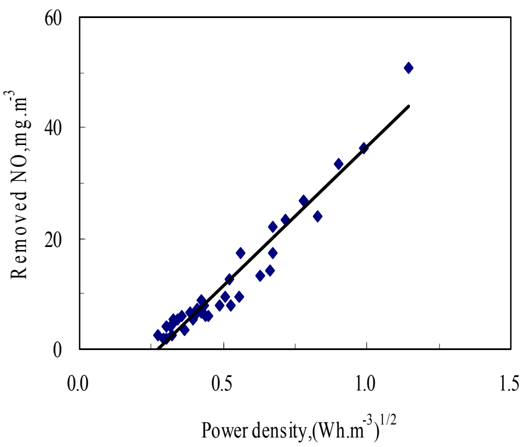


Fig. 9 Removed NO and the power density at room temperature

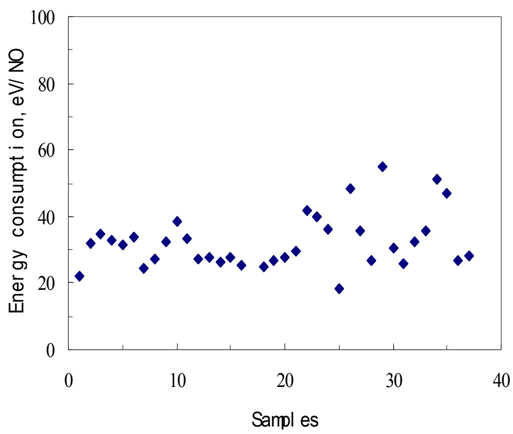


Fig. 10 NO removal energy consumption at room temperature

Fig. 8 shows the results of NO abatement in dry air at room temperature and low flow speed. The stimulated gas is composed of 20.9% oxygen, 270 mg·m^{-3}-400 mg·m^{-3} NO and nitrogen in balance. The average voltage on the reactor is 24 kV with AC 5.5 kV. The injected power per meter of the corona wire is 250 W·m^{-1}-300 W·m^{-1}. The residence time is 10 s. Although the abatement rate may reach over 90%, too long a residence time leads to energy consumption as high as 300 eV/NO -500 eV/NO.

Fig.9 and Fig.10 shows the electric gas discharge NO abatement effect in dry air at room temperature and different flow speeds. The stimulated gas is composed of 20.9% oxygen, 90-140 mg.m^{-3} NO and nitrogen in balance. The average voltage on the reactor is 18 kV-24 kV with AC 4 kV. The injected power per meter of the corona wire is 20 W·m^{-1}-150 W·m^{-1}. The gas flow speed in the reactor is in the range of 1 m·s^{-1}-25 m·s^{-1} with a residence time 0.04 s-0.50 s. We can see that the quantities of NO removal are directly proportional to the square root of the power density. The molecular energy consumption can be as low as 30 eV/NO.

4 CONCLUSIONS

(1) In a multi-tip plate electrode configuration, it is hardly to observe an apparent pure glow. Superposition of AC leads to enlarge the streamer region.

(2) AC/DC streamer discharge shows a very effective chemical reactions. In the test of denitrification the molecular energy consumption to oxidize one NO can be as low as 30 eV.

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