INTEGRATION OF A PHOTOCATALYTIC COATING IN A CORONA DISCHARGE UNIT FOR PLASMA ASSISTED CATALYSIS

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ABSTRACT

The combination of a non-thermal plasma with catalysis is considered as a sustainable indoor air purification technology to achieve complete oxidation at reduced energy cost with a longer electrode lifetime. An optimal window of operation for plasma assisted catalysis is found by varying the polarity, the applied voltage, the relative humidity of the gas phase and the configuration of the plasma reactor. The results show that, in general, negative corona discharge can obtain higher nitric oxide (NO) conversion efficiencies compared to positive corona. It is also clear that at higher applied voltages, higher conversion efficiency can be reached. The effect of relative humidity, however, is not found to be significant in the range (0 – 20.3 %) tested in this work. Additionally, the configuration of the plasma reactor is changed by varying the amount of pins that are attached at the collector electrode. The results show that there is an optimum at 10 pairs of pins to obtain a high conversion efficiency of NO. By applying a coating on the collector electrode of the plasma reactor, it is possible to see the influence of the coating on the performance of the plasma system, which was operating in the previously found optimal window. It stands clear that the use of a plasma assisted catalysis system has high potential as an integrated and sustainable indoor air purification technology.

I. INTRODUCTION

The environmental issue is becoming more and more a world matter of concern. Nowadays air pollution, both indoors and outdoors, is a serious problem for human health as well as for the environment in general. The quality of outdoor air in industrialized countries has improved over the past 10 years, while the indoor air quality (IAQ) drastically declined over the same period. Numerous studies report the occurrence of surprisingly high amounts of pollutants in enclosed environments (Rehfuess et al., 2006; Stranger et al., 2009; Van Durme, 2008). Indoor air pollutant concentrations are often two to five times higher than outdoor levels due to a combined effect of insufficient air exchange and high levels of indoor emission sources (U.S. Environmental Protection Agency & U.S. Consumer Product Safety Commission, 1995; Kolarik et al., 2010). Nonetheless, poor IAQ is still an underestimated problem despite the fact that people spend the largest fraction of their time (85 %) indoors and worldwide 1.5 million people annually die due to inhaling of indoor air pollutants (Bennett, 2007; Van Durme, 2008). It is thus clear that poor IAQ forms a significant health risk and efforts have to be made to improve IAQ.

These efforts can be categorized in three different ways: (1) by controlling the emission of pollutants from indoor sources through the selection of low-emitting materials, (2) by diluting pollutants via ventilating indoor spaces and/or (3) by removing harmful pollutants from the air. Each of these methods has its specific drawback, so it is not sufficient to use one single method. Better would be to combine different methods to achieve a better IAQ. Traditionally, effective infiltration and natural ventilation have been used to affect a controlled exchange of indoor air in order to abate IAQ problems. In the past few years, however, energy efficiency considerations have resulted in an increase in the gas tightness of buildings adversely impacting infiltration and discourages the use of natural ventilation (Bennett, 2007). As a result, these techniques do not improve IAQ sufficiently anymore. New techniques must thus emerge to improve the IAQ. One of the best options to do so is to actually purify the air to remove indoor air pollutants. This can be done by different air purifying methods like mechanical filters, electric filters, (photo)catalytic systems, ozone generators, plasma reactors and the like (Bennett, 2007; Chen et al., 2008; Pichat et al., 2000; Sidheswaran et al., 2012; Van Durme, 2008; Yu et al., 2009; Zhao & Yang, 2003).

More innovative methods for indoor air cleaning are the so called advanced oxidation processes (AOP). They have the potential of degrading a wide range of volatile organic compounds (VOCs) at ambient temperature and pressure. In these processes highly reactive, oxidative species such as ozone, atomic oxygen or hydroxyl radicals are produced. Examples of such AOP are photoysis, photocatalytic oxidation (PCO), ozone generators, plasma reactors, ... (Zhao & Yang, 2003). A short introduction of these AOPs will be given in the following paragraphs.

