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Content

Abstract

The dissertation thesis deals with exhaust and syngas gas cleaning processes by non-thermal plasma and plasma catalysis. The general objective was to investigate selected systems of non-thermal plasma generated by various atmospheric pressure electric discharges (surface barrier discharge, discharge in capillary tubes, packed bed discharge) either alone or in combination with packing materials of various properties (TiO_2, Pt/γAl_2O_3, ZrO_2, $BaTiO_3$, γAl_2O_3, glass beads), shapes (pellets, capillary tubes) and sizes. Physical characteristics of the experimental systems were investigated under various conditions and some of the systems were applied for gas cleaning from selected compounds (polycyclic aromatic hydrocarbons PAHs).

The first part of the thesis presents *theoretical background* related to air pollution, non-thermal plasma generated by atmospheric pressure electric discharges, chemical catalysis as well as to their combination known as plasma catalysis. Moreover, environmental applications of non-thermal plasma, chemical catalysis and plasma catalysis focused on air pollution control are described along with state-of-the-art and related works of other authors. The second part of the thesis is devoted to the own experiments. This *experimental part* contains description of the used experimental systems and methods and presents obtained results supplemented with the discussion.

The first group of the results is associated with electrical, optical and chemical characterisation of special and relatively novel type of discharge: *micro-hollow surface dielectric barrier discharge*. The second group of the results is related to system of the *discharge generation inside a bundle of glass capillary tubes* simulating the real honeycomb-shaped automobile catalytic converter. The plasma inside the tubes was generated by a combination of a micro-hollow surface dielectric barrier discharge and DC high voltage applied across the tubes. The combined system of plasma and automobile catalytic converter could be very useful for exhaust gas cleaning. Finally, the last group of results is associated with *packed bed discharges* combined with various packing materials studied on tar removal. Tars represent a group of stable PAHs that are formed by combustion and gasification of fuels including biomass and municipal solid waste. Naphthalene has been chosen as a model tar compound. We studied the effects of discharge power, carrier gas, packing material and its properties on naphthalene removal and by-products formation.

1. Introduction

The current world economy based primarily on the combustion of fossil fuels is far away from the sustainability as almost each process of energy production is accompanied by exhaust gas emissions. These emissions have negative effect on the environment (global climate change, acid rains, stratospheric ozone depletion) and are also harmful to human health. Growing global energy demand along with evident aversion against the fossil fuels have led to an interest in alternative and cleaner technologies that would significantly reduce exhaust gas emissions. Another option how to reduce the emissions is exhaust gas cleaning using the appropriate techniques. Exhaust gases are generally composed of various kinds of gaseous pollutants, such as nitrogen oxides NOx, sulphur oxides (SOx), particulate matter and various hydrocarbons (volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs)) [1]. One of the major sources of the emissions is a road transport. Nowadays, automotive exhaust gas cleaning technologies are based on catalytic reactions, which transform the pollutant molecules into less harmful compounds by processes of oxidation and reduction. However, the catalytic processes suffer from low efficiency at low operating temperatures, limited catalyst lifetime due to its poisoning and impossibility of effective NOx reduction in strong oxidative environments (in diesel engines) [2].

Among the renewable energy sources that can substitute for fossil fuels is the biomass and municipal solid waste due to their wide availability. In order to produce an energy, the biomass and waste can be either combusted or gasified into a synthesis gas (syngas), which possesses a high energy potential. However, the syngas is usually polluted by intermediate by-products of gasification, that disqualify it from further utilisation. Therefore, the syngas clean-up before its further use is a necessity. Among the by-products, the tars represent major constituents that can be effectively removed (decomposed) at very high temperatures from 700 to 1250°C. The temperature can be slightly lowered by catalytic methods, that require temperatures from 550 to 900°C. However, these methods are characterised by a high energy demand due to high operating temperatures and by a limited catalyst lifetime due to fast catalyst poisoning [3].

Therefore, it is necessary to further improve the current methods of exhaust gas and synthesis gas cleaning as well as to develop new, sufficiently efficient and cheap methods. One of the possible ways how to overcome limitations associated with, for example, catalytic processes of automotive exhaust gas cleaning or catalytic tar removal is utilisation of non-thermal plasma (NTP). The NTP provides a high-reactive environment initiating various chemical reactions even at ambient conditions (ambient temperature, atmospheric pressure), what represents one of the most important benefit of the NTP in contrast to other techniques. The most frequently employed NTP sources are electric discharges (e.g. corona discharge, dielectric barrier discharge (DBD), spark discharge, etc.) [4].

Utilisation of NTP in air pollution control has started at the turn of the 19th and 20th centuries, when a corona discharge was successfully employed as a source of ions in electrostatic precipitators for removal of particulate matter from gas streams [5]. Since then, the NTP was extensively investigated in processes of NOx, SOx and VOC removal in lab-scale experiments [4]. Nowadays, several pilot- and large-scale applications of NTP for air pollution control have been successfully employed [6].

