Optimization of discharge types and electrode structure in a cylinder discharge reactor with saw-wheel array electrodes

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Abstract. The application of corona discharge technology in gas purification and wastewater treatment has been received great attention in recent years. The configuration of discharge electrode and the discharge types directly affect the discharge power and the power density, and then affect the generation of active species as well as the removal efficiency of pollutants. A novel cylinder-type discharge reactor with saw-wheel-array electrodes was developed for removal of SO$_2$/NO$_x$ from flue gas, and influence factors such as electrode structure (ratio of spacing of saw-wheel slices and discharge distance, herein defined as R) and power supply types (positive DC, negative DC, and pulse power) on discharge characteristics and the output power was discussed. The experimental results show that the current and output power of three types of discharges firstly increased with R increasing from 0.3-1.7, and then tended to a stability from 1.7-2.5; while the power density reached a maximum at the ratio of 1.7.

1. Introduction
Non-thermal plasma technologies (NTP) including corona discharge, dielectric barrier discharge etc were widely used in electrostatic precipitators, electrostatic separation, modification of materials and other fields. In recent years, extensive attention has been paid to NTP for gas purification, soil purify and wastewater treatment [1-3].

The corona discharge types and electrode structure directly affect the generation of free radicals and active species and then affect the treatment efficiency of pollutants. Therefore, it is very important to study and optimise the discharge types and electrode structure. Many scholars [4-7] have investigated the optimal configuration of wire-plate and needle-plate reactor, but little has been reported to investigate optimal configuration of the wire-cylinder reactor about corona discharge especially the cylinder-type discharge reactor with saw-wheel-array electrodes.

In the present study, the effect of three kinds of discharge types such as positive DC, negative DC and positive pulse on discharge current, discharge power and power density are investigated using the cylinder-type discharge reactor with saw-wheel-array electrodes, and optimization of discharge types, and electrode configuration in a cylinder reactor with saw-wheel type array electrodes was determined by the discharge characteristics.

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2. Experimental

The corona discharge system was illustrated in figure 1. A stainless steel cylinder with the inner diameter of 56 mm and height of 800 mm was used as ground electrode, and a stainless steel rod, equidistantly linked with several saw-wheel slices, was used as the discharge electrode. The outer diameter of the saw-wheel slices was 14 mm and the thickness of each saw-wheel slice was 1 mm. The schematic of saw-wheel slice was illustrated in figure 2, the tooth number of every saw-wheel slice was 20. Discharge distance between tooth point of saw-wheel slice to cylinder inside was 14 mm.

The pulsed high-voltage supplied by spark gap type pulse power and the circuit principle was shown in figure 3. The voltage of positive and negative DC ranged from 0 kV- 60 kV. The voltage were measured with oscilloscope (Tektronix TDS2014) equipped with high voltage probe (Tektronix P6015A), the positive and negative DC current measured with DC microammeter, pulse discharge current measured with the current probe (Tektronix P6021). The pulse frequency and pulse-forming capacitance Cp were 50 Hz and 500 pF, respectively. The air flow rate was 0.5 m³ h⁻¹, relative humidity (RH) in air was 50%-60%. The power density was defined as:

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P = \frac{P}{Nl}
\]

Where \( P \) is discharge power (W), \( N \) is saw-wheel slice number, \( l \) is spacing of adjacent saw-wheel slices (mm).

1. Power supply; 2. High voltage probe; 3. The reactor; 4. High voltage electrode; 5. Gas pump.

**Figure 1.** Schematic diagram of the experimental set up.

**Figure 2.** Tooth stainless steel pieces.

**Figure 3.** The circuit principle of pulse power.

3. Result and discussion

3.1. Current-voltage characteristics of three discharge types

Different discharge phenomenon were produced by the different discharge types, the experimental results were shown in figure 4, 15 discharge saw-wheel slices linked at a spacing of 15 mm were used in the experiment. In fact, the images of positive pulse, positive DC and negative DC discharges (figure 4) showed brilliant streamer corona across the entire inter-electrode space with the same voltage (13 kV). In addition, the glow corona can be observed only in the vicinity of discharge tooth.
time for negative DC discharge with the same applied voltage. The voltage-current waveforms of the corona discharge for positive DC, negative DC and positive pulse were show in figure 5, figure 6 and figure 7, respectively.

