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Study of Chemical Processes in Electrical Discharges in Liquids

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STUDY OF CHEMICAL PROCESSES IN ELECTRICAL DISCHARGES IN LIQUIDS

STUDIUM CHEMICKÝCH PROCESŮ V ELEKTRICKÝCH VÝBOJÍCH V KAPALINÁCH

SHORT VERSION OF PH.D. THESIS

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CONTENTS

1 INTRODUCTION

Nowadays the claims to the quality of the environment are rapidly increasing. One of the sharply watched subjects is water environment, especially its harmlessness for the human race and nature in general. The wastewater releasing from plants, hard or chemical industry and households often contains harmful compounds, in many cases of organic origin. These compounds can be hazardous or even toxic for the Earth biosphere and they can cause several problems both in the environment and human race. Therefore it is very important not only to observe these compounds in water but also to remove them from this environment. The best way is to prevent the releasing of such contaminated water to the environment and not to use harmful compounds in the households and industry. But if there is no other way, it is important to know, how water can be treated to become harmless.

Especially aromatic compounds represent an important problem in water treatment technologies because these compounds could not be usually removed using the biological methods only. On the other hand, the destruction of the aromatic ring in these molecules and their subsequent decomposition are carried out very easy using technologies of the Advanced Oxidation Processes. The energy applied to the liquid by these methods is sufficient for the removal of, for example, such compounds as halogenated hydrocarbons, especially chlorinated, that have fatal effects on the mankind and that are precursors of many cancer diseases. According to the contemporary investigation, the future technologies would be based on the combination of these processes together with the biological methods.

One way how to produce high energy and reactive species in liquid is an electrical discharge. Therefore the main efforts of this work are focused on a complex study of the electrical discharge in liquids, particularly the diaphragm discharge generated using the DC non-pulsed voltage. The work follows up the previous Diploma Thesis "Diaphragm Discharge in Liquids" [1] of the same author. The main objects of the presented study related to the generation chemical processes initiated by the electrical discharge in water are hydroxyl radicals and hydrogen peroxide. Determination of these reactive species does not require any difficult method, therefore the observation of their production sensitivity to the initial discharge conditions can be easily recorded. For the first attempts focused on the investigation of the degradation processes, organic dyes of various chemical structure are selected. The motivation for the selection of these model compounds is the simple determination of their concentration in the solution using the absorption spectroscopy and the related visible effect of the solution discoloration during the treatment. Subsequently, big effort of this work focuses on a complex study of the dyes decomposition in the diaphragm discharge carried out at various conditions. Next task extends the investigation to another compounds dissolved in water which removal from this environment should be required. For this reason, solutions containing humic acids are used in experiments and their decomposition is observed.

2 EXPERIMENTAL

Experiments were carried out in a batch discharge reactor specially constructed for the diaphragm discharge generation in water environment (Fig. 1, left) [1]. Plasma was created in a small pin-hole in the dielectric diaphragm dividing two chambers with one high voltage electrode in each part. The DC non-pulsed HV source giving the voltage of about 2 kV was used for the discharge generation. The application of the DC non-pulsed voltage allows the simultaneous study of both plasma polarities, one in each part of the reactor. The simplified scheme of plasma streamers generated in both parts of the reactor is given in Fig. 1, right.

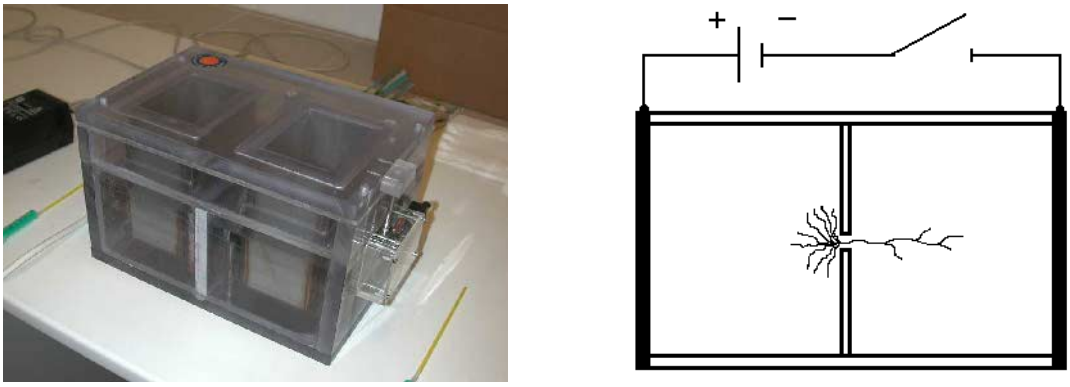

Figure 1: Photograph of the discharge reactor (left) and the simplified scheme of the diaphragm discharge (right).

Water solutions containing etheir pure electrolyte or dissolved organic dye or humic acids mixture (natural or commercial) with added electrolyte to obtain particular solution conductivity were treated by the discharge.

All experiments focused on the reactions in liquid were carried out in the discontinues regime. The sampling frequency was usually 5 or 10 minutes, according to the kind of the experiment. The taken amount also varied according to the specific experiment (3 ml for analysis of degradation processes, 2 ml for the hydrogen peroxide determination, added to 1 ml of titanium reagent). Besides the sampling, it was necessary to exchange the cooling medium during the experiment, because the ice in the cooling mixture was melted by the heating from the discharge. For the determination of reaction products, following analytical methods were used: absorption spectroscopy in UV-VIS region, fluorescence spectroscopy, ICP.

