PLASMA SOURCES, PLASMA REACTORS

ODORS CONTROL WITH NON-THERMAL PLASMA REACTOR

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1. Introduction

Recent public concern about air pollution from production units has prompted more research to develop methods to reduce and control odors. Masking chemicals, oxidation processes, air scrubbers, biofilters and ventilation systems have been studied. Many new techniques for gaseous pollutants removal have been developed recently. In general, there are several industrial applications used to clean gaseous streams containing VOCs. The most common are activated carbon filters[1], photocatalytic oxidation[2] and non-thermal plasma systems[3]. Nowadays the third way is very promising because of the economic reasons and low power consumption. Non-thermal plasma processes have been investigated a lot during the past decade by many researchers for volatile organic compounds (VOCs) control in air. Many different types of low-temperature reactors have been developed[4]. In all reactors plasma is generated and maintained by electrical discharge.

In this research, the prototype non-thermal plasma reactor was proposed and its efficiency in removal of odors was calculated. The back corona discharge phenomenon was used for promoting the rise of the density of plasma in the reactor.

2. Non-thermal plasma reactors

In general, plasma reactors are devices which generate plasma. Typically plasma is an ionized gas and could be divided into two categories: thermal and non-thermal. In the thermal plasma all the particles (electrons, positive ions, neutral atoms) are in thermodynamic equilibrium, whereas in low-temperature plasma, there is a significant difference in kinetic energy i.e. temperature of electrons and ambient gas particles. Electrons with very high self-energy (1–10 eV) collide and interact with molecules of pollutant. It leads to the cleavage of bonds. There are two major methods of the cold plasma generation: the electron accelerators and plasma reactors.

Non-thermal plasma reactors usually are built as a planar or cylindrical construction employing high voltage discharge electrodes system (needles, wires). The most common types of cold plasma reactors are: corona discharge reactor, dielectric barrier discharge (DBD) reactor and packed-bed discharge reactor. The power supply, plasma density and pressure drop of the gas passing through the reactors are completely different in these reactors. Corona discharge reactor is characterized by low discharge intensity what is not desirable from the point of view of pollutant removal. The goal is to get the plasma density as high as possible. The key to enhance the plasma density is in using the back corona discharge phenomenon.

3. Back corona discharge mechanism

The back corona discharge is a special type of the partial discharge. In the electrostatic precipitators being used in industry for removal of solid phase particles from gases this phenomenon was observed[5]. The dust particles were charged electrically and then gathered on the collecting electrodes by electrostatic forces (Coulomb forces). In case of dust particles with volume resistivity above $\rho_v \geq 5 \cdot 10^8$ Ωm the back corona discharge was generated. The schematic diagram depicting the stages in the process of back ionization is shown in Fig. 1.

The mechanism proceeds as follows. At first dielectric layer on the grounded electrode is charged by the corona electrode. If the electric field in the dielectric layer exceeds the critical value the back corona occurs in the channels of the layer. As the result, the great amount of charge of opposite polarity to corona electrode is injected to the space between

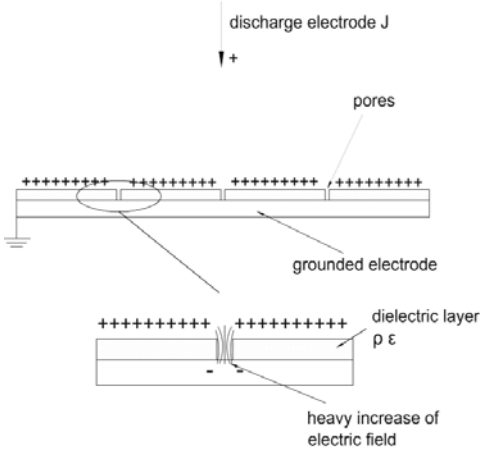

Fig. 1. **Schematic diagram of back corona discharge phenomenon**

the electrodes and the discharge current significantly increase[6]. For the electrostatic precipitator it is a very undesirable effect because its collection efficiency lessens. However this effect is desirable in plasma reactors.

Using perforated dielectric layer with proper volume resistivity on the grounded electrode it is possible to obtain the low-temperature plasma with the proper intensity under the atmospheric pressure. The plasma channels are distributed at a uniform rate in the dielectric layer and the glow is observed.

4. The laboratory-scale plasma reactors

The laboratory-scale plasma reactors were designed and executed. The frontal views of the constructed reactors are shown in Fig. 2. The two different designs were suggested, one with planar electrodes and the other with cylindrical electrodes system.

