The Types of Plasma Reactors in Wastewater Treatment

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Abstract. Water pollution is a serious problem in the development of society of China. The plasma technology is one of the advanced oxidation technologies which is an efficient method in wastewater treatment. In this paper the degradation mechanism of organic pollutants in water by plasma is suggested, which is the main chemical reactions and physical effects, the different types of discharge and the corresponding reactors have been mentioned, including pulsed discharge plasma reactor, gliding arc discharge reactor and contact glow discharge electrolysis plasma reactor, especially the reactions in dielectric barrier discharge plasma. The plasma combined with another oxidation reaction processes also are reviewed, including catalyst, Ultraviolet radiation and Fenton reaction combined with plasma reactor.

1. Introduction
Nowadays, the problem of global water pollution has attracted much attention and the conventional treatment methods, including physical treatment, chemical treatment, biological treatment and so on. Unfortunately these conventional methods [1, 2] which cannot completely remove organic pollutants, therefore an efficient water treatment technology is demanded [3]. The advanced oxidation technologies (AOTs), one of the chemical methods in wastewater treatment are developing and getting more and more attention [4]. Hydroxyl groups or other particles could be produced by AOTs, which will react with oxidize organics. The plasma oxidation has a advantages of high efficiency, no secondary pollution and green environmental protection [5]. In the process of plasma treatment, the high-energy electrons and the neutral radicals are in constant collision to form active substance including electrons, ions, active radicals, and ultraviolet light [5, 6], which will cause some chemical reactions and physical phenomena.

Until now, the research contents of water treatment by plasma, including plasma cooperate with catalytic oxidation, plasma modification of adsorbents, types of discharges, OH· discharge in liquid, etc., have been reported in detail [5, 7, 8]. In this review, the contribution focuses on the effective plasma reactors in water treatment, as well as the degradation mechanism of organic pollutants [5].

2. All reactive mechanism during water treatment by plasma

2.1. Chemical reactions
Plasma is demonstrated a high selectivity and energy efficiency way to enhance chemical reactions [5]. Generally, there are three modes in discharge to treatment liquid solutions, such as discharging above
the liquid surface, direct discharge in liquid, and discharges in bubbles/vapor in liquid [8, 9]. During these discharges, sufficient radicals and species will be produced.

1) Radical reactions based on hydroxyl groups

Decomposition, ionization, rotational, and vibrational excitation reactions will occur when discharge in water. These processes can produce hydroxyl and hydrogen radicals as reactions shown in equations (1)-(7) [5, 10, 11]:

\[
\begin{align*}
\text{H}_2\text{O} + \text{e} & \rightarrow \text{OH} + \text{H} + \text{e} \\
\text{H}_2\text{O} + \text{e} & \rightarrow \text{H}_2\text{O}^+ + 2\text{e} \\
\text{H}_2\text{O} + \text{H}_2\text{O}^+ & \rightarrow \text{H}_3\text{O}^+ + \text{OH} \\
\text{H}_2\text{O} + \text{e} & \rightarrow \text{H}_2\text{O}^* + \text{e} \\
\text{H}_2\text{O} + \text{H}_2\text{O}^* & \rightarrow \text{H}_2\text{O} + \text{OH} + \text{H} \\
\text{H}_2\text{O} + \text{H}_2\text{O}^* & \rightarrow \text{H}_2\text{O} + \text{OH} + \text{H}_2 \\
\end{align*}
\]

Hydroxyl plays a crucial role in water treatment. Shao P. R. et al. [12, 13] investigated the role of hydroxyl radical OH\* in the degradation efficiency of sulfadiazine. The similar method was used in the study of wastewater treatment by Min Wang et al. [14], who also proved that OH\* played a main role in the degradation of antibiotic residues in equation (8). In addition, the degradation was also relative to other active particles such as H\* and e\*\_aq. In aqueous the electrons and H\* radicals are strong reducing agents in plasma chemistry, the e\*\_aq is formed during the radiolysis of water, and the H\* radicals comes from equations (1) and (5) [14].

\[
\text{OH} + \text{other species} \rightarrow \text{oxidized products} \\
\]

2) Ozone reactions

When the plasma generation in oxygen, oxygen can promote the formation of hydroxyl groups, and also react with oxygen to form ozone equations (9)-(10). Furthermore, ozone can dissolve in water to generate hydroxyl radical, which oxidation capability is much stronger than ozone as shown in equations (11)–(13) [14-18].