The experiments focused on the creation of reactive species by the discharge in situ and on the analysis by the optical emission spectroscopy were carried out in the continues regime.

The overall uncertainty of the measurements, devices and sampling was estimated on 10-15 %.

3 RESULTS & DISCUSSION

The diaphragm discharge in liquids, particularly in water solutions, have been investigated from generally two points of view. First of them is the physical base of the discharge itself such as the conditions of the discharge creation in the liquid medium. The second point of view is the investigation of the chemical processes initiated by the electrical discharge in water. This part is focused both on the processes producing reactive species in water and subsequent processes in which these species react with another molecules of compounds dissolved in water and cause their decomposition.

3.1 ELECTRICAL AND SOLUTION PROPERTIES

The time evaluations of both discharge current and voltage were obtained for various discharge parameters such as the source voltage tension adjusted on the HV source or the initial solution conductivity. A typical current-voltage time evaluation of the diaphragm discharge in the Na_2HPO_4 solution is given in Fig. 2 and it points to a quasi-pulsed character of the discharge. This feature probably results from the thermal theory of the discharge creation mechanism. The results also point to the high dependence of both discharge current and voltage on the solution conductivity (Fig. 3). While the mean current is increasing with the increasing conductivity, the voltage on the reactor is decreasing with almost the same size. However, the overall power supplied into the reactor remains constant, and thus it is not dependent on the solution conductivity.

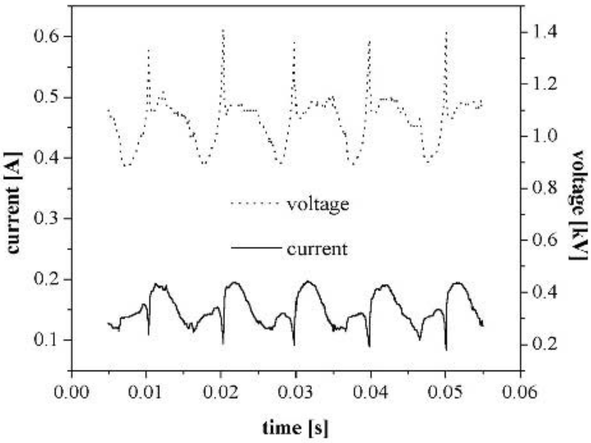

Figure 2: Time evaluations of the discharge current and voltage (left) in 3.7 mM Na_2HPO_4 solution (initial conductivity of 700 μ S·cm^{-1}).

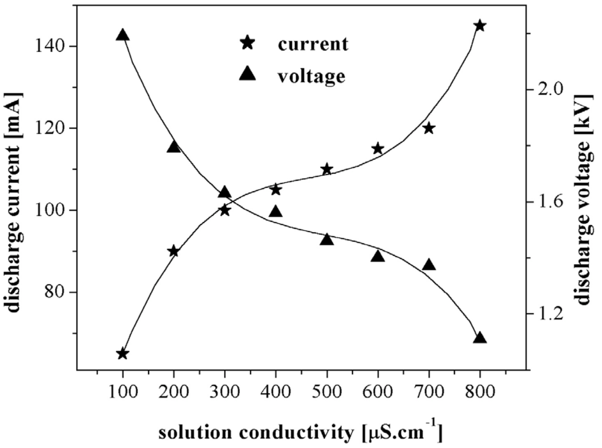

Figure 3: Dependence of the discharge current and voltage on the initial solution conductivity (NaCl solution) at the constant total power (160 W).

The common feature of the conductivity course is its significant increase in time in both discharge polarities (Fig. 4, left). In the first sixty minutes, this increase is approximately linear while after one hour of the experiment, further enhancement in conductivity is only negligible. In the negative discharge, the increase in solution conductivity is much higher than in the case of the positive polarity. The conductivity enhancement is caused by the production of various reactive species such as radicals and ions in the discharge in water solution and by metallic traces (Fe, Cr, etc.) released from the stainless steel electrodes by the electrolysis. Another important and observed parameter is pH of the solution (Fig. 4, right). While in the positive discharge pH is increasing in time, at the negative polarity this parameter is decreasing during the experiment. This opposite behaviour is also caused by the high influence of the electrolytic effect in water solution together with the creation of the reactive species by the discharge itself.