Pathogen destruction can be achieved using UV Lamps (photolysis). However, it is possible that irradiation time-doses may not be sufficient in many cases for the necessary effectiveness (Bennett, 2007).
PCO is a promising approach to improve the IAQ. Titanium dioxide is a well-known semiconductor that has widely been used as a photocatalyst for decomposing VOCs into carbon dioxide and water. UV light activates the catalyst through the production of electron-hole pairs that can induce redox reactions with adsorbed molecular oxygen, water and organic pollutants (Wittmann et al., 2005). The key oxidants in this reaction are OH radicals produced from water, O₂ and electron-hole pairs on the catalyst surface (Van Durme, 2008).

Ozone generators are frequently proposed as efficient indoor air cleaning tools. Ozone is highly oxidative and reacts with unsaturated indoor VOCs. However, ozone levels emitted by these generators are frequently higher than 500 ppb, which is 10 times higher than WHO recommendations for maximum ozone exposure concentrations (Hubbard et al., 2005). Non-thermal plasma (NTP), such as corona discharge and dielectric barrier discharge, consists of electrons which are accelerated by an electric field, gaining typical temperatures in the range of 10000 – 100000 K. These electron temperatures are much higher than the gas temperature (ambient temperature) (Chen et al., 2008). Using an atmospheric non-thermal plasma is energy efficient since most of the electrical energy input goes to the production of energetic electrons rather than to the heating of the gas.

Considering the fact that pollutants in indoor air are normally mixed, integrated pollution control systems are necessary to remove all the harmful components. There is currently no single technology available that provides a solution to remove low levels of indoor air pollutants. Therefore, advanced indoor air cleaning systems on the market mostly consist of a combination of several units like non-thermal plasma, particularly corona discharge, inside an electrostatic precipitator (ESP), a UV source for bacteria control and a chemical decomposition reactor (Chang, 2003). This is the reason why air cleaning technology is often over-dimensionalized, consisting of a serial stacking of filter technologies, resulting in a high cost. Therefore, this study focuses on the development of an integrated, sustainable and efficient indoor air cleaning technology.

For cleaning the air an NTP, and more specific corona discharge, will be used in the present study. Corona discharge is a low energy electrical discharge that occurs in the gas phase between two conductors when the induced electric field exceeds the value required to ionise or radicalise the gas, but is insufficient to cause a spark (Pillai & Sahle-Demessie, 2005). The discharge device usually involves two asymmetric electrodes: one highly curved, to ensure a high electric field, and one of a low curvature. The main objective of generating plasma is to produce radicals through electron-molecule reactions, which in turn react with pollutant molecules to abate them. Additionally, the corona discharge can also produce a low power UV light in the order of ≤ 2 W (Pillai & Sahle-Demessie, 2005). Corona combined with electrostatic precipitation uses electrical forces to move the particles towards one of the electrodes. These particles are given an electric charge by forcing them to pass through a corona. Once the particles are collected on the electrode, they must be removed from it without re-entrainment. Knocking or washing with water usually accomplishes this. The incorporation of non-thermal plasma, e.g. corona discharge, in an ESP offers a unique way to induce gas phase reactions and remove pollutants.

Nevertheless, there are still some disadvantages with the above-mentioned technique. Primarily, there is the formation of by-products, like ozone which is a powerful oxidant and which can upon inhaling, react with the human body its internal tissues. Secondly, the occurrence of irreversible deposition on the collector surface results in a declined removal efficiency. This irreversible deposition can be avoided by improving the discharge mode, including the lay-out of the reactor, and by decreasing the frequency and the voltage of the power supply or by the combination of the discharge unit with a catalyst (Oda, 2003). The latter option will be used in this research, where a photocatalyst is combined with the discharge unit by applying a photocatalytic coating on the collector electrode. Concerning the combination with a photocatalyst, as coating on the collector electrode, one can speak of catalysis assisted plasma, where the creation of a plasma is improved by the photocatalyst, or of plasma assisted catalysis, where the photocatalyst is activated by means of the light produced from the plasma itself (Li et al., 2002; Pillai & Sahle-Demessie, 2005). The focus of this research lies on the latter, implying several advantages. First of all, the aforementioned irreversible deposition can be avoided, which implies that there is no longer a need for additional cleaning of the collector electrode because the catalyst is able to remove the adsorbed species. Secondly, the by-products of the corona discharge can be converted into harmless products. It is thus clear that the addition of a catalyst has high potential to improve the NTP process (Li et al., 2002; Van Durme, 2008).