In addition to chemical catalysis and NTP, there are many other techniques of exhaust gas cleaning, such as adsorption, absorption, filtration, etc. Nevertheless, every technique suffers from its own disadvantages and limitations in efficiency and lifetime [1]. In last two decades, a combination of NTP with catalysis, i.e. plasma catalysis, has shown very promising results in various lab-scale environmental (e.g. air and water pollution control) [7,8] and energy and chemical synthesis applications (e.g. fuel reforming) [9,10]. Plasma catalysis is characterised by synergistic effects, that are "a complex phenomenon, originating from the interplay between the various plasma−catalyst interaction processes" [11]. As a result, the plasma catalysis possesses not only high catalytic selectivity, but also high plasma reactivity leading to high process efficiency with low energy consumption [12,13].

2. Objectives of the dissertation

Main objectives of this thesis can be defined as follows:

- To investigate electrical and optical characteristics of non-thermal plasmas generated by various electric discharges at atmospheric pressure (surface barrier discharge, discharge in capillary tubes, packed bed discharge) without or with various types of catalysts under various operating conditions (discharge power, carrier gas, gas flow rate, gas relative humidity).
- To investigate chemical effects of electric discharges without or with a catalyst and to confront them with their physical characteristics.
- To test several materials of various catalytic properties (TiO_2, γAl_2O_3, $Pt/\gamma Al_2O_3$, $BaTiO_3$, ZrO_2), shapes, sizes and specific surface areas and to study their effect on stability, characteristics and distribution of the discharge.

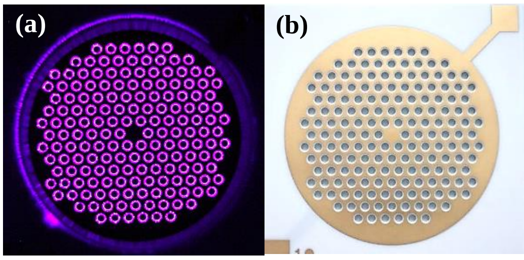
- To analyse gaseous and solid by-products of target compounds (tars: naphthalene) decomposition by means of absorption infrared spectroscopy, scanning electron microscopy and energy-dispersive X-ray spectroscopy.

3. Micro-hollow surface dielectric barrier discharge

First part of the results is devoted to electrical, optical and chemical characterisation of a relatively novel type of DBD: micro-hollow surface dielectric barrier discharge (micro-hollow SDBD) (Fig. 1 (a)). Although many authors have studied and used the micro-hollow SDBD in several applications [14–16], electrical and optical characterisation of the discharge in different operating conditions, to our best knowledge, is still missing. However, in respect to the discharge eventual environmental and even biomedical applications and their further optimisation especially in ambient conditions the discharge characterisation is simply crucial.

The micro-hollow SDBD is typically generated using a perforated ceramic substrate made of laminated ceramic sheets of two basic electrode configurations. First configuration consists of two plate perforated parallel electrodes embedded inside the ceramic between the ceramic sheets. In the second configuration one electrode is embedded inside the ceramic and the other one printed on the ceramic surface (air-exposed electrode). In this work, the second configuration with the air-exposed electrode was utilised and investigated (Fig. 1 (b)). This type of discharge has an advantage of easy scalability and it offers “grid-like” geometry suitable for flow control applications. Besides, the geometry enables efficient gas mixing with the plasma, what can possibly be used in many environmental applications (such as air pollution control). Furthermore, the micro-hollow SDBD may be employed for a generation of stable discharge inside channels of honeycomb catalyst.

The micro-hollow SDBD was operated under various conditions of applied voltage (amplitude (3–6 kV), frequency (200–2000 Hz)), air flow rates (0.5–2.4 L/min) and air relative humidities (RHs) (0–80%). The effects of these parameters were investigated on electrical (peak current and number of current pulses) and optical characteristics (light emission intensity) of the discharge.



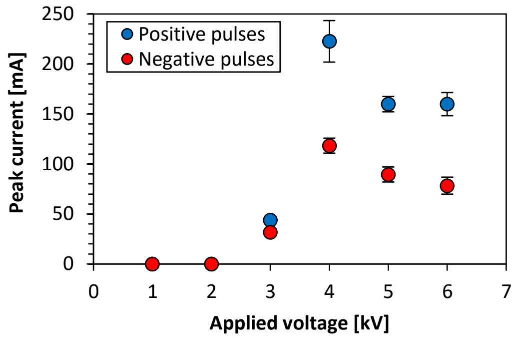


Fig. 1 (a, b) The photographs of (a) micro-hollow SDBD and (b) ceramic substrate (4 kV at 1 kHz) [Exposure time 3 s, f/5.6, ISO 400].

Fig. 2 Positive and negative peak current as a function of the applied voltage (1 kHz; dry air; 2.4 L/min).

The results showed, that the overall number of current pulses increased with the amplitude of the applied voltage and discharge power, and the positive pulses were found to be more numerous than negative ones. The effect of air flow rate and air RH on number of positive and negative pulses was found to be different: with an increase of air flow rate and air RH the number of positive pulses was relatively stable, whereas the number of negative pulses increased significantly. The highest positive and negative peak currents (i.e. maximum amplitudes of current pulses) were always observed at applied voltage of 4 kV (at 1 kHz) and they further decreased at higher amplitudes of applied voltage (Fig. 2). Besides, the increase of peak current was observed with an increase of air flow rate. The effect of air RH on peak current was found to be opposite for positive and negative one: the positive peak current decreased, while the negative peak current increased with an increase of air RH at a given discharge power.