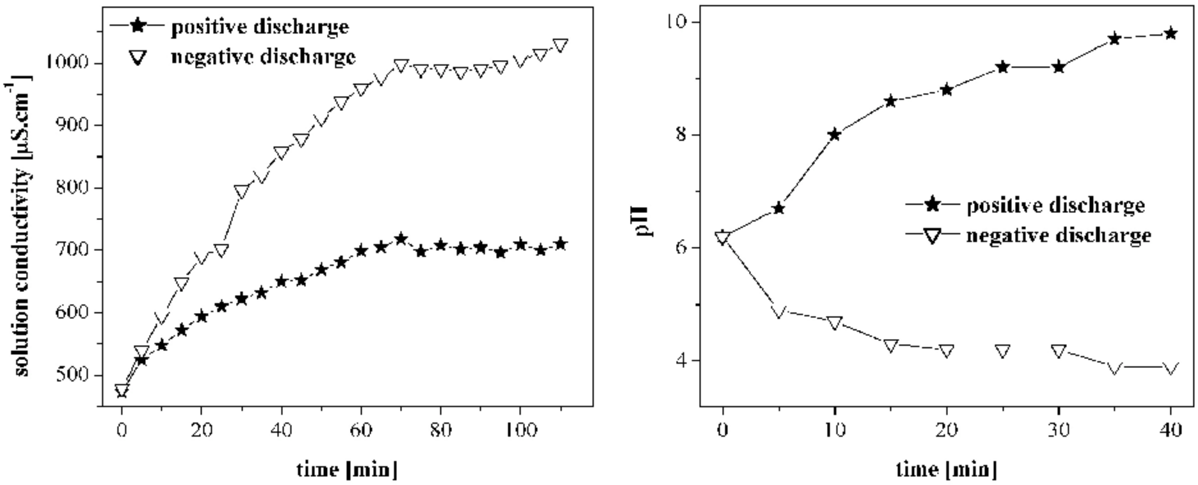

Figure 4: Changes in the solution conductivity (left) and pH (right) during the discharge treatment in 5 mM NaCl solution (260 W).

3.2 GENERATION OF REACTIVE SPECIES

Generally, electrical discharges in water produce various active species such as radicals, ions and neutral molecules [2-4]. In this work, two of these species were selected for the investigation, OH radical and hydrogen peroxide. The study investigates conditions of their creation by the diaphragm discharge in water solutions and also the influence of experimental parameters on their production.

3.2.1 Hydroxyl radicals

One of the most important species produced by the electrical discharge in water is hydroxyl radical. This specie belongs to the most reactive particles in general, its oxidation potential of 2.80 V is the second highest after fluorine [4]. In our investigated system, it represents the most reactive specie, so it is responsible for majority of the chemical reactions in the solution.

Determination of hydroxyl radicals was carried out by the optical emission spectroscopy. For the next comparison of the obtained results, the relative integral emission intensity of hydroxyl radicals was calculated over the range of 306.5-318 nm. This parameter represents a better quantitative interpretation of each experiment. The calculation is possible due to the fact that the OH spectrum in the defined region does not overlap another spectral lines of elements contained in the solution.

In all tested solutions, the emission intensity, and therefore the amount of the produced OH radicals, increases with the increasing applied power. The enhancement is more or less directly proportional to the discharge power. The common feature in all cases is also the OH emission intensity decrease in time. The most stable behaviour of the discharge and the OH generation was observed in the 4 mM NaCl solution at the conductivity of 400 µS·cm^{-1}.

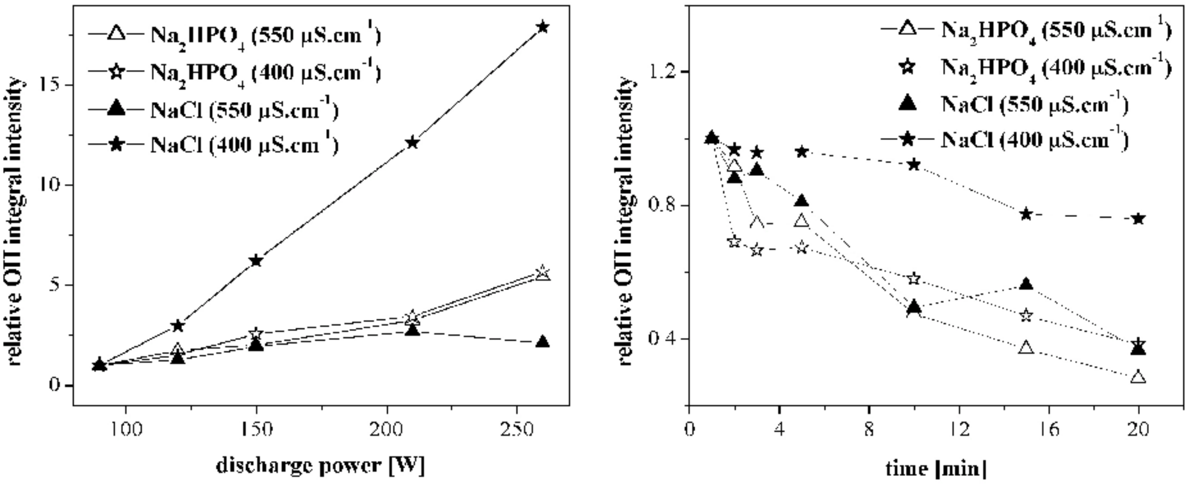

Figure 5: Influence of the discharge power (left) and treatment time (right) on the relative OH emission intensity in two electrolytes of various initial solution conductivity.

3.2.2 Hydrogen peroxide

Due to the reaction of hydroxyl radicals produced by the electrical discharge in water, molecules of hydrogen peroxide are formed according to the equation [5]:

$$\cdot OH + \cdot OH \rightarrow H_2O_2.$$

A selective determination of hydrogen peroxide can be carried out by the specific colorimetric method using the titanium reagent. The linear evaluation of hydrogen peroxide during the discharge treatment enables us to calculate the rate constant of hydrogen peroxide formation for each experiment [5]:

$$c_{H2O2,\,t} = k_{H2O2} \cdot t,$$

where $c_{H2O2,\,t}$ is the H_2O_2 concentration in a particular time and k_{H2O2} represents the rate constant of hydrogen peroxide formation by the discharge.