To summarize, the focus of this work lies on the implementation of an appropriate coating which can be implemented in a corona discharge unit for plasma assisted catalysis. Among semiconductor photocatalysts, TiO₂ is the most studied active one, due to its photo-stability, strong oxidizing power, non-toxicity, chemical and biological inertness, stability, as well as its low cost (Fujishima et al., 2004). Balasubramanian et al. (2003, 2004) developed a TiO₂ photocatalytic film on stainless steel using the P25 powder modified sol gel method (PPMSGM). By using this method, enhanced photocatalytic activity and adhesion is achieved compared with conventional sol-gel procedures. This coating is optimized in previous work with respect to TTIP:P25 molar ratio while a good adhesion to a metal substrate, a low resistivity and a good photocatalytic activity in the gas phase is achieved (Van Wesenbeeck et al., 2013). It was concluded that a P25 powder-modified sol-gel with a TTIP:P25 molar ratio of 1 has promising properties for a sustainable application in air purification. Therefore, the tests in this article are performed with the coating with a TTIP:P25 molar ratio of 1. Before combining photocatalysis and corona discharge, an optimal window of operation for plasma assisted catalysis is determined. Different parameters, like polarity, voltage, relative humidity and reactor configuration are tested, resulting in a set of conditions that are optimal for the mineralisation of pollutants. This set of conditions will be used further on as a starting point in order to obtain the best set of operating conditions for the plasma assisted catalytic set-up.

II. MATERIALS AND METHODS

II.1 The plasma reactor

A schematic diagram of the experimental setup is shown in figure 1. The configuration of the plasma reactor, which is an ESP based on corona discharge, is a conventional wire-to-cylinder type with a wire electrode (SS 316, 7 mm diameter and 140 mm long) and an outer cylinder electrode (SS 316, 80 mm diameter and 150 mm long). On the discharge electrode, i.e. the wire, a set of pairs of pins
(galvanized steel, 1 mm diameter and 15 mm long) was equally distributed over the wire. A high DC voltage supply (PHYWE systeme GMBH, type 13671.93) was used in the experiments.

The polluted gas flow (65 ppmv NO; 2000 cm³ min⁻¹) was controlled by four mass flow controllers (MFC, MKS instruments) and consisted of NO (1 % NO in N₂, Air Liquide), O₂ (Air Liquide) and N₂. The latter could be moistened by guiding the flow through a gas wash bottle filled with water, as shown in figure 1. It was always ensured that the oxygen concentration was 21 % in order to approach the indoor air conditions best.

Each of the performed experiments existed of 5 different phases (Tytgat et al., 2011). Phases 1 and 5 are the reference level of the pollutant in bypass (10 min), i.e. without going through the reactor. In phases 2 and 4, a gas flow is sent through the reactor to measure the effect of adsorption and desorption respectively. During these phases no voltage is applied (10 min). In the third phase the high power voltage unit was switched on to measure the degradation of the pollutants in the reactor (15 min). The difference between phases 2, 4 and phase 3 is a measure for the amount of reagent converted and reaction products formed. Throughout the experiment, a real-time monitoring of the gas flow is performed with Fourier transform infrared (FTIR) spectroscopy. For determining the pollutants conversion in percentages, the peak height of the pollutants with and without an applied voltage is compared. For NO, the peak height is taken at 1900 cm⁻¹ (ν1(NO)), while the peak height for O₃ is taken at 1057 cm⁻¹ (νυ(O₃)) (Gerhard, 1932; Hadjiivanov, 2000). These positions were carefully selected so there was no interference with other bands in the FTIR spectrum.

