Plasma reactor with back ionisation

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Abstract. Cold plasma reactor construction and its discharge properties is described in the paper. The laboratory scale plasma reactor is constructed in cylindrical geometry with the corona electrode in the form of a set of parallel strings placed symmetrically around the inner tube electrode. The inner electrode is covered by the perforated dielectric layer enabling development of the back corona discharges. Application of the back corona phenomenon allows reaching much higher efficiency of the reactor. The total volume of the reactor is equal 240 cm\textsuperscript{3}. Applicability of the reactor for the decomposition of Volatile Organic Compounds is tested on the example of toluene vapours in the air. Results of spectroscopic measurements (mass spectrometer QMS 200) point out that the conversion efficiency is strongly dependent on the electrode polarisation conditions. For the hydrocarbon concentration on the level of 300 ppm and for the current densities of the order of 10-15 µA/cm\textsuperscript{2} the decomposition efficiency can be as high as 99% for the gas flow level equal ca 5 l/h.

1. Introduction

The removal and destruction of toxic volatile organic compounds (VOCs) from air streams is important for safety as well as environmental reasons. Current decomposition methods include many different processes. Non-thermal plasma (NTP) is a very effective technique to decompose various kinds of dilute concentrations of gaseous pollutants in large-volume atmospheric pressure air streams [1,2]. There was proposed many types of cold plasma reactors exhibiting different electrical and flow properties [3]. Reactors with high discharge intensity and concentration of high energy electrons exhibit relatively high pressure drop between their inlets and outlets. Reactors using corona discharges in non-symmetric electrode systems usually produce cold plasma with relatively low density of electrons and ions. One of possibilities to increase discharge current and simultaneously density of charged molecules in the discharge region offers back discharge phenomenon.

2. Back discharge phenomenon

The phenomenon called as a “back discharge” or “back corona” was observed for the first time on high resistivity powder layers in electrostatic precipitators [4]. The discharges have led to a serious precipitator discharge current increase as well as to visible decrease in its collecting efficiency. Applying dielectric perforated layer deposited on the low-field electrode of the corona discharge system should lead to an increase in the discharge current of the electrode system. The phenomenon
was observed on layers exhibiting volume resistivity higher then \( \rho_V > 5 \times 10^8 \Omega \text{m} \). The stated hypothesis was checked experimentally on the example of a tubular reactor using low-field electrode covered with perforated dielectric layer. The glass fabric was applied as the perforated dielectric layer.

### 3. Reactor

The general view of the laboratory type reactor operating under atmospheric pressure was shown in the figure 1. A 300 mm long quartz tube (1) creates the main body of the reactor. Internal diameter of the tube was 36 mm. Inside the tube a low field electrode (2) made of stainless steel tube (14 mm in diameter) was mounted. The inner, low-field electrode was covered with a quartz glass fabric. Four strings (Cu-Ni alloy, 0.5 mm in diameter) corona electrodes (3) were mounted symmetrically around the inner electrode inside the reactor in a distance of 1 mm from the tube wall. All the strings (corona electrodes) were supported by metallic spacers (4). Both ends of the reactor were covered with non-conducting cups (5) with built-in inlet and outlet connections of the reactor.

![Figure 1. General view of the concentric cold plasma reactor. The inner electrode 1 – quartz tube- housing, 2 – inner electrode covered with a glass fabric, 3 - corona strings, 4 – corona electrode-housing spacer, 5 - covering cups equipped with an inlet and outlet.](image)

The experimental apparatus was composed of three units, including a standard VOCs gas generation unit (aeration cylinders), a plasma reactor and a gas analysis unit. The toluene and intermediates in reaction were analysed by in-situ method using mass-spectrometer (MS) (Omnistar QMS-200 Balzers). The experiments were carried out at room temperature of around 25 °C. Initial concentration of toluene in air was set at the level of 300 ppm and the operating flow rate was kept constant and equal 100 ml/min. The conversion \( C(\%) \) of toluene was calculated as follows:

\[
C = \frac{C_0 - C_i}{C_0} \times 100\%
\]

where \( C_0 \) is the inlet concentration, and \( C_i \) the outlet concentration at steady state.

### 4. Results and discussion

The current-voltage characteristics of the reactor for the low-field electrode smooth and covered with dielectric layer were shown in the figure 2. Discharge currents observed for the case with the covered inner electrode were much higher (2 to 5 times) in comparison to that observed for the smooth inner electrode - without covering. Increase in the current density leads to visible discharges in gas...
Figure 2. Discharge current-voltage characteristic for the reactor shown in the figure 1 obtained for low field electrode non-covered and covered with a glass fabric. Corona electrodes polarized with positive voltage.

channels existing in the fabric covering. Photography illustrating back discharges on the low-field electrode when covered with glass layer was shown in the figure 3. Both of the mentioned phenomena totally confirm appearance of the back discharges.

Decomposition and oxidation of toluene vapors in air, carried out with application of the reactor, was illustrated in the figure 4. Differences in the values of the Mass Spectrometer ionic current obtained for different supply conditions describe influence of the discharge intensity on the toluene decomposition efficiency. The DC discharges started to decompose toluene at about 5.5 kV with conversion factor of the order of 90% reaching decomposition level of near 100% for 9-12 kV with no benzene as a by-product. Decreasing in the toluene concentration was accompanied by increase in CO$_2$ concentration. It was also found, that application of the positive polarization of string electrodes lead

Figure 3. Corona (white points on strings) and back corona (blue glow) discharges observed for covering of the inner electrode with the perforated dielectric layer (glass fabric). String electrodes polarised with voltage (-)12 kV, current density ca 13.3 µA/cm$^2$. String - inner electrode distance - 8 mm, four strings placed symmetrically. Discharges were observed in the air, in ambient conditions.
Figure 4. Time dependence of toluene and CO$_2$ concentration (results of toluene oxidation) at the outlet of plasma reactor during toluene decomposition in air for different electrode polarization voltages of corona electrode. Negative polarization of string electrodes.

to more efficient decomposition of toluene in air. It was also found, that the toluene conversion factor decreased with an increase of toluene concentration at the reactor inlet.

Conclusions
Application of the back corona phenomenon allows reaching much higher current densities and finally the higher efficiency of the toluene conversion as compared with typical DC streamer corona plasma reactor [5]. Modifying the plasma operation conditions allow to tailor the plasma chemical reactivity in such away as to enhance the desired remediation of given pollutant, while at the same time minimizing the formation of unwanted by-products like benzene. Application of positive polarization of corona (string) electrodes led to more efficient toluene decomposition in air. By a half (approximately) lower input power (ca. 5 W) was required to obtain 99% toluene decomposition factor in comparison with negative polarization.

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