Optical spectroscopy measurements showed, that discharge light emission intensity increased with a frequency of the applied voltage and decreased with an increase of air flow rate and air RH. Measurements of surface temperature of ceramic substrate during the discharge operation were also carried out. The maximum surface temperature of the substrate was found to be approx. 68°C at discharge power of 5 W and air flow rate of 0.5 L/min.

In addition, the chemical activity of the discharge, i.e. production of long-lived gaseous reactive species (O_3, N_2O, N_2O_5, HNO_3) was also evaluated and was found to be strictly dependent on discharge power, air flow rate and air RH. The maximum ozone O_3 concentration of 1750 ppm was observed at discharge power of 3 W and air flow rate of 0.5 L/min, i.e. for specific input energy (SIE) of 360 J/L (Fig. 3 (a)), with corresponding production yield (PY) of 34 g/kWh. The maximum PY of O_3 (77 g/kWh) was found at 1 W and 2.4 L/min (i.e. 25 J/L). Further, a maximum production of nitrous oxide N_2O (73 ppm) was observed at discharge power of 5 W and air flow rate 0.5 L/min (for SIE of 600 J/L) (Fig. 3 (b)) with corresponding PY of 0.8 g/kWh. Concentrations of both O_3 and N_2O were the highest in dry air and decreased with air humidity. On the contrary, traces of nitric acid HNO_3 with maximum concentration of approx. 125 ppm were detected only in conditions of low air flow rates and its production increased with an increase of air RH.

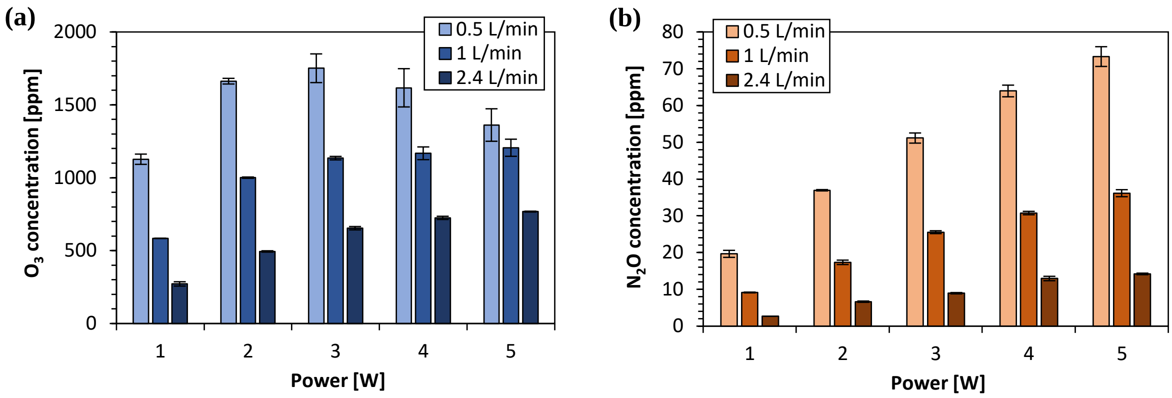


Fig. 3 (a, b) Concentration of (a) ozone O_3 and (b) nitrous oxide N_2O as a function of discharge power for various air flow rates (1 kHz; dry air).

The investigated micro-hollow SDBD represents a versatile NTP source allowing operation at low powers (< 5 W) and at relatively low applied voltages (3–6 kV at 1 kHz). The geometry of the ceramic substrate composed of many holes allows for a direct contact of generated plasma with flowing gases and represents a promising system for biomedical and, especially, environmental applications. However, one of the greatest drawbacks of the discharge in a configuration with the air-exposed electrode is limited lifetime of ceramic substrate (tens of hours in average) associated with erosion and sputtering of the electrode due to bombardment of energetic particles from the generated plasma.

4. Honeycomb discharge

The plasma catalysis provides a beneficial combination of NTP with catalysis, that has many potential applications, although it is still facing significant challenges in scalability, energy efficiency, lifetime, understanding of surface processes, etc. Besides, the combination of NTP with a honeycomb catalyst represents one of the major challenges in plasma catalysis from the technological point of view.

The honeycomb catalysts are of great importance in heterogeneous catalysis, as they provide high surface-to-volume ratio, low pressure drop and high mass and heat transfer. They are composed of many long, narrow, parallel channels the most commonly of circular, hexagonal or square shape. Moreover, the honeycomb catalysts are also employed in automotive catalytic converters where they are used for exhaust gas cleaning. However, their high activities are reached only at elevated temperatures (> 400°C) [2] what limits their efficiency especially during winter months. Their other drawbacks are limited lifetime in real conditions due to catalyst poisoning and impossibility of NOx reduction in strong oxidative environments (i.e. exhaust gases of diesel engines).