\[
\begin{align*}
\text{O} + \text{H}_2\text{O} & \rightarrow 2\text{OH} \\
\text{O} + \text{O}_2 & \rightarrow \text{O}_3 \\
\text{OH}^- + \text{O}_3 & \rightarrow \text{HO}_2^- + \text{O}_2^- \\
\text{O}_2^- + \text{H}^+ + \text{O}_3 & \rightarrow \text{HO}_3^- + \text{O}_2 \\
\text{HO}_3^- & \rightarrow \text{OH} + \text{O}_2 \\
\end{align*}
\]

3) Hydrogen peroxide reactions

Another active molecule is hydrogen peroxide (H₂O₂), which can be formed in discharge as equations (14)-(15) show. As known H₂O₂ is also widely used in industrial applications [19, 20]. In plasma, hydrogen peroxide will react with e\*\_aq and H\* at the same time as equations (17)-(18) shows [21]; Moreover, hydrogen peroxide will also react with ozone to form free radicals(equations (18) ) [21, 22]:

\[
\text{OH} + \text{OH} \rightarrow \text{H}_2\text{O}_2 \\
\]
\[
\begin{align*}
2H_2O & \rightarrow H_2O_2 + H_2 \quad (15) \\
H_2O_2 + e^{-} & \rightarrow OH^{-} + OH \cdot \quad (16) \\
H_2O_2 + H & \rightarrow H_2O + OH \cdot \quad (17) \\
H_2O_2 + O_3 & \rightarrow HO_2^{-} + O_2 + OH \cdot \quad (18)
\end{align*}
\]

### 2.2. The physical phenomena

Ultraviolet (UV) irradiation is inevitable in the plasma discharge. UV disinfection [23] and UV degradation [24] have become an alternative of chemical treatment in water treatment. It can also decompose hydrogen peroxide to hydroxyl groups during plasma as equations (19) shows [10, 25]:

\[
H_2O_2 + h\nu \rightarrow OH^{-} + OH \cdot 
\]

Besides, the shockwave is also in discharge [26]. Shock wave can make pyrolysis and chemical reactions, resulting in the formation of more free radicals and hydrogen peroxide.

As known in non-thermal plasma process, the discharge can make high temperature. [5]. It is helpful for the decomposition of waste water. Joshua P. Kearns et al. [27] studied the pyrolysis charcoals to remove 2, 4-D herbicide in polluted water. The results was that the pyrolysis technology can efficiently destroy the organic structure.

### 3. The plasma reactors inorganic pollutant degradations

#### 3.1. Dielectric barrier discharge (DBD) reactor

Dielectric barrier discharge is a non-thermal or non-equilibrium plasma and can be generated at atmospheric pressure [28]. It is known that the typical DBD plasma is generated between two electrodes (plate type and coaxial cylinder type) [18, 29]. Dielectric barrier is generally quartz glass, ceramics or Teflon and so on [17]. There are also some specially configured DBD devices, such as sliding discharge and asymmetric surface DBD, DBD with the dielectric is perforated, micro cavity plasma devices, Resistive Barrier Discharge (RBD) with a highly resistive sheet [30].

When DBD plasma is applied in water treatment, a large number of active species are emerged. Kefeng Shang [4] designed plate-to-plate configuration in cylindrical DBD reactor (Fig. 1a), they studied the degradation of acid orange 7 (AO7) dye with persulfate (PS). The possible reason was more SO\(_4^{-}\) and \(\cdot\)OH radicals producing just like equations (20)-(22).

\[
\begin{align*}
S_2O_8^{2-} & \rightarrow SO_4^{-} \cdot + SO_4^{2-} \quad (20) \\
SO_4^{-} + OH^{-} & \rightarrow SO_4^{2-} + OH \cdot \quad (21) \\
SO_4^{-} + H_2O & \rightarrow HSO_4^{-} + OH \cdot \quad (22)
\end{align*}
\]

Fig. 1b shows other type DBD plasma source for wastewater treatment. The plasma formed in a special porous ceramic tube reactor, which was employed to degrade aqueous bisphenol A (BPA) solution [15]. Ozone and hydroxyl radicals could completely oxidize BPA into intermediate compounds after 30 min. It is worthy that the using of porous ceramic tube is beneficial for discharging in liquid, which improves the degradation efficiency of waste water. A novel DBD loop reactor shown in Fig. 1c was designed for degrading of cyanide anion (CN\(^-\)) in waste water [19]. The liquid was circulated through the discharge zone which was beneficial to the generation of active species to efficiently moving CN\(^-\). The CN\(^-\) concentration was linearly decreased during treatment period.