![Figure 1. Schematic diagram of the experimental set-up. The dashed line represents the bypass](image)

### II.2 Determining an optimal window of operation for the plasma reactor

To obtain an optimal window of operation for the plasma reactor, certain parameters are varied. The parameters under consideration in this study are polarity, applied voltage, relative humidity of the gas stream and configuration of the plasma reactor.

First of all, a distinction based on the polarity of the electrode where the high electric field is located has to be made. A positive corona discharge is obtained when high voltage is applied on the discharge electrode while the collector electrode is grounded. One speaks of negative corona when the high voltage is applied on the collector electrode while the discharge electrode is grounded. Secondly, the applied voltage is varied between 10 kV, 12.5 kV and 15 kV. Next, the humidity is varied by sending 0 % and 100 %, respectively.

Finally, the amount of pins varies from 2 pairs till 12 pairs. Each pair of pins is equally distributed over the wire electrode.

### II.3 Preparation of TiO₂ film based on the P25 powder-modified sol-gel method

The standard procedure for preparing the P25 based powder-modified sol-gel is similar to the method previously published by Van der Maat et al. (2011) and Van Wesenbeeck et al. (2013). For this reason, commercial titanium isopropoxide (TTIP, 97 %, Aldrich), isopropanol (i-PrOH, Sigma-Aldrich), diethanolamine (DEA, Sigma-Aldrich) and Aerosol TiO₂ P25 (Evonik) were used.

The uncoated SS 316 cylinder was pretreated with ethanol (96 %, Royal Nedalco) after which it was dried at 105 °C for 24 h prior to coating. Afterwards, 15 mL of the sol was applied on the inner wall by unrolling the cylindrical electrode to a flat surface so that a homogeneous coating could be obtained. Thereafter, the electrode was vertically hung up in order to let the excess of sol run off the wall. After this step, the cylinder was dried for 24 h at room temperature. Subsequently, the coated substrate was heated in air with a gradient of 3 °C min⁻¹ until a temperature of 100 °C was reached. This temperature was held for 1 h. Afterwards, the temperature was further increased with 3 °C min⁻¹ until 500 °C was reached. The temperature was again kept for 1 h. Finally, the coating was cooled to room temperature by natural convection. The complete cooling process took approximately 12 h. As a result, a deposition of 0.45 mg cm⁻² was obtained on the electrode.
III. RESULTS AND DISCUSSION

III.1 Optimal window of operation for plasma assisted catalysis

In this study, an optimal window of operation for plasma assisted catalysis is determined. Different parameters, like polarity, applied voltage, relative humidity and reactor configuration (i.e. the amount of pins that are attached on the wire electrode) are tested, resulting in a set of conditions that are optimal for the mineralization of pollutants. Each of these parameters will be discussed in the following paragraphs. The conversion of NO under an applied voltage is used as case study to confirm the activity of the plasma in the gas phase. This conversion is expressed in terms of NO conversion percentage. An overview of these results is shown in table 1.

<table>
<thead>
<tr>
<th>Table 1. Overview of the results for the determination of an optimal window of operation for plasma assisted catalysis</th>
<th>0 % relative humidity</th>
<th>0 % relative humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td># pairs of pins</td>
<td>+ 10 kV</td>
<td>+ 12.5 kV</td>
</tr>
<tr>
<td>1</td>
<td>0.78 %</td>
<td>2.11 %</td>
</tr>
<tr>
<td>4</td>
<td>3.37 %</td>
<td>16.80 %</td>
</tr>
<tr>
<td>6</td>
<td>0.66 %</td>
<td>0.44 %</td>
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<td>8</td>
<td>1.19 %</td>
<td>2.10 %</td>
</tr>
<tr>
<td>10</td>
<td>0.34 %</td>
<td>2.08 %</td>
</tr>
<tr>
<td>12</td>
<td>1.92 %</td>
<td>2.55 %</td>
</tr>
</tbody>
</table>

III.1.1 Polarity

Because there are two different operation modes possible, namely positive and negative (Yan et al., 1998), to obtain corona discharge, the first parameter under study will be this electrode polarity. As can be seen in table 1, negative corona generally has more conversion of NO compared to positive corona. When taking a closer look at figure 2, wherein the NO conversion for different voltages is expressed in function of the relative humidity, it is also clear that the negative corona has more conversion of NO when using the same circumstances, i.e. 21 % O₂, the same amount of pins and the same relative humidity. The reason of this difference in NO conversion can be explained by different phenomena, which will further be discussed in the following paragraphs.

