Volatile Organic Compounds depletion by Surface Dielectric Barrier Discharge

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Introduction   Air pollution can be harmful to both the environment and the human health. As a result of a systematic application of strict regulations, the emissions of atmospheric pollutants have been reduced significantly, especially in heavily industrialized countries, during the last decades. Despite these efforts, the concentrations of pollutants within large urban zones remain too high. A large and important group of pollutants such as volatile organic compounds (VOCs) are produced in the environment and diffusing out into the atmosphere and further improvement in the atmospheric air quality is still an issue requiring specific studies.

Several methods have been proposed for VOCs depletion, including Non-Thermal Plasmas (NTP) [1]. In a NTP, chemical reactions among charged species and radicals are produced in steady-state conditions [2, 3]. These processes are highly non-selective, creating a chemical reactive environment able to treat materials, as well as gases, at room temperature [4, 5]. A number of experiments have shown that, at room temperature, NTP are very effective for the treatment of material surfaces by employing different gas precursors, due to their ability to highly dissociate molecules in the gas phase, producing very reactive chemical groups [6]. As a result, the material surface is not damaged but it can be easily functionalized [7]. If NTP are generated at atmospheric pressure, the resulting plasma produces chemical species which are able to dissociate also VOC molecules [8]. Despite the success of NTP in VOC dissociation, the efficiency is not optimized and further research (including chemical simulations) is required in order to understand the underlying phenomenology of dissociation.

Surface DBDs (SDBD) constitute an alternative technique in which a discharge is performed on the surface of the dielectric layer, where also one of the electrodes is located [1]. The absence of a fixed discharge gap allows to work at even lower potentials and energies, increasing the efficiency, as well as to treat larger amounts of VOC in comparison with conventional DBD.

In this work, we aim at studying the kinetics of intermediate products induced by an SDBD during the abatement of pentane. To this end, an SDBD reactor, which admits different ge-

ometrical configurations, is employed for the decomposition of pentane by varying both the discharge energy and the gas concentration. The efficiency of the process is evaluated as a function of energy, especially regarding the intermediate reaction products. In this way, we can draw conclusions about the effects of the catalyst on the resulting abatement process.

Equipment setup   For this experiment we used a Surface Dielectric Barrier Discharge (SDBD) with two electrodes made by deposed copper (35 μm thick, 4 cm wide, and 12 cm long) placed on the two opposide side of a vetronite sheet (1.5 mm thick). The electrodes are laterally shifted from each other by about 0.5 cm. The lower electrode was fed at a high voltage (HV) and was covered with an insulating material, whereas the upper one was fed to the ground and was exposed to air. The sketch is in Fig. 1a, while a photo is in Fig. 1b. We placed the SDBD in a closed box that, thanks to a proper flow meter system could be filled by a decided amount of Volatile Organic Compounds (VOC).

As a VOC we used pentane (C_5H_{12}) and for its detection we used micro gas chromatograph Agilent 3000. The gas chromatograph was calibrated as reported in a previous paper [8]. The voltage applied to the electrode was measured by an HV probe, the current produced by the discharge by means of a Rogowski coil [9] and the plasma power by means of the Lissajous figure [10]. The ozone (O_3) measurement were done using the MQ131 ozone sensor coupled with Arduino Mega2560 pure air, to avoid VOC sensor cross-sensitivity.
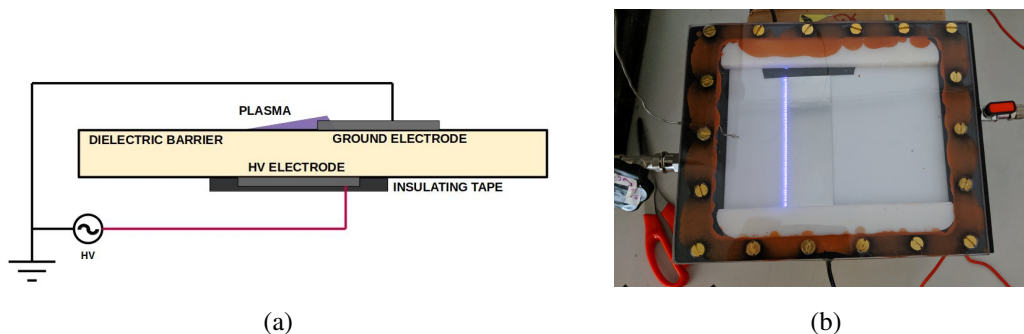

Figure 1: *(a) Scheme and (b) photo of the SDBD.*

Results and discussion   We investigated the depletion of C_5H_{12} for different starting concentration and for different plasma power [8].

From Fig. 2a we can notice that for low plasma power the percentage of the residual concentration of pentane (100 c_t/c_0, where c_t is the pentane concentration at time t and c_0 is the starting

concentration) follows the same trend for $c_0 = 600$ and $1200\,\text{ppm}$ and low plasma power, while it decreases faster for low concentration, $c_0 = 300\,\text{ppm}$.