Abdulet al. [28] developed a winding electrode DBD plasma water treatment system (Fig. 1d) to reduce chemical oxygen demand (COD) in industrial rubber wastewater. But the winding of copper wire...
might affect the production of plasma. Kil-Seong Kim et al. [31] described the atmospheric-pressure DBD reactor (Fig. 1e) to degrading the sulfonamide antibiotics. A ceramic gas diffuser was installed at the bottom of the device to generate a large number of bubbles, which can help the diffusion of plasma. The effects of relative humidity (RH) on removal efficiency of common carcinogenic compound-benzene were investigated by Ma Tianpeng et al which based on a double dielectric reactor [32].

![Diagrammatic sketches of various DBD reactors.](image)

**Figure 1.** Diagrammatic sketches of various DBD reactors. a plate-to-plate reactor [4], b porous ceramic tube reactor [15], c loop reactor [19], d copper wire wrapped reactor [28], e underwater reactor [31], f double dielectric reactor [32].
dielectric DBD reactor [32]. As Fig. 1f showed, an experiment was studied to degrade red acidic waste solution in industry with DBD by Xueji Xu [18].

And we can see clearly from the above device, some discharge system work in the stationary, like a, c and f in Figure 1, and some work in a continuous flow mode or a diffusion type, including b, e and d. And we can find that the latter has the advantage of degrading target pollutants, especially the degradation rate, it increases the frequency of interaction with the plasma. In conclusion, it is an obvious that DBD plasma has more advantages than other discharge forms. Lots of particles, electrons, free radicals are full with plasma channel. However, there are still a lot of problems about higher energy input, cost issues, etc. still can’t be solved.

### 3.2. Other representative types of discharge reactors

Besides DBD, other types of discharge reactors were also designed in recent years for waste water treatment. Selma Mededovic Thagard et al. [9] evaluated plasma-based water treatment (PWT) for the

![Figure 2](image_url)

**Figure 2.** Diagrammatic sketches of another types of discharge reactors. a enhanced-contact reactor [9]. b multiple mobile iron (Fe) based electrodes reactor [34]. c bubble spread reactor [33]. d gas-phase pulsed corona discharge reactor [16].

Treating 23 types of environmental contaminants by enhanced-contact reactor in argon bubbling (Fig. 2a). The multiple mobile iron (Fe) based electrodes reactor (Fig. 2b) [34], discharge propagating in a bubble in water reactor (Fig. 2c) [34], and gas-phase pulsed corona discharge (PCD) reactor (Fig. 2d) [16] were also using in the waste water treatments. All these plasma device could produce sufficient species, such as H2O2, ·OH, ultraviolet radiations, atomic nitrogen, and atomic oxygen which are efficient for decomposing waste water.

#### 3.2.1. Pulsed discharge plasma reactor

To degrade f Nano-Filtration (NF) in Wastewater Treatment Plant in a gas phase of PCD reactor. The BOD7/COD ratio of the Nano-filtration (NF) concentrate was increased 3.7 times due to the oxidation [35]. Pulsed plasma discharge combined with charcoal was used in methyl orange (MO) treatment reported by Faria et al (Fig. 3a) [13]. The reaction system adopted a multi-needle-to-plate reactor. Experimental results showed that the MO degradation efficiency reached to 69.8% within 7.5 min. Ozone and ·OH radicals were generated from oxygen and water.

Pulsed-streamer corona discharge (Fig. 3b) [36] has been utilized by Roya Pourzarea for treatment of carbamazepine (CBZ) in aqueous solution. CBZ has been removed and degradation levels of 14-94% were achieved within 25 minutes of treatment. A pulsed spark plasma (Fig. 3c) [37] discharge system was developed and tested as an energy efficient water sterilization method by Jiansheng Zheng. Results showed that this system has high energy efficiency and without secondary pollution. Besides the above reactions, there are also DC impulse-free (Fig. 3d) [38] corona discharge reactions. A dual pin-to-plate high-voltage corona discharge system was studied to degrade the Acid Blue 25 dye. By El-Tayeb A et al. In corona discharge, active species like the hydroxyl radical (OH·) and hydrogen atoms (H) were produced.