There is a significant difference between the hydrogen peroxide generation in the positive and negative discharge observed in all experiments. In the case of the positive polarity, the concentration linear increase is much higher and the final H_2O_2 concentration becomes approximately 1.8 mmol·l^{-1} (60 mg·l^{-1}) after one hour of the discharge treatment. On the other hand, the final concentration reaches the value of only 0.25 mmol·l^{-1} (8.5 mg·l^{-1}) in the opposite polarity, that is seven times lower. The reason of this difference we can find in the energetic scheme of the diaphragm discharge in liquids.

The dependence of the hydrogen peroxide production on the overall discharge power is almost directly proportional (Fig. 7) and the final H_2O_2 concentration after the one-hour experiment significantly rises by the increasing applied power.

At a lower conductivity of the NaCl solution, until approximately 200 $\mu S \cdot cm^{-1}$, the generation of H_2O_2 is weak, also due to the lower stability of the discharge itself. If the initial conductivity is adjusted in the range of 300-500 $\mu S \cdot cm^{-1}$, the final concentration of produced hydrogen peroxide reaches the maximal value. Further enhancement of the conductivity leads to the significant decrease in the H_2O_2 formation. A similar situation is achieved in the $NaHPO_4$ solution, only the optimal value of the conductivity is shifted to approximately 900 $\mu S \cdot cm^{-1}$ (Fig. 8).

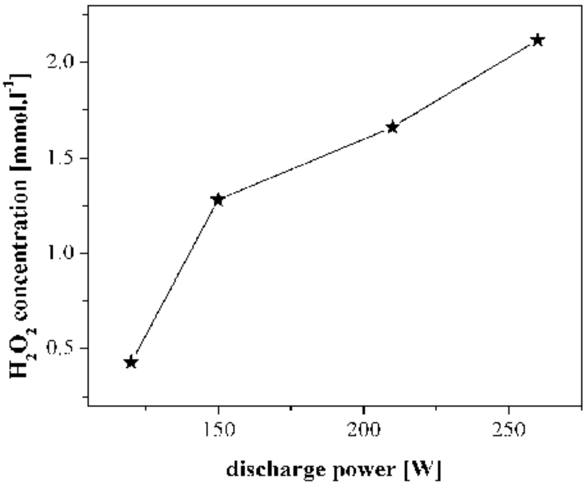

Figure 7: Influence of the discharge power on the final H_2O_2 concentration produced by the one hour positive discharge treatment (3 mM NaCl, initial conductivity of 300 $\mu S \cdot cm^{-1}$).

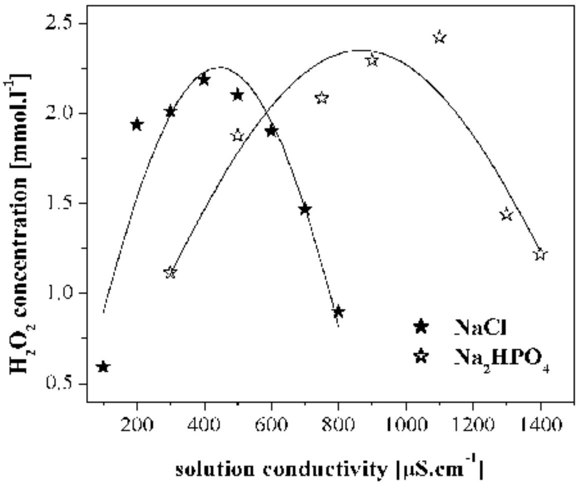

Figure 8: Influence of the initial solution conductivity on the final H_2O_2 concentration produced by the one hour positive discharge treatment, applied power of 200 W (Na_2HPO_4) and 260 W (NaCl).

Various diaphragm materials of the different thickness were tested in H_2O_2 generation experiments. The final results in the form of the appropriate rate constants are summarised in Table 1. The diaphragm material should be chemically inert and also mechanically stable in the discharge, that is a very aggressive environment. The best results in the hydrogen peroxide production were obtained if the material PES of the thickness of about 0.20 mm was used. On the other hand, PTFE material was totally unsuitable because of its fast mechanical degradation.

Table 1: Rate constants of hydrogen peroxide generation by the discharge created using various dielectric diaphragms.

Material	Thickness (mm)	Rate constant ($mol \cdot l^{-1} \cdot s^{-1}$)
PET	0.25	$3.750 \cdot 10^{-7}$
PES	0.05	$1.167 \cdot 10^{-7}$
PES	0.19	$3.600 \cdot 10^{-7}$
PTFE	0.50	unmeasurable
PTFE	1.00	unmeasurable
POM-C	1.00	$4.667 \cdot 10^{-8}$

3.3 DEGRADATION OF ORGANIC COMPOUNDS

Electrical discharge in water produces various chemical reactive species (radicals, ions, molecules) that can further initiate subsequent chemical reactions. The main role in these degradation processes is played by hydroxyl radicals, the most reactive species in the system.

3.3.1 Organic dyes

Each dye absorbs the light from the UV-VIS region of electromagnetic radiation and the wavelength with the maximal absorption intensity is a specific characteristic for each compound. The absorption intensity is directly proportional to the dye concentration in the solution, according to the Lambert-Beer law. Therefore, the simplest analytical method used for the determination of the dye concentration is the absorption spectroscopy over the wavelengths region of 200-700 nm.