Figure 2. NO conversion (%) for different voltages in function of the relative humidity (%) when 6 pin pairs are attached on the wire electrode and 21 % O₂ is applied.

As mentioned in the introduction, a corona discharge, either positive or negative, is a sustained non-thermal plasma which occurs in close vicinity to a sharp discharge electrode such as a pin or a wire at a high voltage (Van Durme, 2008). Although both positive and negative corona share many similar characteristics, the physical processes involved differ (Chen & Davidson, 2003a), which provides a first explanation for the difference concerning the observed NO conversion.

One important aspect in corona discharge is the formation of an electron avalanche. Such an avalanche occurs when a strong electric field acts on natural occurring free electrons in the air. Due to the electric field, the electrons accelerate thereby gaining sufficient kinetic energy to cause ionisation when colliding with neutral gas molecules. During these inelastic collisions, additional electrons are released, which in turn are also able to ionise after acceleration. As the process continues, more electron-ion pairs are produced in a self-sustained process, which is referred to as the electron avalanche (Chen & Davidson, 2003a; Loeb, 1947, 1965; Raizer, 1997). Although the initiation of the electron avalanche is the same for both polarities, there are some differences present regarding the way the electron avalanche is sustained.

The movement of the electrons in the avalanche depends on the polarity, so consequently a different generation mechanism of secondary electrons, required for sustaining the avalanche, occurs. In case of a positive corona, the electrons are accelerated towards the wire as the avalanche progresses. The secondary electrons are in this case mostly generated at the boundary of the ionisation region, i.e. the position where the rate of ionisation equals the rate of electron attachment, by photons of short wavelength light. These photons are formed when electron collisions excite the positive ions. When such photons strike neutral gas molecules, they release electrons through the photoelectric effect, which are drawn to the positive electrode. It are these electrons that seed and sustain further avalanches (Chen & Davidson, 2003a).

Unlike the positive corona, the electrons in a negative corona travel in the opposite direction and thus away from the wire. Therefore, secondary electrons ionized from the neutral gas are of relatively little use in sustaining a negative corona. Instead, the most significant mechanism for the generation of secondary electrons is the photoelectric action of photons striking the surface of the electrode. The energy required to release electrons from the electrode surface is considerably lower than the energy required to ionize ambient air. Consequently, the avalanche seed electrons are generated on the surface of the electrode by photoemission and are repelled from it. As these electrons leave the ionisation region, they attach themselves to neutral gas molecules and form small negative air ions which drift towards the collector electrode. The yield of such photoelectrons depends as well as the work function of the discharge electrode material. The fact that the secondary electrons in negative corona are generated from the surface of the electrode, means that the plasma conversion of NO depends on the material of the electrodes in the case of negative corona (Chen & Davidson, 2003a; Horvatz et al., 2010). This distinction explains the fact that there is a difference in NO conversion between positive and negative corona.

Another significant difference in negative and positive corona is the number of electrons within the plasma. This difference is shown in figure 3 which gives the comparison of the electron density in the positive and negative corona. For the negative corona, the electron density increases rapidly with increasing distance from the wire surface up to a distance of 100 µm. This rapid increase is due to the dominance of ionisation. Further away from the wire, the electron density remains relatively constant because of the fact that ionisation and attachment are of equal importance. Of course, it is true that the electrons near the collector electrode are considerably less energetic than those at the wire electrode. The density of positive ions decreases with increasing distance from the wire surface, while the density of negative ions increases, where it is two orders of magnitude higher than the electron density of positive ions (Chen & Davidson, 2003a). For the positive corona, the opposite can be observed. At the wire electrode, the electron density is very high, but it decreases rapidly with increasing distance from the wire electrode. Apart from the zone in close proximity of the wire, the density of electrons in the negative corona is nearly four orders of magnitude greater than that in the positive corona. The total number of electrons in the negative corona plasma is more than 50 times than the ones produced in the positive corona (Chen & Davidson, 2003a, 2003b).