The main difference in reactors was the realization of low-field electrode. The reactors shown in the Fig. 2a, 2b had a polystyrene as a dielectric layer on the grounded electrodes and discharge electrodes were made of copper wire, Ø 0.35 mm. The volume resistivity of this aromatic polymer (about 10^{12} Ωm) allowed the back ionization. The phenomenon occurred in pores of polystyrene layer. The reactor shown in the Figure 2c was equipped with the low field metallic electrode covered with a high quartz glass fabric (volume resistivity about 10^{10} Ωm) as the dielectric. Furthermore corona electrodes were made of Cu-Ni alloy wire, Ø 0.30 mm.

The construction of this particular non-thermal plasma reactor allow the gas to cross the plasma chamber perpendicularly to the electric field direction. Also all the reactors were featured by a low drop of pressure between their inlets and outlets. The volumes of the reactors equaled to 2500 cm^3 (Fig. 2a), 900 cm^3 (Fig. 2b) and 1500 cm^3 (Fig. 2c).

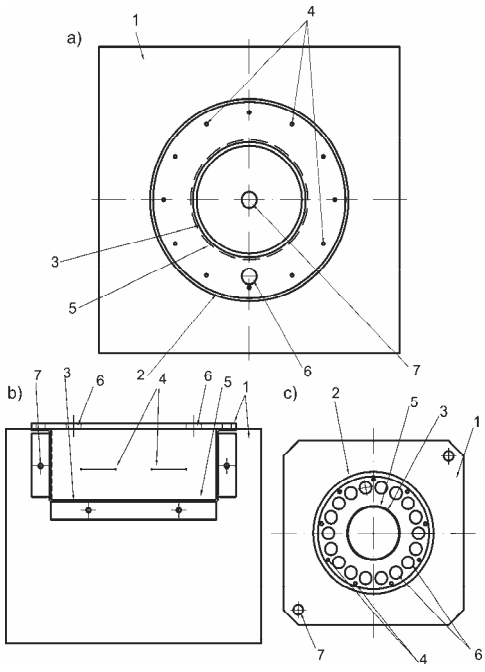

Fig. 2. **The scheme of the non-thermal plasma reactors with cylindrical (a, c) and planar (b) electrodes system:** 1 – dielectric walls made of plexiglass, 2 – cylindrical housing made of epoxy resin with glass fibre (Figure 2a) or of glass (Figure 2c), 3 – metallic grounded electrode, 4 – corona discharge electrodes, 5 – perforated dielectric layer, 6 – gas inlet (outlet), 7 – holes for screws

5. Electrical measurements

The corona discharge electrodes were connected with dc high voltage power supply. During measurements the voltage was risen up to 20 kV. The current – voltage characteristics of the reactors with the back corona discharges occurring in the pores of the dielectric layer are shown in Fig. 3. The power consumption in the reactors as a function of the applied negative dc voltage are presented in Fig. 4.

It was estimated, that reactor with a glass fabric covered grounded electrode generated the highest discharge current

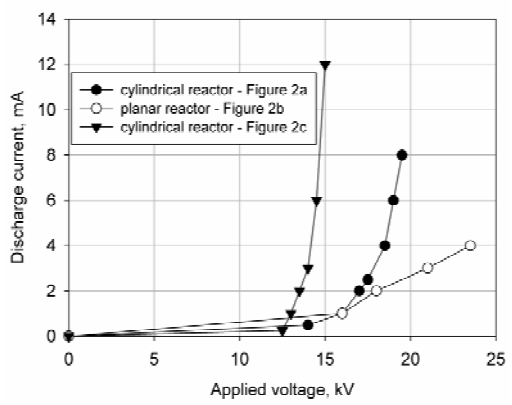

Fig. 3. **Current – voltage characteristics of plasma reactors shown in Fig. 2, under the atmospheric pressure and at room temperature for negative polarization of discharge electrodes**

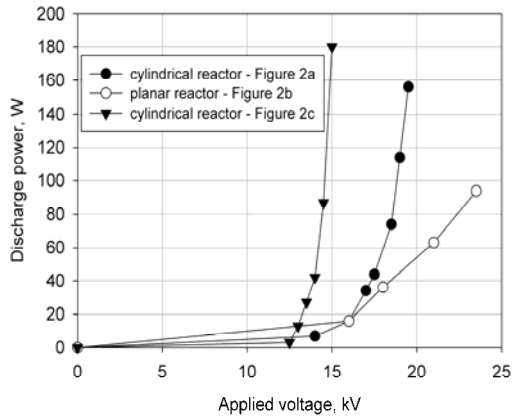

Fig. 4. **Discharge power as a function of the applied negative dc voltage**

12 mA, with density of 24 μA cm^{-2}. In other reactors with polystyrene as dielectric layer these values were much lower. For planar reactor they were 4 mA and 11 μA cm^{-2} respectively, while for the last cylindrical reactor they were 8 mA, 10 μA cm^{-2}. It was estimated, that non-thermal systems used in this experimental were low power-consuming. In any case the discharge power did not exceed 200 W and was on the level of 180 W in the case of reactor in Fig. 2c, 160 W for the reactor in Fig. 2a and 100 W for the reactor in Fig. 2b. The influence of the temperature on corona discharge process was noticeable. The plasma reactor was heated up.