#### 3.2.2. Gliding arc discharge reactor

Mehnaz Gharagozalian et al. [10] studied the gliding arc (G Arc) plasma treatment reactor (Fig. 3e). They reported that G Arc plasma was very efficient to
6
decontaminate waste water. Degradation of three kinds of textile dyes and their mixture were investigated by C. Du and J. Yan [39] by using the gliding arc discharge plasma. It is observed that the degradation rates are 96.55% for AA, 94.66% for AOII, and 89.69% for AAB. Hao Zhang et al. [40] studied the hydrogen production from methanol in a novel direct current (DC) rotating gliding arc (RGA) plasma reactor. AlHamad Bet al. designed a non-thermal gliding-arc plasma discharge reactor [41]. A series of reactive species (OH⁻, NO, and H₂O₂) were formed in the discharge.

3.2.3. Contact glow discharge electrolysis plasma reactor. Among the various AOTs, contact glow discharge electrolysis (CGDE) has already been shown to be a suitable plasma process for the degradation of various pollutants in water. In the reaction region, hydroxyl radicals can be formed and work as the main oxidant together with hydrogen peroxide [42]. Susanta K. Sen Gupta used CGDE [43, 44] or plasma electrolysis (PE) to treat waste water. The results showed that it was efficient to degrade aromatics, trichloroacetic acid, bromoform, dichloromethane, dyes, ionic liquids, antibiotics etc. [45]. Similar works were done by Ryo Amano and Meguru Tezuka [44] (Fig. 3f) to degrade and mineralize of alkyl benzene sulfonates (ABS). ABS could converse completely to inorganic carbon and sulfate ions.

This study was done by Sen Gupta SK [46] aimed to degrade Remazol Red in batch system by CGDE method. CGDE is generated between the surface of an electrolytic solution and an anode, it was reported by Saksono N et al. [42]. The Difluoro phenols (DFPs) and the total organic carbon (TOC) in water were degraded and consumed.

3.2.4. Atmospheric pressure glow discharge (APGD) plasma reactor. Agata Motyka et al. [47] studied antibacterial properties of direct current atmospheric pressure glow discharge (dc-APGD) generated in contact with flowing bacterial suspensions, which were examined against five species of phytopathogens. It can complete eradication or logarithmic reduction in population densities, bactericidal activity of dc-APGD was primarily due to presence of these reactive species as well as to UVA, UVB, and UVC irradiation generated by the dc-APGD source.

A new atmospheric pressure glow discharge (APGD) plasma-reaction system was reported by Piotr Jamroz et al. [48] (Fig. 3g). Various organic dyes were degraded. A similar type of device in the work of Piotr Jamroz’ et al. [49]. The following species, OH⁻, NH, NO, N₂, H and O were excited in discharge. As discussed in the previous section, typical type of discharge and corresponding reactors were studied. Some common organic compounds in wastewater were treated, and some experiment results are compared in Table 1.

Figure 3. a PPD–charcoal reactor [13]. b pulsed spark plasma discharge reactor [37]. c DC pulseless corona discharge reactor [38]. d Pulsed-streamer corona discharge reactor [36]. e gliding arc (G Arc) plasma [10]. f CGDE reactor [44]. g APGD reactor [48].
Table 1. Summary of the typical reactor configurations of different plasma for organic compounds removal

| Type of discharge reactor | Conditions | Removal efficiency (%) | Energy efficiency | Refs.   |
|---------------------------|------------|------------------------|-------------------|---------|
| DBD                       | sulfonamide antibiotics | 90            | 104.8J/mg        | [31]    |
| PCD                       | RCW,BTCW   | 93                     | 10 kW h/m3       | [50]    |
| Pulsed-streamer corona discharge pulsed spark plasma | CBZ | 94 | Not mentioned | [36] |
| DC pulseless corona discharge | Acid Blue 25 | 99.03 | 162 J/mL | [38] |
| G Arc                     | RB19       | 98.19                  | Not mentioned    | [41]    |
| CGDE                      | Remazol Red | 99.97                  | 0.08–0.33g/kWh   | [48]    |
| APGD                      | organic dyes | 92–100                | Not mentioned    | [46]    |

4. Various forms of coordination reaction reactor

4.1. Catalyst and plasma reactor
A combination of ZrO2/CeO2 and non-thermal plasma for the removal of pollutants in water has been studied by Reddy PM Set al. [51]. The degradation rate of SMX and TOC were better than that only in plasma, which increased by 22% and 9.3%, respectively. Nano-structured hematite as the catalyst for degradation of Acid Red 17 was prepared by Khataee Aet al. [52] in the N2 plasma. In the Plasma-treated hematite/H2O2 process, there is 50% removal increase contrasted with natural hematite/H2O2 system, due to the enhancement of the NH surface area.