The typical time evaluation of the relative dye concentration during the discharge treatment is presented in Fig. 9, left. In the negative discharge, the discoloration goes much faster than in the opposite polarity. The concentration decreases almost exponentially, it drops to approximately 20 % of the initial concentration after the first 10 minutes of the discharge but further decrease is more or less negligible. In the case of the positive discharge, the decomposition goes more slowly but after 100 minutes, it reaches almost the same final concentration as in the negative polarity (20 % of the initial concentration). The experiment with the pure electrolysis in the reactor was carried out to confirm the hypothesis focused on the degradation mechanism based on the electrochemical oxidation (Fig. 9, right). The dye concentration decreases in time and the decomposition is also more significant in the part with the positive electrode. But the decrease is not so much rapid as in the case of the discharge treatment, the final dye concentration becomes approximately 50 % of the initial concentration after the one-hour treatment.

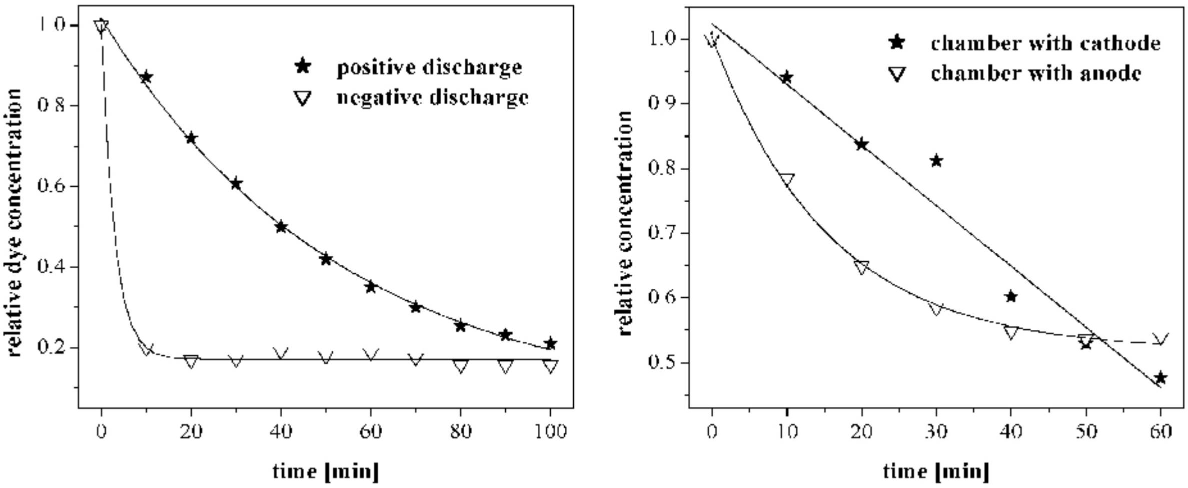

Figure 9: Relative concentration decrease of the dye Direct Red 79 during the discharge treatment (left: 120 W) and during the electrolysis (right: 40 W) in both discharge polarities (5 mM NaCl, initial conductivity of 500 μS·cm^{-1} and initial dye concentration of 12 mg·l^{-1}).

The dye decomposition is highly influenced by the increasing discharge power and the dependence of the final dye concentration decrease on the applied power is almost directly proportional (Fig. 10, left). The dye decomposition is much sensitive to the applied power in the positive plasma.

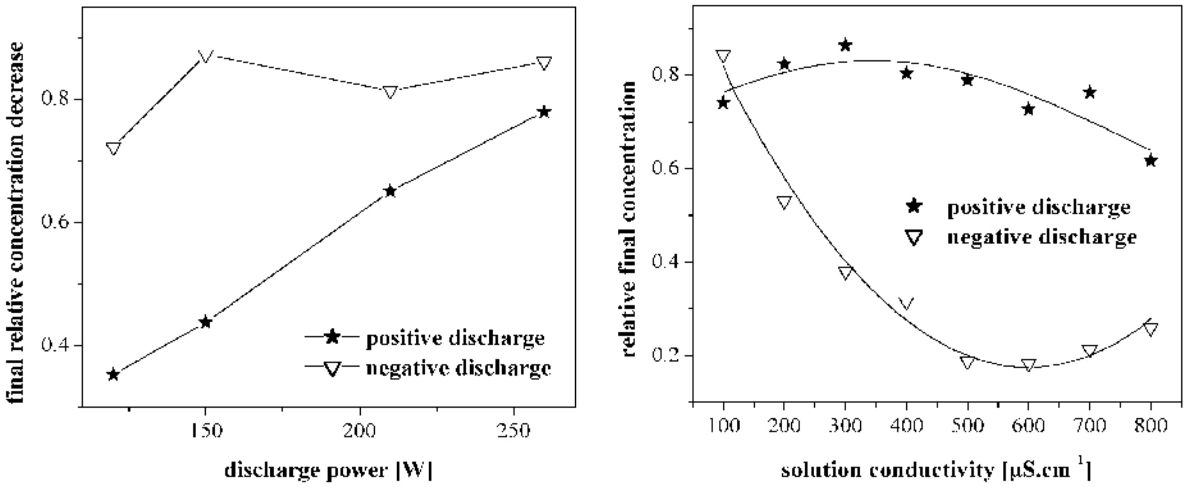

Figure 10: Influence of the discharge power on the organic dye Direct Red 79 decomposition (left). Final dye concentration in the relative scale after 30 minutes of the discharge treatment for various initial conductivity of the NaCl + Direct Red 79 solution (160 W, initial dye concentration of 12 mg·l^{-1}).