For these reasons, it is necessary to search and investigate new possibilities to limit drawbacks of honeycomb catalysts. Their coupling with NTP seems to be a promising method, as it allows for their low-temperature activation as well as lifetime enhancement. Nevertheless, the combination of NTP with honeycomb catalyst is still far from practical use because of the difficulty of stable plasma discharge generation inside specific long and narrow honeycomb channels. Several works related to coupling of NTP with honeycomb catalyst have been already published showing basic technological ideas and concepts [17–21]. The process was also studied by numerical modelling [22,23].

Our research followed our previous work and the works of other authors from recent years [17,19,20] and its objective was to improve the methods of honeycomb discharge generation and investigate its basic electrical and optical properties. In our work, a bundle of glass capillary tubes simulated real honeycomb catalyst in order to be able to perform optical emission spectroscopy measurements of discharges generated inside the tubes. We investigated several experimental arrangements (single- and multi-capillary) and the discharge inside capillary tubes was generated without or with an assistance of another NTP source. Indeed, the most promising results with respect to the quality of the discharge were obtained with an assistance of another NTP source, particularly when the micro-hollow SDBD generated by a perforated ceramic substrate with the air-exposed electrode was employed. The capillary tubes were placed perpendicularly to ceramic substrate facing the side of air-exposed electrode (Fig. 4 (a)). Firstly, the auxiliary discharge plasma was generated by applying AC HV to the air-exposed electrode, while the embedded electrode was grounded. Secondly, the DC HV was applied to a remote mesh electrode placed at the other nozzle ends of capillary tubes. Then, the DC electric field applied across the capillaries extended plasma streamers from the auxiliary micro-hollow SDBD into them (Fig. 4 (a–d)). From a physical point of view, the mechanism governing honeycomb discharge generation can be explained as a superposition of AC powered surface barrier discharge and DC powered corona discharge. The first one serves as an ioniser producing charged particles, while the latter one produce and maintain the ionic wind toward the DC electrode [17].

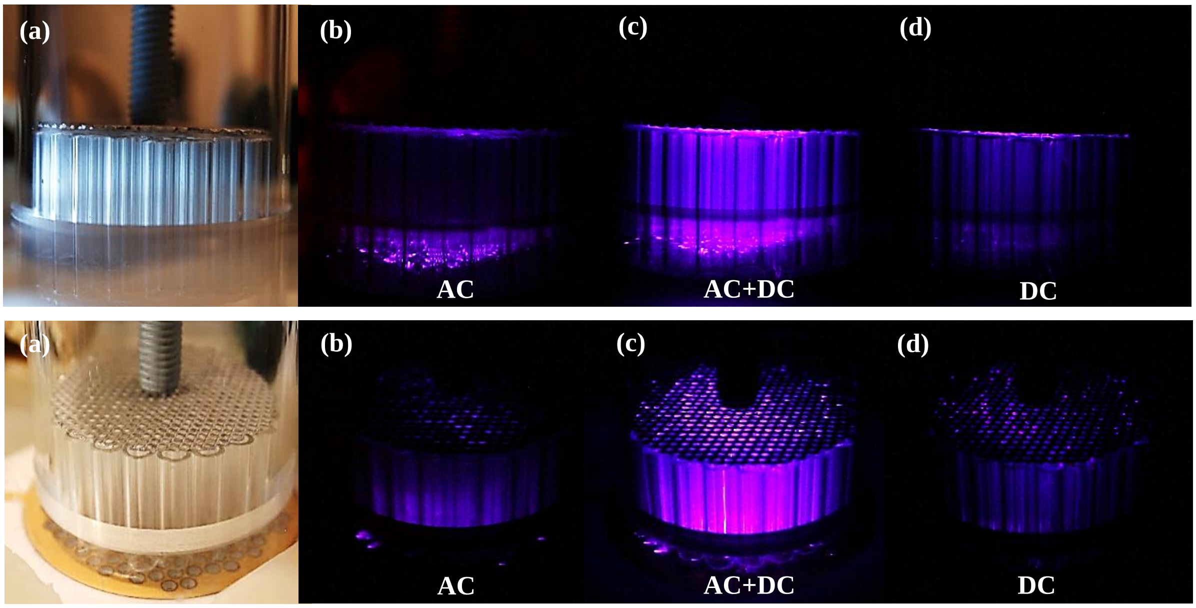


Fig. 4 (a–d) The ceramic substrate with glass capillary tubes – side and upper view: (a) without discharge; (b) with applied AC HV only (4 kV at 1 kHz); (c) with applied both AC and DC HV (4 kV at 1 kHz; +14 kV, respectively); (d) with applied DC HV only (+14 kV) (air; RH~60%; 2.4 L/min; R=9.4 MΩ) [Exposure time 8 s, f/5.6, ISO 400].

Electrical and optical characteristics of honeycomb discharge were investigated under various conditions of AC and +/– DC applied voltage, air flow rate and air RH. When amplitude of AC HV was set to 4 kV (at 1 kHz), the honeycomb discharge started to occur for DC HV amplitudes in a range of 12–14 kV. Then, an average onset electric field strength for honeycomb discharge generation was found to be 8–9 kV/cm. The maximum amplitude of DC HV (i.e. sparking voltage) was found to be 16–17 kV. Above this value a permanent sparking inside capillary tubes occurred. The results further showed, that the honeycomb discharge did not form in dry air regardless of both AC and DC applied voltages and its light emission intensity was positively supported by air flow rate and air RH (Fig. 5 (a, b)). We consider, that air flow supported a transport of charged particles from the "seeding" surface barrier discharge into the capillary tubes, while a presence of humidity resulted in enhancement of surface electrical conductivity of the glass capillary tubes due to adsorption of water molecules onto their surface what in turn enhanced honeycomb discharge generation [24]. Furthermore, light emission intensity of the discharge was higher for positive DC HV when comparing to negative DC HV.