Zhang Q et al. [53] reported a gas phase surface discharge plasma system to eliminate Humic Acid (HA). The experimental results showed that approximately 89.4% of HA could be smoothly eliminated after 40 min treatment. The inorganic ions (CO3−, Cl−, NO3−, SO42−) influenced HA degradation mainly due to these reactions with OH radicals.

4.2. Ultraviolet radiation and plasma reactor
In order to oxidize NaCl to sodium hypochlorite, a water treatment using plasma technologies in a flash corona reactor was studied by Piskarev IM [54]. It is investigated the mechanism of sodium hypochlorite formation in isotonic solution (0.9%NaCl). Non-thermal plasma and nano-particle application with UV as methods for degrading Microcystins (MCs) in water was studied by Jiang X et al. [55]. When TiO2 was coated on the outside of the UV treatment container showed about 10% improvement in degrading MCs.

A structurally simple dielectric barrier discharge reactor has been developed by Prakash Ret al. [56], which can produce UV radiation of wavelength from 240 to 280 nm the developed UV source has been used for bacterial deactivation studies for five types of bacteria, which have been demonstrated reductions in less than ten seconds.

4.3. Fenton reaction and plasma reactor
The nano-structured magnetite was used as the iron source in heterogeneous Fenton to degrade Basic Blue 3 (BB3) dye was reported by Khataee Aetal. [57]. 3 gram of magnetite particles were placed in a chamber in a glow discharge plasma reactor. The dechlorization efficiency of 96% in the presence of plasma-treated magnetite was approximately two times higher than that of untreated magnetite. Another similar experiment was studied about Nano–sized clinoptilolite, which was used in the corona discharge plasma reactor by Khataee Aetal. [58]. The plasma-modified clinoptilolite (PMC) catalyst for treatment of phenazo pyridine, it was compared to the natural clinoptilolite, which obtain the highest degradation rate. The Fe3O4/FeAl2O4 composite coatings as a catalyst were successfully fabricated on Q235 carbon steel was studied by Wang J et al. [59], they used plasma to degrade phenol pollutant in wastewater. The phenol was totally removed within 60 min of reaction.
5. Conclusions and future outlooks
The advantages of DBD discharge plasma reactor can be summarized as follows: a stable and uniform discharge can be achieved under atmospheric pressure, with a wide frequency range, which can adapt to most reaction conditions. The dielectric barrier can prevent the formation of local spark or arc discharge, and ensure the safety of the device. It can form a large plasma discharge area, which is beneficial to make full contact reaction. These characteristics are not available in other non-equilibrium plasmas. Compared with corona discharge, gliding arc discharge and glow discharge technology, it has more application prospects.

In decades, the applications of plasma technology for aqueous pollutant treatments have significantly increased, we have reviewed the common plasma reactors and compared the efficiency in degrading pollutants in waste water. The similarities of different reactors all can produce active species to oxidize pollutants, and hydroxyl plays a major role. Some key issues for plasma technique in the wastewater treatment were also emphasized, including the partial types, the species energy, and the treatment periods. In the coordination reaction reactor, the presence of plasma is crucial. We generally believe that the high voltage, the short pulse, the reciprocating cycle reactor demonstrated better efficiency in removal of organic pollutants. Plasma technology combined with catalysts treatment are promising methods [5]. Ultraviolet radiation and Fenton reaction combined with plasma also have been more and more widely studied and used.

There are still some challenges in incomplete mineralization of contaminants, the chemical waste, the generation of second pollution, the high energy consumption and the high cost etc., which all need to be considered in the plasma device. Looking ahead, there are still many obstacles remaining to be surmounted for further research and development in order to meet the industrial demand.

Acknowledgments
This work was financially supported by the Beijing Municipal Commission of Education project (Grant No. KM201810015001 and KZ201610015014).