The influence of the initial solution conductivity on the degradation process had been investigated, too. While in the positive discharge, the decomposition is generally weak at each tested conductivity value, more interesting results were obtained in the negative discharge (Fig. 10, right). We can assume that there is an optimal initial conductivity of the solution for the degradation process in the diaphragm discharge and this conductivity should be adjusted at 500-600 μS·cm^{-1} for the NaCl solution. This value closely corresponds to the optimal conductivity value for the hydrogen peroxide generation.

Ferrous ions contained in the solution catalysed the decomposition of hydrogen peroxide to hydroxyl radicals in the so-called Fenton reaction. Thus, the presence of iron, either involved from the stainless steel electrodes by the electrolysis or specially added in the form of an electrolyte into the solution, enhances the production of OH radicals. This phenomenon is the reason of higher dye decomposition in the presence of ferrous ions (Fig. 11).

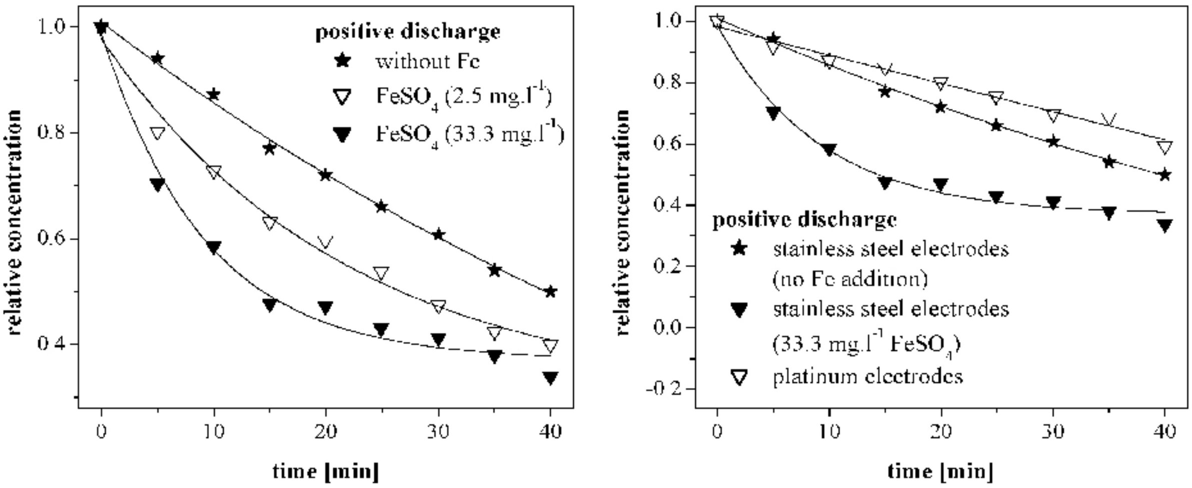

Figure 11: Influence of ferrous ions on the dye decomposition (Direct Red 79, initial concentration of 6 mg·l^{-1}, initial solution conductivity of 500 μS·cm^{-1}, 160 W).

3.3.2 Humic acids

The ability of the diaphragm discharge generated in liquids to decompose organic compounds in general has been already confirmed by the attempts with various organic dyes [6]. Next efforts lead to the removal of compounds occurring also in natural water environment and thus the humic matters were selected for our further investigation. Water solutions containing mixtures of humic acids (HA) either of natural and commercial origin (HUMIN-P 755) were treated by the discharge. Qualitative changes in the solutions were determined by the absorption spectroscopy in the UV-VIS region and by the fluorescence spectroscopy.

The time evaluation of the relative concentration according to the absorption intensity is given in Fig. 12 for the natural humic solution, the discharge treatment of the commercial solution gave almost the same results. The decrease of the absorption intensity at the investigated wavelength in the negative discharge treatment is only slight and after approximately 25 minutes even increasing, and in the positive discharge, the decrease is nearly negligible. This phenomenon is caused by the increasing concentration of hydrogen peroxide produced by the discharge. This specie absorbs the light at the similar wavelength as humic acids, and thus it disturb the determination of humic concentration using the absorption spectroscopy.

Therefore, another determination of humic acids properties in the solution was carried out. The quality index characterising humin solutions and mixtures, so-called the humification index, was calculated on the basis of the emission intensity obtained from the fluorescence spectra [7]. This index gives to the ratio the fluorescence emission intensity at 470 nm and 400 nm and its value is related to the degree of humic acids mixture decomposition. The values of humification index are compared in Fig. 13 as a function of treatment time. The index slightly decreases in the positive plasma treatment. This effect represents the decrease of aromatic and the increase of aliphatic components in the mixture. In the negative discharge, the humification index shows the initial increase of the aromatic character, but after approximately 20 minutes of the treatment, the tendency changes and the content of aliphatic components in the solution significantly increases. We can finally assume that the character of humic acids solution treated by the diaphragm discharge leads to the lower content of aromatic components in the solution.