On the basis of the above mentioned results the cylindrical reactor equipped with glass fabric as perforated dielectric layer was selected to the further investigations.

6. Odors removal in the plasma reactor

A schematic diagram of laboratory apparatus for the investigations of gaseous pollutants removal by plasma reactor with back discharges is shown in Fig. 5. The apparatus composes of plasma reactor, odors generator and gas analyzer. The quantitative analysis of gaseous samples was carried out using vapor-phase chromatography (HP 5890II Hewlett Packard) and odors conversion rate was analyzed using mass spectrometer (HP 5973).

The investigations were carried out as follows. Odors in liquid or gaseous phase where injected into the odors generator where they were warmed and mixed to obtain a uniform compound. Then the compound was pumped to the flow regulator. The second flow regulator was coupled with the air compressor. This apparatus allowed to adjust the operating flow during the experiments from 29 to 214 l h^{-1}. The concentration of odors in air was controlled over the wide (1.3–104 ppm) range. The odors from the mixer flowed through the plasma reactor which was supplied with sufficiently high voltage to get the back discharges but to avoid sparks between the electrodes.

The experiments were realized at room temperature and under atmospheric pressure. The negative polarity was set at corona electrodes during the experiments, as this application led to the higher rate of VOC's decomposition. It was proved in the previous paper[7].

Alcohols, ketones, alkenes, cycloalkenes, aromatic hydrocarbons and their mixture were used as odorous compounds. The energetic electrons in the non-thermal plasma reactor with back ionization produced free radicals which let the removal process take place. Dependencies of the compounds decomposition on the power input and current discharge are shown in the Fig. 6, 7. The gas mixtures with cyclopentene, pentene and cyclohexane content equal to 1.3 ppm and the flow rate equal to 214 l h^{-1} were subjected to the action of plasma. It was estimated, that the increase of the discharge current and power input led to the higher efficiency in odors decomposition. The maximum removal rate was 90 % as above some saturation due to electrical properties of the plasma reactor and flow properties took place.

The influence of the flow rate and the initial odors concentration on their conversion efficiency was also checked and verified. The flow rates were adjusted at 180 l h^{-1} for the mixture acetone – toluene (Fig. 8), 120 l h^{-1} for the ethyl ether – acetone – benzene – toluene mixture (Fig. 9) and at 29 l h^{-1} for the mixture ethyl ether – benzene (Fig. 10). In all the cases the corona electrodes were supplied with the constant dc voltage value of 12 kV (negative polarity). The conversion rate of the odors depended strongly on their concentration in air stream and its flow rate. The influence of the flow rate and odors content on the decomposition rate was following. For the mixture of gaseous compounds flowing at a rate of 180 l h^{-1} containing 1 ppm of toluene and acetone their removal ratios were at 75 % and 63 %, whereas for 7.5 ppm these ratios were at 34 % and 17 % respectively. In the case of toluene and acetone mixture (3 ppm) at the flow rate of 180 l h^{-1}, the removal efficiency was 38 % and 25 % for toluene and acetone respectively (Fig. 8). When ethyl ether, acetone, benzene and toluene were mixed so as the concentrations of the particular component at the flow rate of 120 l h^{-1} and the rate of toluene removal was 40 % and acetone 5 % (Fig. 9). Therefore it was

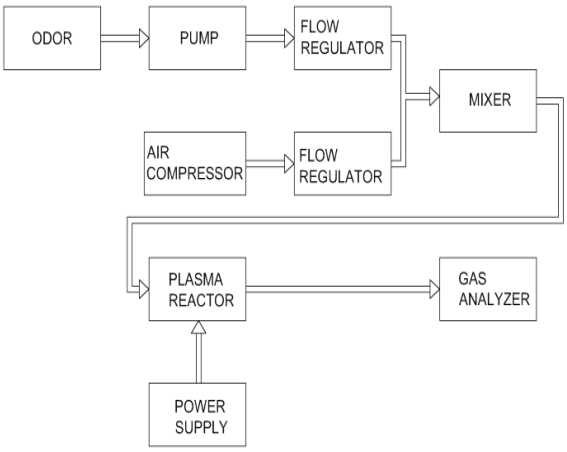

Fig. 5. **Schematic diagram of apparatus for odors removal using the non-thermal plasma reactor**