References
[1] Kim Kil-Seong, Yang Churl-Shin, Mok Y. S., Degradation of veterinary antibiotics by dielectric barrier discharge plasma, Chemical Engineering Journal,2013,219, pp. 19-27.
[2] Tezcan Un Umran, Topal Seher, Ates Funda, Electrocoagulation of tissue paper wastewater and an evaluation of sludge for pyrolysis, Desalination and Water Treatment,2016,57(59), pp. 28724-28733.
[3] Tijani Jimoh O., Fatoba Ojo O., Madzivire Godfrey, Petrik Leslie F., A Review of Combined Advanced Oxidation Technologies for the Removal of Organic Pollutants from Water, Water, Air, & Soil Pollution,2014,225(9), pp.
[4] Shang Kefeng, Wang Xiaojing, Li Jie, et al., Effect of Persulfate on the Degradation of Acid Orange 7 (AO7) by Dielectric Barrier Discharge Plasma, Topics in Catalysis,2017,60(12-14), pp. 973-979.
[5] Jiang Bo, Zheng Jingtang, Qiu Shi, et al., Review on electrical discharge plasma technology for wastewater remediation, Chemical Engineering Journal,2014,236, pp. 348-368.
[6] Bratescu M. A., Saito N., Analysis of benzoquinone decomposition in solution plasma process, Journal of Instrumentation,2016,11(01), pp. C01009-C01009.
[7] Shengxia Duan Xia Liu, Yanan Wang, Yuedong Meng, Ahmed Alsaedi, Tasawar Hayat, Jiaxing Li, Plasma surface modification of materials and their entrapment of water contaminant: A review, Plasma Processes & Polymers,2017,14(9), pp. 1-30.
[8] B. R. Locke* M. Sato, P. Sunka, M. R. Hoffmann, J.-S. Chang, Electrohydraulic Discharge and Nonthermal Plasma for Water Treatment, INDUSTRIAL & ENGINEERING CHEMISTRY RESEARCH,2006,45(3), pp. 882-905.
[9] Mededovic Thagard Selma, Stratton Gunnar R., Dai Fei, et al., Plasma-based water treatment: development of a general mechanistic model to estimate the treatability of different types of
contaminants, Journal of Physics D: Applied Physics, 2017, 50(1), pp. 014003.

[10] Gharagozalian Mehrnaz, Dorrani Davoud, Ghoranneviss Mahmoud, Water treatment by the AC gliding arc air plasma, Journal of Theoretical and Applied Physics, 2017, 11(3), pp. 171-180.

[11] Khlyustova Anna, Khomyakova Natalija, Sirotkin Nikolaj, Marfin Yuriy, The Effect of pH on OH Radical Generation in Aqueous Solutions by Atmospheric Pressure Glow Discharge, Plasma Chemistry and Plasma Processing, 2016, 36(5), pp. 1229-1238.

[12] Rong Shao-Peng, Sun Ya-Bing, Zhao Ze-Hua, Degradation of sulfadiazine antibiotics by water falling film dielectric barrier discharge, Chinese Chemical Letters, 2014, 25(1), pp. 187-192.

[13] Wang T., Qu G., Pei S., Liang D., Hu S., Research on dye wastewater decoloration by pulse discharge plasma combined with charcoal derived from spent tea leaves, Environmental science and pollution research international, 2016, Jul, 23(13), pp. 13448-13457.

[14] Wang M., Zhang L., Zhang G., et al., In situ degradation of antibiotic residues in medical intravenous infusion bottles using high energy electron beam irradiation, Scientific reports, 2017, Jan 3, 7, pp. 39928.

[15] Jo Jin-Oh, Choi Kyeong Yun, Gim Suji, Mok Young Sun, Atmospheric Pressure Plasma Treatment of Aqueous Bisphenol A Solution, Applied Chemistry for Engineering, 2015, 26(3), pp. 311-318.

[16] Ajo Petri, Kornev Iakov, Preis Sergei, Pulsed Corona Discharge in Water Treatment: The Effect of Hydrodynamic Conditions on Oxidation Energy Efficiency, Industrial & Engineering Chemistry Research, 2015, 54(30), pp. 7452-7458.

[17] Kogelschatz Ulrich, Dielectric-barrier Discharges: Their History, Discharge Physics, and Industrial Applications, Plasma Chemistry and Plasma Processing, 2003, 23(1), pp. 1-46.