As showed in figures 5-7, the discharge current increased with the applied voltage, but it firstly increased slowly, and then increased dramatically. When the spacing between saw-wheel slices increased from 5 mm to 35 mm, the breakdown voltage decreased. Moreover, at the same voltage, with the increase of tooth slices spacing from 5 mm to 35 mm, the discharge current firstly increased gradually, and then tended stability (figure 5 and figure 6) or even decreased (figure 7). The phenomenon indicated that with the increase of the spacing between saw-wheel slices, the inhibitory effect between tooth slices gradually declined, and the instability of electric field rose, thus, the discharge current increased. Compared with the positive and negative DC discharges, the discharge current of negative DC was larger than that of positive DC under the condition of the same applied voltage, with lower initial voltage, higher break-up voltage, and larger glow discharge area.

Figure 4. The images of three types of discharge with the same voltage (13 kV).

Figure 5. V-I waveforms of positive DC.

Figure 6. V-I waveforms of negative DC.

Figure 7. V-I waveforms of positive pulse discharge.

3.2. The influence of saw-wheel slice spacing on the output power and power density

In order to investigate the influence of saw-wheel slice spacing on output power and power density of three discharge types, 15 saw-wheel slices linked at spacing of 5, 10, and 20 mm were used. A high voltage of 11.5 kV was used in this study, and the pulse frequency and pulse-forming capacitance $C_p$ were 50 Hz and 500 pF, respectively. The effects of saw-wheel slice spacing on the output power and power density were showed in figure 8 and figure 9, respectively.
As showed in figure 8, at the same voltage of 11.5 kV, the discharge output power of three discharge types increased with the saw-wheel slice spacing, and it was more remarkable with the spacing increasing from 5 to 25 mm, correspondingly, the ratio (r) of saw-wheel slices spacing and discharge distance changed from 0.3 to 1.7. Then it tended stability when the saw-wheel slice spacing increased from 25 to 35 mm, with the ratio (r) range from 1.7 to 2.5. When the saw-wheel slice spacing was less than 25 mm, the electric field between saw-wheel slices could be inhibited, and it was also reported that too many discharge points might lead to corona shield phenomenon. When the spacing was larger than 25 mm, the shield phenomenon did not occur in this study. Additionally, it was found that discharge output power of positive and negative DC was significantly larger than that of positive pulse discharge.

As showed in figure 9, the power density firstly increased with the saw-wheel slice spacing increased from 5 -25 mm, and then it decreased with the further increase of the saw-wheel slice spacing. Therefore, the power density of three types of discharge reached a maximum at the distance of 25 mm, and the corresponding ratio of the saw-wheel slice spacing and discharge distance was 1.7.

Furthermore, as could be seen in figure 8 and figure 9, the change of the saw-wheel slice spacing had the most remarkable impact on the positive DC discharge, and followed by pulse discharge, and the weakest occurred in negative DC discharge. For positive DC discharge, low mobility of free electrons from the head of electron avalanche generated a larger high electric area, but for negative DC discharge, electron avalanche only produced a small area near the tooth point of the saw-wheel slice, however, the high electric area of positive pulse discharge (as a special form of corona discharge) was bigger than that of negative DC discharge, but it was smaller than that of positive DC discharge.

4. Conclusions

1) The current and output power of three types of discharges increased with the ratio (r) of saw-wheel slices spacing and discharge distance increasing from 0.3 to 1.7, then reached stability or even decreased when the ratio (r) changed from 1.7 to 2.5. The initial voltage increased but the breakdown voltage decreased with an increase in the spacing (l) between the neighbouring saw-wheel slices. In addition, the change of l had the greatest impact on the positive DC discharge, and had the least impact on the negative DC discharge.

2) The power density firstly increased with l and then decreased, and the optimum power density was obtained at the ratio (r) of saw-wheel slices spacing and discharge distance of 1.7, and it did not affect by the discharge types.
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