![Figure 3. Comparison of the electron number density distribution in the positive and negative corona plasma.](image)

A third difference between both polarities is the thickness of the plasma region. The negative corona plasma is thicker than the positive plasma. For the positive corona, the ionisation boundary coincides with the boundary of the plasma region. Thus, the electron density is negligible outside this region. For the negative corona, the plasma region, i.e. the region where electron-impact reactions occur, extends 200 µm beyond the ionisation boundary (Chen, J. & Davidson, J.H., 2003a).

Based on the significant differences in thickness and number of electrons in positive and negative coronas, it is reasonable to expect the rates of electron impact reactions, and thus the production of ozone, to be far greater in negative corona than in positive corona. The decomposition of NO by ozone molecules occurs via the following reaction: \( \text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 \). This means that the more ozone is produced, the more NO is converted. Although, the presence of ozone gas was never observed, it is impossible that no ozone is present in the oxygen-rich corona plasmas.
formed, due to the abundant presence of oxygen in the gas flow (Morent, 2004). So as long as there is NO present, the produced ozone will be used to convert this NO. Due to the role of ozone in NO oxidation, it is clear that negative corona shows better NO degrading efficiency. Indeed, there is more ozone formation when using negative corona discharge.

As a result, these experiments in changing the polarity showed that negative corona provides higher conversion efficiencies compared to positive corona, due to both the higher electron density and the greater production of ozone.

**III.1.2 Applied voltage**

Table 1 also shows that generally a higher applied voltage, results in a higher NO conversion efficiency. This can also be seen in figure 4, where the NO conversion for different voltages is expressed in function of the relative humidity. This phenomenon can be explained by the definition of voltage: it is a measurement of the energy contained within an electric field. At higher electric fields charged particles may gain sufficient energy between collisions to cause ionisation with neutral molecules (Kuffel et al., 2000). Ionisation by electron impact is the most important process leading to gas breakdown. The effectiveness of ionisation by electron impact depends upon the energy that an electron can gain along the mean free path in the direction of the field.

In other words, the higher the voltage, the more energy the electric field contains and the more energy the electrons will have. As a result, more conversion can be obtained, as shown in figure 4.

![Figure 4. NO conversion (%) for different voltages in function of the relative humidity (%).](image)

**III.1.3 Relative humidity**

In case of varying the relative humidity, a small influence can be observed when looking at table 1. For the positive corona discharge, it can be seen that the addition of water does not have a significant effect on the conversion efficiency of NO. On the other hand, the negative corona has a small decrease in conversion efficiency when increasing the humidity. This can be explained by the fact that humidity affects the ozone production, as shown by Van Durme et al. (2007) who found a decreased ozone production with increased humidity. Since, as mentioned before, ozone molecules actively participate in the decomposition of NO, there is a clear relation between ozone concentration and NO decomposition. In fact, the lower the concentration of ozone, the lower the decomposition of NO. Knowing from the polarity experiments that the production of ozone is far greater in the negative corona than in the positive corona, the influence of humidity is more visible in the negative corona than in the positive corona.

Although theoretically the higher the humidity, the lower the decomposition of ozone will be, the experimental results show only a small influence. Therefore, it was decided to work with a humidity of 20.3 % in further experiments because this more realistically approaches the conditions of indoor air.

**III.1.4 Configuration of the reactor: Amount of pins attached on the wire electrode**

A corona discharge is, by definition, a gas discharge where the geometry confines the gas ionizing processes to high-field ionisation regions around the active electrodes (Goldman et al., 1985). This explains the general trend that can be observed and is shown in table 1 with regard to the configuration of the plasma reactor.