[18] Xu Xueji, Dielectric barrier discharge—properties and applications., Thin Solid Films, 2001, 390, pp. 237-242.

[19] Wang Bo, A Novel Dielectric-Barrier-Discharge Loop Reactor for Cyanide Water Treatment, Plasma Chemistry and Plasma Processing, 2017, 37(4), pp. 1121-1131.

[20] Reid Robertson, Electrogeneration of hydrogen peroxide for applications in water/wastewater treatment, 2017, pp. 1-111.

[21] Reddy P. Manoj Kumar, Subrahmanyam Ch, Green Approach for Wastewater Treatment—Degradation and Mineralization of Aqueous Organic Pollutants by Discharge Plasma, Industrial & Engineering Chemistry Research, 2012, 51(34), pp. 11097-11103.

[22] Yongjing Wang Jianwei Yu, * Dong Zhang, Min Yang, Addition of hydrogen peroxide for the simultaneous control of bromate and odor during advanced drinking water treatment using ozone, Journal of Environmental Sciences 2014, 26, pp. 550-554.

[23] Song K., Mohseni M., Taghipour F., Application of ultraviolet light-emitting diodes (UV-LEDs) for water disinfection: A review, Water research, 2016, May 01, 94, pp. 341-349.

[24] Weritele M. A., Kolbe T., Lipsz M., et al., Application of GaN-based ultraviolet-C light emitting diodes--UV LEDs--for water disinfection, Water research, 2011, Jan, 45(3), pp. 1481-1489.

[25] Syoufian A., Nakashima K., Degradation of methylene blue in aqueous dispersion of hollow titania photocatalyst: study of reaction enhancement by various electron scavengers, Journal of colloid and interface science, 2008, Jan 15, 317(2), pp. 507-512.

[26] Zhang C., Namihira T., Kiyan T., et al., Investigation of Shockwave Produced by Large Volume Pulsed Discharge Under Water, 2005, pp. 1377-1380.

[27] Kearns Joshua P., Knappe Detlef R. U., Summers R. Scott, Feasibility of Using Traditional Kiln Charcoals in Low-Cost Water Treatment: Role of Pyrolysis Conditions on 2,4-D Herbicide Adsorption, Environmental Engineering Science, 2015, 32(11), pp. 912-921.

[28] Abdul SYAKUR Badrus ZAMAN, Faizan AFFIF, Siti NURJANNAH, Dias Yunita NUMRALIAKASIH, Application of dielectric barrier discharge plasma forreducing Chemical Oxygen Demand (COD) on industrial rubber wastewater, International Conference on Information Technology 2017, pp. 1-5.
[29] Yuan Dingkun, Ding Can, He Yong, et al., Characteristics of Dielectric Barrier Discharge Ozone Synthesis for Different Pulse Modes, Plasma Chemistry and Plasma Processing, 2017, 37(4), pp. 1165-1173.

[30] Brandenburg Ronny, Dielectric barrier discharges: progress on plasma sources and on the understanding of regimes and single filaments, Plasma Sources Science and Technology, 2017, 26(5), pp. 053001.

[31] Kim Kil-Seong, Kam Sang Kyu, Mok Young Sun, Elucidation of the degradation pathways of sulfonamide antibiotics in a dielectric barrier discharge plasma system, Chemical Engineering Journal, 2015, 271, pp. 31-42.

[32] Ma Tianpeng, Zhao Qiong, Liu Jianqi, Zhong Fangchuan, Study of Humidity Effect on Benzene Decomposition by the Dielectric Barrier Discharge Nonthermal Plasma Reactor, Plasma Science and Technology, 2016, 18(6), pp. 686-692.

[33] Meirovich Ariel, Parkansky Naum, Boxman Raymond L., Berkh Olga, Barkay Zahava, Rosenberg Yuri, Treatment of Methylene Blue water solution by submerged pulse arc in multi-electrode reactor, Journal of Water Process Engineering, 2016, 13, pp. 53-60.

[34] Iwabuchi Masashi, Wada Keita, Takahashi Katsuyuki, Takaki Koichi, Satta Naoya, Simultaneous Decomposition of Phenol and Sodium Formate by Discharge Inside Bubble in Water, Transactions of the Materials Research Society of Japan, 2016, 41(2), pp. 183-187.