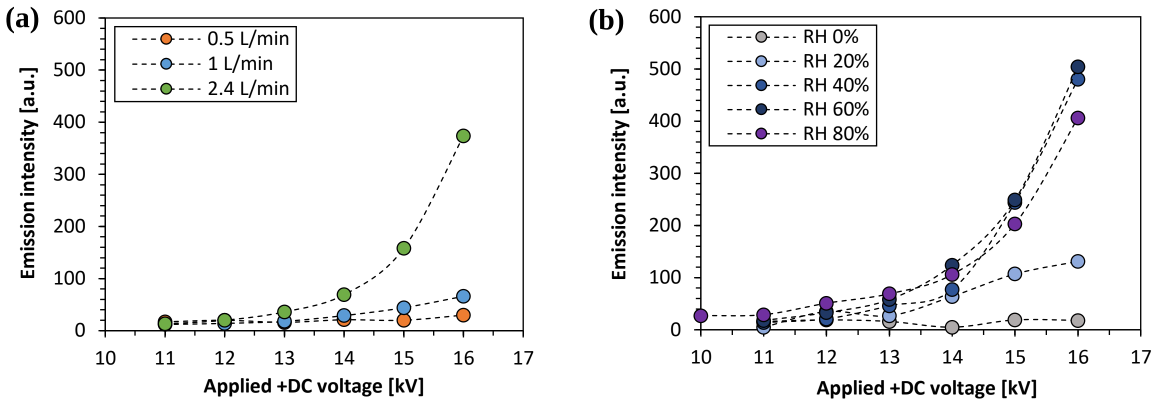


Fig. 5 (a, b) Emission intensity of honeycomb discharge as a function of applied positive DC HV for (a) various air flow rates (AC HV 4 kV at 1 kHz; air; RH~55%; R=9.4 MΩ) and (b) various air RHs (AC HV 4 kV at 1 kHz; air; 2.4 L/min; R=9.4 MΩ).

A brief evaluation of chemical activity of the honeycomb discharge in terms of ozone O_3 production was also carried out and showed, that O_3 concentration increased with an increase of amplitude of both AC and DC HV and was higher for positive than for negative polarity of DC HV.

Our results demonstrated, that generation and sustaining a stable plasma discharge inside the honeycomb structure simulated by glass capillary tubes is possible with an assistance of surface barrier discharge coupled in series with the DC electric field applied across the capillaries. The results further showed a positive effect of the increase in air flow rate and air RH on stability, homogeneity and light emission intensity of the honeycomb discharge. Our work may serve as a good starting point for future experimental investigations at larger scales.

5. Tars removal by plasma catalysis

Last part of the thesis focused on tars removal processes by plasma catalysis. The tars represent a group of stable polycyclic aromatic hydrocarbons that are formed during the gasification processes of biomass or municipal solid waste as intermediate products of incomplete oxidation. Gasification leads to production of syngas that possesses high energy potential. However, all industrial processes dealing with the syngas require its high purity and quality. For this reason, the syngas clean-up before its utilisation is a necessity. In addition, the tars are also formed in combustion processes of fossil fuels with lower amounts compared to gasification, however, their removal from exhaust gases is also important due to environmental issues.

Since tar removal process represents a major challenge in order to make syngas technologies commercially and technically feasible, the objective of this part of thesis was to investigate the potential of removing the tars by plasma catalysis. The NTP was generated by atmospheric pressure DBD either alone or in combination with various packing materials, including catalysts (TiO_2, Pt/γAl_2O_3, ZrO_2) and other dielectric materials ($BaTiO_3$, γAl_2O_3, glass beads). In our work, naphthalene ($C_{10}H_8$) was chosen as a model tar compound. The effects of the discharge operating parameters (amplitude (3–14 kV) and frequency (200 and 500 Hz) of the applied voltage, discharge power), carrier gas (air, N_2, O_2) and packing material on electrical characteristics of the discharge, naphthalene removal and the formation of gaseous and solid by-products were investigated. Moreover, the packing materials were characterised by a distinct shape (spherical and cylindrical pellets and beads), size (2–5 mm in diameter), dielectric constant (5–4000), and specific surface area (SSA) (37–150 m^2/g), and the effects of these properties on electrical characteristics of the discharge and naphthalene removal were also studied. In contrast to the existing works on naphthalene removal by plasma catalysis [25–32], we performed our experiments at a relatively low operating temperature (below 150°C) and with a relatively high initial concentration of naphthalene (approx. 5000 ppm).