The configuration of the plasma reactor is changed by varying the amount of pin pairs that are attached on the wire electrode. This can be noticed that the conversion efficiency of NO begins to decrease with an increasing amount of pins.

Between each tip of a pin and the collector electrode, gas discharges are formed. Consequently, in first instance, the higher the amount of pins, the more discharges and thus the more NO conversion. But it is possible that the corona discharges interfere when the pins are too close to each other. Since an electric field is a vector quantity, it can be represented by a vector arrow. For any given location, the strength of the electric field is represented by the length of the arrow and the direction of the electric field is represented by the direction of the arrow. Thus, the magnitude and direction of the electric field at each location is simply the vector sum of the electric field vectors for each individual charge. This means that the electric fields can strengthen but also weaken each other.
This latter effect can be observed in figure 5, wherein the NO conversion is given in function of the amount of pin pairs for the negative corona discharges by a relative humidity of 20.3 %. A maximum can be observed for 10 pairs of pins. After this maximum, the conversion efficiency decreases.

In general, the more pins that are attached, the more discharges that can take place. This means that the NO conversion is promoted as long as the discharge zones of the plasma do not have a negative influence on each other. Therefore, a maximum conversion efficiency of NO in function of the amount of pin pairs can be observed.

**III.2 Plasma assisted catalysis: integration of a photocatalytic coating in the plasma reactor**

The previous paragraphs described the determination of an optimal window of operation, which will be used in the final stage of this study, where a coating was applied on the collector electrode of the plasma reactor. The risk of implementing a coating on the collector electrode involves that the charged particles are not attracted to the collector electrode anymore since the coating gives a loss in conductivity of the electrode. It is thus requested that the coating does not have an adverse effect on the efficiency of the corona discharge reactor.

The conversion efficiency of NO in the reactor was determined before and after supplying the coating when using the predetermined window of operation. This means 21 % O2, negative corona and 20.3 % relative humidity. Although it was clear that in general a higher voltage gives higher conversions, still all the negative voltages were included in the experiment, of which the results are given in figure 6.

As can be seen in figure 6, there is no significant difference found between conversion efficiency of the reactor with and without coating. This means that implementing the coating does not significantly inhibit the working of the corona discharge itself.
IV. CONCLUSIONS

The purpose of this research is to combine photocatalysis and corona discharge in order to obtain a plasma assisted catalytic system as a sustainable and reliable indoor air purification technology. Therefore, an optimal window of operation is determined by varying several characteristics, namely polarity, applied voltage, reactor configuration and relative humidity. By combining the conclusions of each characteristic, it is possible to define the optimal window of operation for the mineralization of pollutants by plasma assisted catalysis.

First of all, negative corona generally gives higher conversion efficiencies compared to positive corona due to the higher electron density and the greater production of ozone. Secondly, it became clear that with higher applied voltage, the conversion efficiency of NO also increases because of the electric field that contains more energy. Thus, working with a voltage of 15 kV is preferable. A third conclusion was that the influence of the relative humidity is very small. Therefore, it is preferred to work with higher relative humidity, namely 20.3 %, in order to better approach realistic indoor air conditions. The last parameter that was changed, was the configuration of the plasma reactor and more specifically, the amount of pin pairs that are attached to the discharge electrode. Here it can be concluded that there is indeed a maximum amount of pins to obtain a high NO conversion efficiency. This maximum is determined in this reactor setup to be 10 pin pairs.

By applying a coating on the collector electrode of the plasma reactor, it was possible to see the influence of the coating on the performance of the plasma system when operating in the found optimal window of operation. It was thereby clear that the coating does not have a negative effect on the plasma.

This study illustrates that the implementation of a photocatalytic coating within a corona discharge reactor, also referred to as plasma assisted catalysis, has high potential as an integrated and sustainable indoor air purification technology.

ACKNOWLEDGMENTS

The authors wish to thank the University of Antwerp for supporting and funding this research. Tom Tytgat and Hilde Vanderstappen are greatly acknowledged for their help during the experiments.

REFERENCES