Non-thermal plasma reactor with back corona discharge electrode

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Abstract. The new design of plasma reactor with back discharge electrode is presented and characterized. The laboratory scale plasma reactor was constructed in a plane parallel geometry with a gas permeable low-field electrode system. The low-field electrode was covered with a dielectric layer enabling the appearance of back corona discharges. The total volume of the reactor is equal to 2 dm³. The discharge properties of the reactor operating at dc voltage in air under normal conditions are given. The results of optimizing the electrical properties are also presented. The influence of back discharges on the discharge current is discussed. The maximum discharge current density obtained during the experiment was equal to about 25 μA/cm².

1. Introduction
Nowadays plasma technology is widely and successfully used in many technological applications such as plasma surface treatment, environmental plasma chemical technologies, reactive magnetron sputtering and more [1]. In general, a plasma is an ionized gas (excited electrically, thermally or from electromagnetic irradiation) containing electrons, ions, radicals and atoms. It is possible to distinguish two types of plasma: thermal and non-thermal ones with completely different features. The energetic level of the particular particles is crucial in this division. Mainly electrical discharges in gases (e.g. corona discharge, dielectric barrier discharge, high frequency discharge) and electron beam irradiation are used for generating a low temperature plasma [2]. The most common and still developed non-thermal plasma (NTP) applications are gaseous pollutant removal, water purification, film deposition and surface modification. Decomposition of volatile organic compounds (VOCs) is realized using plasma reactors. So far there were proposed many types of plasma reactors with different discharges generating the plasma (e.g. with corona discharges, dielectric barrier). There is also possibility of increasing the discharge current and, finally, charged particles in the discharge region by utilising the back corona discharge phenomenon.

2. Back corona discharge phenomenon
The phenomenon of back corona discharge was observed for the first time in electrostatic precipitators [3] as a damaging one, causing serious decrease of their collecting efficiency. The electric charge during the corona discharge accumulated on the dielectric layer covering the counter electrode. As a result the electric field across the dielectric layer was intensified. When the accumulated charge exceeded a critical value, breakdown through the dielectric layer appeared from the counter electrode.
as a back discharge. Charge of opposite polarity was then injected into the inter-electrode region. The phenomenon occurred for layers exhibiting volume resistivity $\rho_V$ higher than $5 \times 10^8 \Omega \text{m}$ [4].

Much research was undertaken to describe and understand the back corona discharge phenomenon. Initial investigations described ways of preventing the negative effect in the electrostatic precipitators. Subsequent scientific attempts were focused on applications using this phenomenon such as decomposition of hydrocarbon gaseous contaminants and ozone production [5]. In this paper a new design of plasma reactor utilising the back corona discharge phenomenon is presented. This reactor is intended to be used for VOCs decomposition from air streams.

3. Reactor and measurement system

The cross-section of the laboratory type reactor is shown in figure 1. The reactor was constructed in a plane parallel geometry. The reactor housing consisted of transparent dielectric side walls (1) tightened by clamping screws (2).

![Figure 1. Scheme of the plasma reactor with gas permeable low field electrode and plane parallel geometry.](image)

The earthed low-field electrodes (3) were made of perforated metal sheet (perforated stainless steel with pores diameter $\Omega = 0.5 \text{ mm}$, distance between particular pores equal to $1.09 \text{ mm}$) covered with dielectric layer (4). Perforation of the electrodes should enable the processed gas to flow in parallel to the vector of the electrical field in the discharge region. The reactor was also equipped with inlet (6) and outlet (7) pneumatic connectors.

A ceramic glaze was used as the dielectric layer. Permittivity, volume resistivity and thickness of the applied layer were $\varepsilon=6.8$, $\rho_V=7 \times 10^{12} \Omega \text{m}$ and $d=30 \mu\text{m}$ respectively Metal strings (Cu-Ni alloy wires $\Omega = 0.3 \text{ mm}$) mounted in parallel, operated as the corona electrode (5). The total volume of the reactor was equal to $2 \text{ dm}^3$.

The reactor discharge system was supplied from two stabilized dc high voltage power supplies – Glassman PS/EW40P150YQ2 and PS/EW40N150YQ1 types, regulated in the range of 0 to $\pm 20 \text{ kV}$. The discharge current was measured by an analogue dc current meter WUT PA 100.

4. Results and discussion

All of the measurements were carried out with the reactor filled with the air under atmospheric pressure and at room temperature. The current-voltage (I-V) characteristics for dc corona discharge (low field electrode without dielectric layer) and back corona discharges (low field electrode covered by dielectric layer) are presented in figure 2.
Discharge currents obtained for back corona discharges were much higher (even up to 10 times) in comparison to the case with corona discharges only. A similar effect of the back corona was observed for opposite polarity of applied voltage. The influence of polarity of applied voltage on the back discharge current was also shown in figure 2. The results were obtained for a fixed distance between wires and low field electrode $a$, distance between adjacent strings $b$ and number of strings $n$.

**Figure 2.** Dependence of discharge current on the type of discharges in the reactor (corona discharges or back discharges for negative polarity, $a=25$ mm, $b=25$ mm, $n=5$) and polarity of applied voltage to corona electrodes ($a=20$ mm, $b=40$ mm, $n=3$).

It was noticed, that the onset (inception) voltage was lower for negative polarity of applied voltage to the strings. On the other hand, the critical value of discharge current was obtained more rapidly for positive voltage ($I-V$ characteristics were shifted in relation to each other). The maximum discharge current densities for both polarities were equal to about $26 \mu$A/cm$^2$. The discharge was very unstable and following increase of voltage led to streamer discharges. The results of the optimization of the electrical properties are shown in figure 3. During this experiment parameters $a$, $b$, $n$ describing the configuration of the electrode system were changed to obtain optimal discharge properties.

**Figure 3.** Dependence of discharge current on configuration of corona strings in the plasma reactor. Results obtained for negative polarity of applied voltage to corona strings.

It was found that the distance between the corona electrodes and the low field electrode $a$ strongly influenced the discharge current. There was a visible shift between the obtained $I-V$ characteristics.
The same value of discharge current was obtained (e.g. 10 mA) for a lower value of applied voltage when the distance \( a \) decreased. It was also noticed that electrical properties were not dependent on the number of corona strings \( n \). The number of used corona strings may be important for expanding the extent of the back discharge occurring on the low field electrode. The distribution of back corona (on the low field electrode) and corona discharges (from strings) in the reactor is shown in figure 4.

![10 mm](image)

**Figure. 4.** Corona and back corona discharges observed in the plasma reactor in air in normal conditions for \( a=15 \) mm, \( b=15 \) mm and \( n=9 \). Average current density ca 15 \( \mu \)A/cm\(^2\). The bright points on the corona electrodes were local discharges for negative polarization voltage.

5. **Conclusions**

Back corona development on the perforated dielectric layer was experimentally confirmed for both polarities of the voltage applied to the corona electrode. The back discharge phenomenon led to reach discharge current density even 10-times higher than the current density measured in the plasma reactor with corona discharges only – figure 4.

The critical value of discharge current density leading to streamer discharge was equal to 26 \( \mu \)A/cm\(^2\). Applying positive voltage to the corona electrode led to a more rapid increase of discharge current and lower onset voltage (see figure 2). This is consistent with theory of electrical breakdown in gases. The maximum density power dissipated in the reactor was about 280 W/dm\(^3\).

The configuration of the electrode system also influenced the discharge properties of the reactor – figure 3.

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