The results showed that naphthalene removal efficiency (NRE) increased with an increase of the amplitude and frequency of the applied voltage, as well as with the discharge power. In oxygen carrier gas, the NRE reached almost 100% and confirmed the dominant role of reactive oxygen species in processes of naphthalene oxidation. The corresponding energy efficiency (EE) in oxygen was very high (up to approx. 370 g/kWh in the plasma catalytic TiO_2 reactor). In ambient air, the NRE and EE obtained with various reactors for the SIE of 320 J/L followed a sequence: TiO_2 > Pt/γAl_2O_3 > ZrO_2 > γAl_2O_3 > glass beads > $BaTiO_3$ > plasma alone (Fig. 6 (a, b)). The highest NRE and EE of plasma catalytic TiO_2 reactor were 88% and 207 g/kWh, respectively, on the other hand the lowest NRE and EE of plasma reactor were 41% and 95 g/kWh (for 320 J/L), respectively. The positive effect on both NRE and EE was observed with increasing specific surface area (SSA) of the catalyst, however, a shape of catalyst pellets was found to be even more important: the NRE obtained with cylindrical TiO_2 with SSA of 37 and 150 m^2/g were 52 and 70% for 320 J/L, respectively, while spherical TiO_2 with moderate SSA of 70 m^2/g achieved even higher NRE of 88%. In addition, improvement in the NRE was also found with smaller glass beads (Ø 3 mm) when comparing to bigger glass beads (Ø 5 mm) (64 vs. 45% for 320 J/L, respectively).

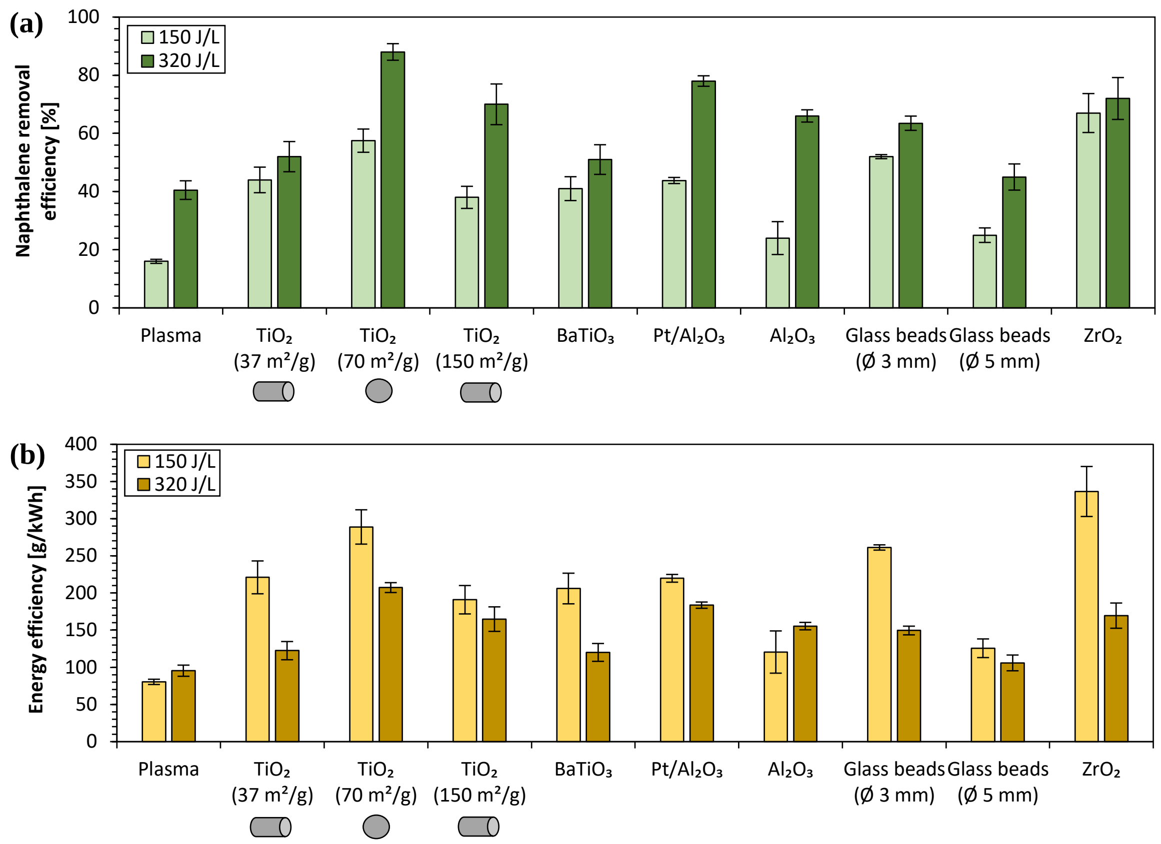


Fig. 6 (a, b) (a) Naphthalene removal efficiency and (b) energy efficiency for plasma and plasma catalytic reactors with various packing materials for specific input energy of 150 and 320 J/L (air).