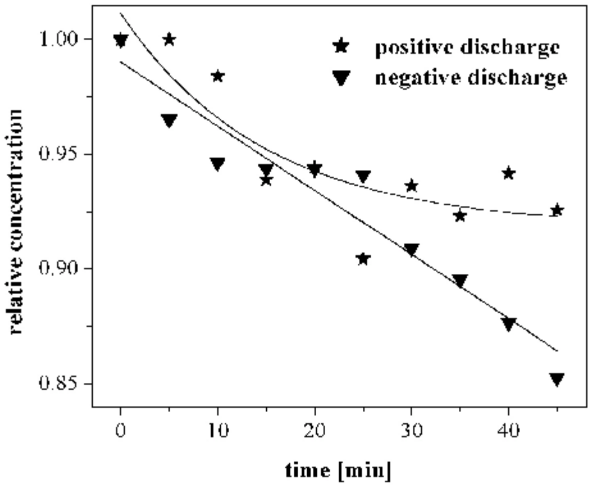

Figure 12: Relative concentration decrease of humic acids in the natural solution treated by the diaphragm discharge (initial HA concentration of 1.9 mg·l^{-1}, maximal absorbance at 291 nm, 5 mM NaCl, initial solution conductivity of 500 µS·cm^{-1}, initial pH value of 5.7, input power of 160 W).

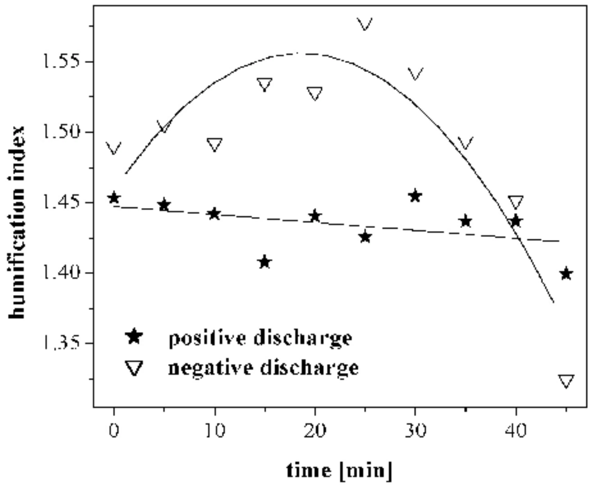

Figure 13: Values of humification index as a function of the treatment time for both discharge polarities (12 mg·l^{-1} HA solution, 5 mM NaCl, initial solution conductivity of 500 µS·cm^{-1}, initial pH value of 6.8, input power of 160 W).

4 CONCLUSION

The main aim of this work focuses on the investigation of chemical processes initiated by the electrical discharge in liquids, particularly in various water solutions. The study follows up contemporary world-wide trends in the field of advanced oxidation processes. This work is in fact a continuation of the Diploma thesis of the same author, “Diaphragm discharge in liquids” [1], and it extends the region of interest to more subjects, processes and general effects related to the electrical discharge in water. The final result should demonstrate a complex view on this phenomenon and its possible application in water treatment. Therefore not only chemical, but also physical processes are observed to obtain a wide spectrum of characteristics representing the discharge behaviour at various conditions and concerning economic aspects, too. The control of the optimal process operating is one of the most important tasks.

In this work, the diaphragm discharge in water solutions is generated using the DC non-pulsed high voltage source. Two kinds of plasma streamers with the opposite polarity and different properties such as the velocity of propagation and structure are created in such system, and thus the simultaneous study of the processes in both discharge polarities can be observed.

The first part of the work is focused on the discharge generation itself, its electrical characteristics and experimental conditions that can influence the discharge stability. The electric measurements point to the quasi-pulsed character of the diaphragm discharge generated in liquids. Measurements of the discharge current and voltage show the significant current increase with the increasing solution conductivity and on the synchronous voltage drop connected to the solution conductivity enhancement. However, the overall discharge power supplied into the reactor remains constant in the studied range of solution conductivity. The discharge stability requires an optimal value of conductivity depending on the particular electrolyte used for the conductivity adjustment.

The study determines the significant increase in conductivity during the whole discharge treatment. The main two reasons of this enhancement are related to the production of various reactive species by the discharge in water and also to the presence of metallic traces (iron, chromium, etc.) released from the electrodes by the electrolysis. Also the pH value of the solution significantly changes during the discharge. It increases in the positive plasma while in the negative discharge, it decreases. This phenomenon is mainly supported by the electrolysis.

The main task of this work contains two greater parts investigating the processes initiated by the diaphragm discharge in water solutions, the generation of various active species and the subsequent degradation of organic compounds dissolved in water. These processes are studied as a function of various discharge parameters.

The most important species generated by the electrical discharge in water are hydroxyl radicals because of their high oxidation potential. Production of hydroxyl radicals is slightly decreasing in time, probably due to some changes in the pin-hole properties during the discharge treatment. On the other hand, their generation remarkably increases with the increasing input power and the enhancement is more or less linear.

Hydrogen peroxide is created in the reaction of hydroxyl radicals and its amount linearly increases during the discharge treatment. The much higher production is achieved in the positive plasma, the final H_2O_2 concentration obtained after one-hour experiment reaches approximately 60 $\text{mg}\cdot\text{l}^{-1}$ (input power of 200 W), while in the negative discharge, the obtained concentration is nearly seven times lower, only about 8.5 $\text{mg}\cdot\text{l}^{-1}$ at the same experimental conditions. The increasing discharge power significantly enhances the hydrogen peroxide formation and the dependence of the final H_2O_2 concentration on the supplied power is more or less linear. The optimal value of solution conductivity differs according to the selected electrolyte (300–500 $\mu\text{S}\cdot\text{cm}^{-1}$ for NaCl solution). An important parameter is the quality of the dielectric material (PET with the thickness of 0.20 mm was assumed as the most convenient material).