For higher plasma power (Fig. 2b) there is a very fast pentane dissociation in the first minute for all the studied concentrations, then a stabilizing situation occours for the following minutes at $c_0 = 1200\,\text{ppm}$. There is almost total pentane decomposition after 2 and 3 minutes for $c_0 = 300$ and $600\,\text{ppm}$, respectively.

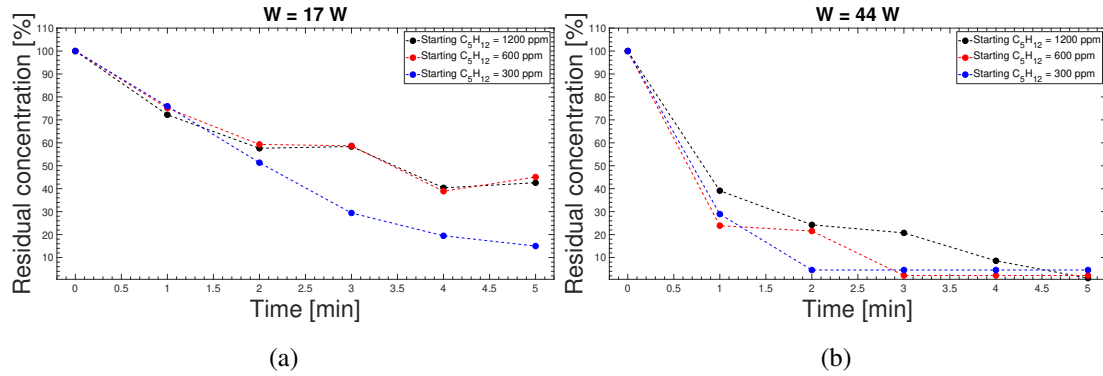(a)   (b)

Figure 2: *Percentage residual concentration of pentane after different treatment time for different starting concentrations (i.e. 300, 600 and 1200 ppm) and (a) 17 W and (b) 44 W plasma power.*

During the pentane decomposition, there is a formation of intermediate species, deriving from pentane, that we are going to call sub-products and ozone (O_3). The ozone is always produced by DBDs in air. We measured that O_3 has a fast increase followed by a decrease similar the propane depletion. The decrease of O_3 could be ascribed to the formation of NO_x species.

We found a production of acetylene (C_2H_2) and propane (C_3H_8), depending on power propane and pentane concentration. We analyzed the sub-products produced from a pentane starting concentration of 1200 ppm. For low plasma power (Fig. 3a) the sub-products concentrations continuously increase at high pentane concentration. We could conclude that the pentane at high concentration (1200 ppm) is not effectively dissociated and it generates acetylene and propane in large amount (up to 250 ppm for propane). Propane concentration is always larger then the acetylene one.

At higher plasma power (Fig. 3b) the trend is different: propane and acetylene concentrations are decreasing. In this plasma conditions (44 W input power and 1200 ppm pentane starting concentration) in a few minutes pentane is almost completely depleted and only a small amout of propane ($\sim 100\,\text{ppm}$) and acetylene ($\sim 30\,\text{ppm}$) remains.

We can assume that also at low plasma power there is a similar decreasing trend but at longer treatment times.
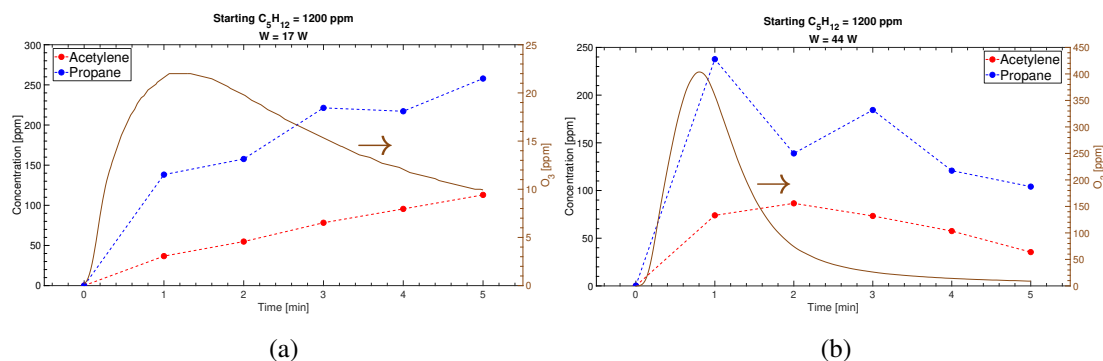
Figure 3: *(left axis) Concentration of acetylene and propane for starting pentane concentration of about 1200 ppm and (right axis) ozone concentration at (a) 17 W and (b) 44 W plasma power.*

Conclusions A study of VOC depletion using a plasma system based on surface dielectric barrier discharge has been carried out. The analyses of the temporal evolution of pentane and of the plasma generated sub-products have been performed as a function of the power. We find that the pentane depletion rate increases as a function of plasma power and only at relatively high power ($\sim 44\,\mathrm{W}$) the abatement occurs on pentane and their sub-products.

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