In addition to discharge power, the other macroscopic electrical characteristics of the current pulses in various reactors were also evaluated (peak current, maximum duration and number of pulses) using a digital oscilloscope of high temporal resolution. The analysis of electrical characteristics of current pulses allowed us to assess the correlation between these characteristics and observed plasma chemical effects of tars removal. The results showed significant differences in electrical properties of packed bed DBD reactors depending on the packing material. For a given SIE of 320 J/L, the highest peak current was found in Pt/γAl_2O_3 reactor, the longest duration of pulses in ZrO_2 and γAl_2O_3 reactors and the most numerous pulses in $BaTiO_3$ reactor. However, the highest NRE was reached with TiO_2 reactor, where moderate number of current pulses of moderate amplitude and moderate duration was observed. Based on these results we conclude, that there is no clear correlation between electrical properties of reactors and their plasma catalytic chemical effects. Thus, a sequence of the NRE obtained with various reactors cannot be fully explained by considering the characteristics of current pulses only as observed plasma catalytic chemical effects are not a result of modification of plasma macroscopic properties by a presence of catalyst. We assume, that only an interplay among multiple parameters and effects, such as plasma modifying catalytic processes and catalyst modifying plasma properties, can ensure an adequate chemical efficiency of plasma catalysis.

The by-products formed by naphthalene decomposition were found in the gas phase as well as in the solid phase as deposits on the windows of the gas cell, reactor walls and surface of packing materials. Surface analysis of packing materials was carried out by means of the scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX). Solid deposits of naphthalene decomposition by-products found on the surface of packing materials were composed of round particles (diameter in range of 1–5 μm) with strong agglomerating tendencies (Fig. 7). Additionally, significant differences in distribution of solid deposits on the surface of packing materials were observed. While spherical catalysts were covered by solid deposits almost uniformly, the deposits on cylindrical catalysts agglomerated in circular patterns with a diameter of approx. 1 mm and were randomly distributed along the entire surface. The same, but much stronger effect was observed with a high dielectric constant material $BaTiO_3$ (Fig. 8). The differences indicate, that various reactors were characterised by different discharge modes. We hypothesise, that reactors packed with spherical catalysts were typical with surface discharges propagating along the catalyst surface, whereas reactors packed with cylindrical catalysts and $BaTiO_3$ were dominated by filamentary microdischarge mode with less intense or none surface discharges. Uniform and intense distribution of surface discharges within a reactor leads to an activation of larger area of the catalyst. Thus, their presence could lead to more uniform distribution of solid deposits along the entire catalyst surface, while spatially localised filamentary microdischarges caused agglomeration of solid deposits into circular patterns. Therefore, not only dielectric constant of packing material, but also its shape can alter a discharge mode in packed bed DBD reactors.

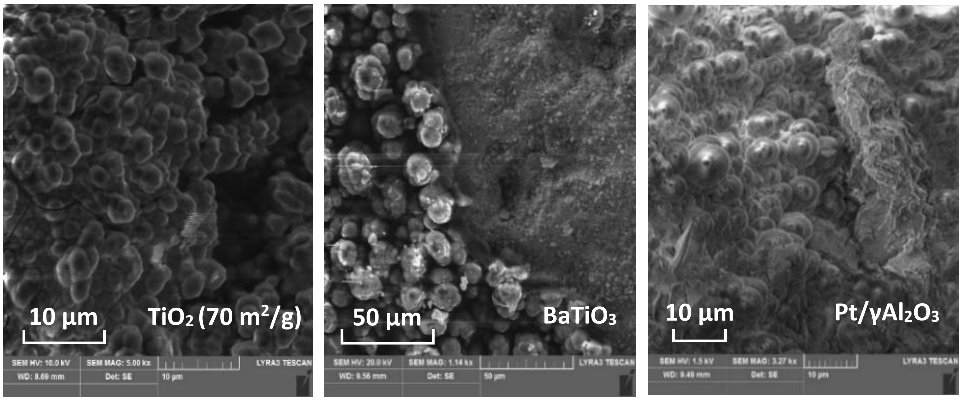


Fig. 7 Detailed SEM images of solid carbon deposits on surface of various catalysts. Note, that different magnifications are used.

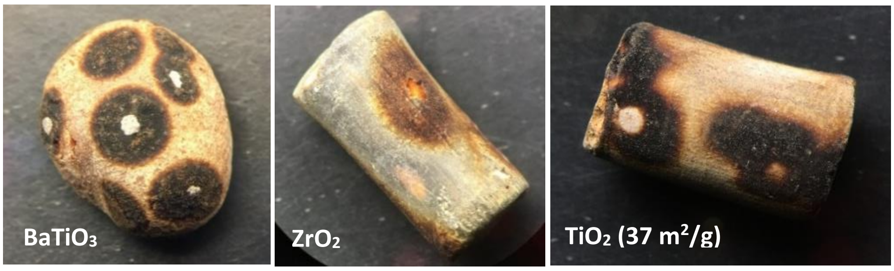


Fig. 8 Photographs of catalysts surface with circular patterns of solid deposits (magnification 250x).