Organic dyes were selected as model compounds for the investigation of the degradation processes initiated by the diaphragm discharge in water solutions (in most of experiments, Direct Red 79). The mechanisms of the dye destruction were assumed as following: the attack of hydroxyl radicals generated by the discharge and the electrochemical oxidation taking place on the electrodes due to the electrolysis. The influence of UV radiation produced by the discharge had not been investigating.

The discharge polarity significantly influences the process. In the negative plasma, the dye decomposition goes very fast and the concentration drops to approximately 20 % already in the first 10 minutes of the treatment (input power of 120 W). On the other hand, the same concentration value is achieved till after 100 minutes in the positive plasma at the same conditions. The process has the opposite result as the H_2O_2 generation, probably due to the significant influence of the electrolysis that is much important factor in the DC non-pulsed discharges than in other ways of plasma generation. The magnitude of the input power significantly influences foremost the degradation by the positive discharge and the dye decomposition is enhanced by the increasing power almost linearly. The dye degradation process also requires an optimal value of the solution conductivity (500–600 $\mu S \cdot cm^{-1}$ for NaCl solution). The influence of the dye structure and various electrolyte kind on the dye degradation by the discharge is studied by this work, too. The presence of iron (particularly ferrous ions) remarkably enhances the dye decomposition.

This work also represents a pilot study in the field of humic acids problems, both of natural and commercial origin. The index of humification, representing the mutual content of aliphatic and aromatic components in the humic mixture, points to the decreasing humification degree during the discharge treatment. The results show a certain agreement in degradation processes in the solutions of both organic dyes and humic acids, however, the processes in humic acids mixtures are more complicated and require further detailed investigation.

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SOUHRN

Hlavním cílem disertační práce je snaha o komplexní popis elektrického výboje generovaného v kapalinách. Studium se konkrétně zaměřuje na diafragmový výboj buzený pomocí stejnosměrného nepulsního napětí o velikosti okolo 2 kV. Experimenty jsou realizovány ve speciálně zkonstruovaném reaktoru využívajícím pro generaci elektrického výboje dielektrickou diafragmu. Jelikož je ke generaci výboje použito stejnosměrné nepulsní napětí, v systému se tvoří dva různé typy plazmových kanálů s opačnou polaritou, které dále propagují k příslušné elektrodě, a tak je možno sledovat vybrané procesy pro obě polarity současně. Důležitým parametrem, který má podstatný vliv na stabilitu výboje, je vodivost použitého roztoku, přičemž záleží i na typu elektrolytu. Naproti tomu ale celkový vstupní výkon dodávaný do reaktoru není na vodivosti závislý. Vodivost je nastavována rozpuštěním definovaného množství zvoleného elektrolytu v destilované vodě.

Práce se zaměřuje na studium generace hydroxylových radikálů a peroxidu vodíku pomocí výboje buzeného v různých vodných roztocích. Souběžně je sledován také vliv podmínek výboje na tyto procesy. K přímému stanovení produkce OH radikálů slouží optická emisní spektroskopie, koncentrace generovaného peroxidu vodíku je stanovována nepřímo kolorimetrickou metodou. Proces generace obou částic ovlivňuje zejména velikost přiloženého napětí, produkce se s rostoucím napětím výrazně zvyšuje. Tvorba peroxidu vodíku je navíc silně závislá na polaritě dodávaného napětí, vyšší efektivity je dosahováno v kladném výboji, při použití záporné polarity výboje je generace téměř řádově nižší. V práci je rovněž věnována pozornost detailnímu studiu vlivu dalších parametrů, jakými jsou např. vodivost roztoku, druh použitého elektrolytu, vlastnosti dielektrické diafragmy apod.

Druhá část práce je zaměřena na studium degradace organických látek v diafragmovém výboji. Jako modelové látky byly použity vodné roztoky různých organických barviv. Rozklad těchto látek je spojen s jejich odbarvením, proto lze pro stanovení koncentrace barviva jednoduše využít absorpční spektroskopii. Degradační procesy jsou diskutovány s ohledem na vliv různých podmínek výboje. Ve stručnosti lze shrnout, že rozklad barviva je mnohem vyšší při použití záporné polarity výboje. Dalšího zvýšení rozpadu barviva lze dosáhnout vyšším napětím a přítomností železnatých iontů v roztoku. Pro vyšší efektivitu procesu je nutné nastavit optimální vodivost zkoumaného roztoku. Hodnota optimální vodivosti roztoku je specifická pro každý druh elektrolytu a úzce souvisí s optimální hodnotou vodivosti zjištěnou pro proces generace peroxidu vodíku.

Poslední část práce je věnována studiu diafragmového výboje realizovaného v roztocích obsahujících směsi huminových kyselin, ať už přírodních či komerčních, a představuje pilotní studii pro další pokračování výzkumu s cílem praktické aplikace vhodné pro využití v ochraně životního prostředí. Z fluorescenčních spekter získaných před a po úpravě výbojem lze stanovit tzv. index humifikace, který porovnává obsah aromatických a alifatických složek ve směsi. Výsledky ukazují na pokles stupně humifikace během výboje v roztoku, tedy dochází k vzrůstu obsahu alifatických složek.