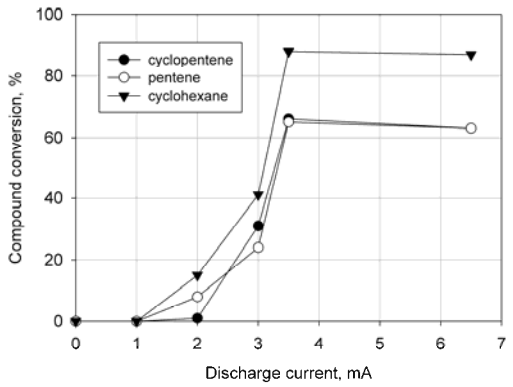

Fig. 6. **Conversion efficiency as a function of discharge current in the plasma reactor for compounds content equal to 1.3 ppm and flow rate equal to 214 l h^{-1}**

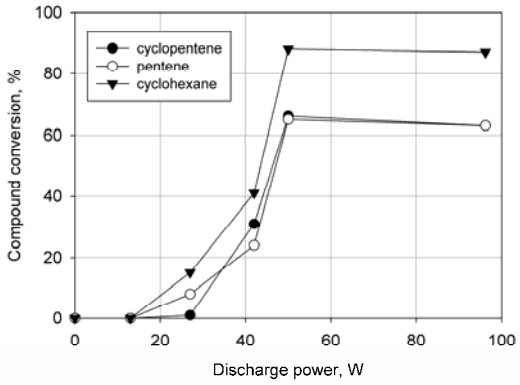

Fig. 7. **Conversion efficiency as a function of power input in the plasma reactor for compounds content equal to 1.3 ppm and flow rate equal to 214 l h^{-1}**

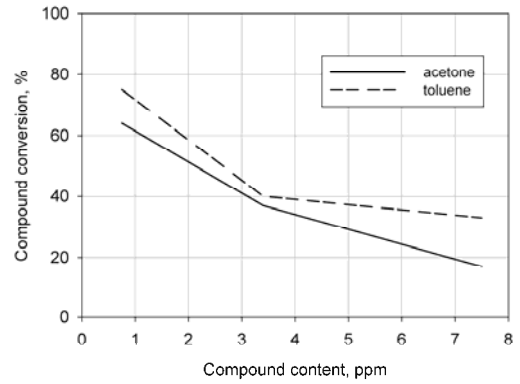

Fig. 9. **Dependence of the removal ratio of ethyl ether, acetone, benzene, toluene on their initial concentration for flow rate equal to 120 l h^{-1}**

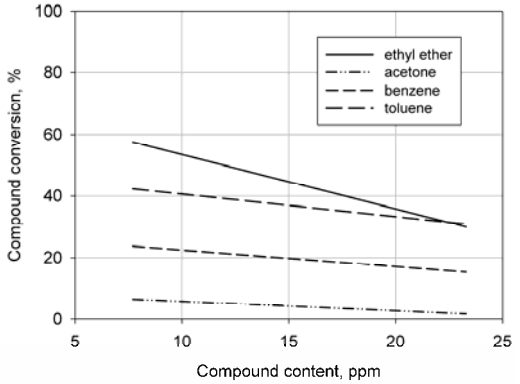

Fig. 8. **Dependence of the conversion ratio of acetone and toluene on their initial content for flow rate equal to 180 l h^{-1}**

concluded, that the process of odors conversion depend also on the type of the mixture. For flow rate of 29 l h^{-1} it was found out, that the plasma control was very sensitive on the component content in the mixture. The conversion rate of

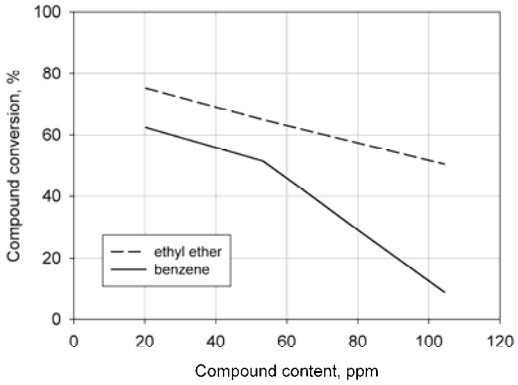

Fig. 10. **Dependence of the conversion ratio of ethyl ether and benzene on their initial content for flow rate equal to 29 l h^{-1}**

ethyl ether changed from 75 % to 50 % while the conversion rate of benzene was 62 % and 8.9 % (Fig. 10) while their concentrations in mixture increase from 20 to 100 ppm.

7. Conclusions

Non-thermal plasma reactor described in this paper is an alternate proposition to be applied for air odors control under atmospheric pressure. The back discharge phenomenon was used for promoting the rise of the density of the excited species.

The power consumption in conversion process was at low level. This was an important advantage from the view point of the energy savings.

The reactor applicability to odors control was proven. The significant dependence of the decomposition efficiency on the flow rate of air containing odors and on their content in gas mixture was estimated. The rate of the particular compound removal was varied. To rise the conversion efficiency of the gaseous compounds the reactor electrical properties have to be modified.

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