In addition to SEM and EDX analyses, the Fourier-transform infrared (FTIR) spectroscopy analysis was also carried out and served for the identification of gaseous and solid by-products of naphthalene decomposition. Among the main gaseous products, CO, CO_2, H_2O and HCOOH were mostly found. Moreover, in the FTIR spectra, several other complex gaseous and solid by-products were identified (Fig. 9), including phthalic anhydride, maleic anhydride, 1,2- and 1,4-naphthoquinone and 1,4-benzoquinone in the gas phase, and salicylic acid, phthalide, and 1,8-naphthalic anhydride in the solid phase. The compounds found in the spectra represent organic gaseous and solid intermediates of naphthalene decomposition and indicate its incomplete oxidation to the desired products of CO_2 and H_2O.

Finally, the NRE and EE we obtained can be well compared to the results of other authors and groups. Even though our initial naphthalene concentration was relatively high and our operating temperature low, i.e. less favourable for achieving efficient naphthalene removal, we obtained reasonable removal and energy efficiency. Our results proved that plasma catalysis is a very effective method for tar removal.

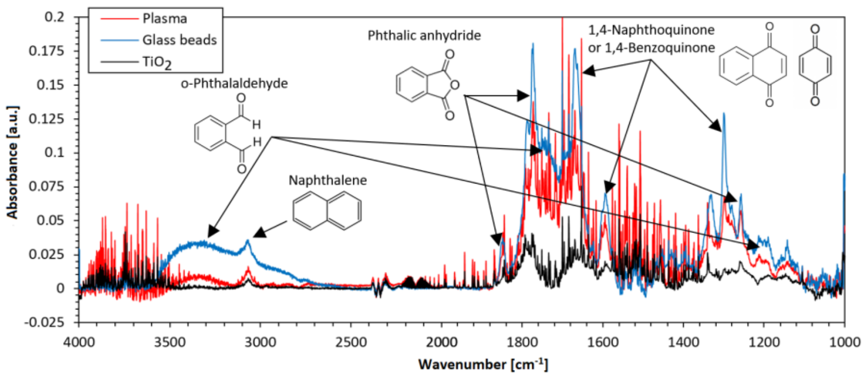


Fig. 9 Infrared absorption spectra of gaseous and solid by-products of naphthalene decomposition for the plasma and plasma catalytic reactors packed with glass bead and TiO_2.

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List of author's publications

ADC Vedecké práce v zahraničných karentovaných časopisoch

ADC01 Cimerman, Richard [UKOMFKAFZM] (55%) - Račková, Diana (5%) - Hensel, Karol [UKOMFKAFZM] (40%): Tars removal by non-thermal plasma and plasma catalysis
Lit.: 83 zázn.
In: Journal of Physics D. - Roč. 51, č. 27 (2018), s. 1-13, Art. No. 274003. - ISSN (print) 0022-3727
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Indikátor časopisu:
IF (JCR) 2017=2.373
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Ohlasy (8):
[o1] 2019 Liu, L. - Zhang, Z. - Das, S. - Kawi, S.: Reforming of tar from biomass gasification in a hybrid catalysis-plasma system: A review. In: Applied Catalysis B-Environmental, Vol. 250, 2019, s. 250-272 - SCI ; SCOPUS
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AFC Publikované príspevky na zahraničných vedeckých konferenciách

AFC01 Cimerman, Richard [UKOMFKAFZM] (60%) - Račková, Diana (10%) - Hensel, Karol [UKOMFKAFZM] (30%): Tar removal by combination of plasma with catalyst [elektronický dokument]
Lit.: 16 zázn.
In: WDS 2017 - Proceedings of Contributed Papers - Physics [elektronický dokument] : Proceedings of the 26th Annual Conference of Doctoral Students WDS 2017. - Praha : MatfyzPress, 2017. - S. 127-132 [online]. - ISBN 978-80-7378-356-3
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AFD Publikované príspevky na domácich vedeckých konferenciách

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AFG01 Cimerman, Richard [UKOMFKAFZM] (60%) - Račková, Diana (20%) - Hensel, Karol [UKOMFKAFZM] (20%): Tar removal by combination of non-thermal plasma with catalyst
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AFH Abstrakty príspevkov z domácich vedeckých konferencií

AFH01 Cimerman, Richard [UKOMFKAFZM] (90%) - Maťaš, Emanuel (10%): Generovanie výboja v štruktúrach podobným automobilovým katalyzátorom (rozšírený abstrakt)
Lit.: 2 zázn.
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BEE Odborné práce v zahraničných zborníkoch (konferenčných aj nekonferenčných)

BEE01 Cimerman, Richard [UKOMFKAFZM] (60%) - Maťaš, Emanuel (10%) - Hensel, Karol [UKOMFKAFZM] (30%): Discharge formation inside the honeycomb structures assisted by surface barrier discharge [elektronický dokument]
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Štatistika kategórií (Záznamov spolu: 11):
ADC Vedecké práce v zahraničných karentovaných časopisoch (1)
AFC Publikované príspevky na zahraničných vedeckých konferenciách (1)
AFD Publikované príspevky na domácich vedeckých konferenciách (3)
AFG Abstrakty príspevkov zo zahraničných vedeckých konferencií (3)
AFH Abstrakty príspevkov z domácich vedeckých konferencií (1)
BEE Odborné práce v zahraničných zborníkoch (konferenčných aj nekonferenčných) (2)

Štatistika ohlasov (8):
[o1] Citácie v zahraničných publikáciách registrované v citačných indexoch (8)

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