[35] Arola Kimmo, Kallioinen Mari, Reinikainen Satu-Pia, Hatakka Henry, Määttäri Mika, Advanced treatment of membrane concentrate with pulsed corona discharge, Separation and Purification Technology, 2017, pp.

[36] Roya Pourzarea M.Sc., Removal of Pharmaceutical Carbamazepine Using Pulsed Corona Discharge Generated in Water, Civil Engineering, 2017, pp. xv, 105.

[37] Zheng J., Inactivation of Staphylococcus aureus in water by pulsed spark discharge, Scientific reports, 2017, Sep, 4,7(1), pp. 10311.

[38] El-Tayeb A., El-Shazly A. H., Elkady M. F., Abdel-Rahman A. B., Investigation of the decolorization efficiency of two pin-to-plate corona discharge plasma system for industrial wastewater treatment, Plasma Physics Reports, 2016, 42(9), pp. 887-899.

[39] Du ChangMing, Yan JianHua, Degradation and Discoloration of Textile Dyes Using Gliding Arc Plasma Combined with Fenton Catalysis, 2017, pp. 21-39.

[40] Hao Zhang Fengsen Zhu, Xiaodong Li, Kefa Cen, a Changming Dub and Xin Tu, Enhanced hydrogen production by methanol decomposition using a novel rotating gliding arc discharge plasma, RSC Advances, 2016, pp. 1-13.

[41] AlHamad Bassam, Al-Bastaki Nader, Degradation of Reactive Blue 19 using advanced oxidation methods: gliding-arc plasma discharge, Desalination and Water Treatment, 2016, 57(51), pp. 24352-24358.

[42] Yang Haiming, Zhao Xiaotong, Mengen Giya, et al., Defluorination and Mineralization of Difluorophenols in Water by Anodic Contact Glow Discharge Electrosynthesis, Plasma Chemistry and Plasma Processing, 2016, 36(4), pp. 993-1009.

[43] Jinzhang Gao Xiaoyan Wang, Zhongai Hu, Hualing Deng, Jingguo Hou, Xiaoquan Lu, Jingwan Kang, Plasma degradation of dyes in water with contact glow discharge electrolysis, Water research, 2003, 37, pp. 267-272.

[44] Amano R., Tezuka M., Mineralization of alkylbenzenesulfonates in water by means of contact glow discharge electrolysis, Water research, 2006, May, 40(9), pp. 1857-1863.

[45] Sen Gupta Susanta K., Contact Glow Discharge Electrosynthesis: A Novel Tool for Manifold Applications, Plasma Chemistry and Plasma Processing, 2017, 37(4), pp. 897-945.

[46] Saksono Nelson, Putri Dita Amelia, Suminar Dian Ratna, Degradation of Remazol Red in batik dye waste water by contact glow discharge electrolysis method using NaOH and NaCl electrolytes, 2017, 1821, pp. 020004.

[47] Motyka A., Dzmitrywicz A., Jamroz P., Lojkowska E., Sledz W., Pohl P., Rapid eradication of bacterial phytopathogens by atmospheric pressure glow discharge generated in contact with a
flowing liquid cathode, Biotechnology and bioengineering, 2018, Jun, 115(6), pp. 1581-1593.

[48] Jamroz Piotr, Dzimitrowicz Anna, Pohl Pawel, Decolorization of organic dyes solution by atmospheric pressure glow discharge system working in a liquid flow-through mode, Plasma Processes and Polymers, 2018, 15(1), pp. 1700083.

[49] Jamróz Piotr, Gręda Krzysztof, Pohl Pawel, Żyrnicki Wiesław, Atmospheric Pressure Glow Discharges Generated in Contact with Flowing Liquid Cathode: Production of Active Species and Application in Wastewater Purification Processes, Plasma Chemistry and Plasma Processing, 2013, 34(1), pp. 25-37.

[50] Liu Ming, Preis Sergei, Kornev Iakov, Hu Yun, Wei Chao-Hai, Pulsed corona discharge for improving treatability of coking wastewater, Journal of Environmental Sciences, 2017, pp.

[51] Reddy P. Madhu Sudana, Kumar V. Phani, Sarvesh B., Field data collection for assessment of reliability and modeling for CASH ACCEPTOR module in an ATM, 2015, pp. 161-166.

[52] Khataee Alireza, Gholami Peyman, Vahid Behrouz, Catalytic performance of hematite nanostructures prepared by N2 glow discharge plasma in heterogeneous Fenton-like process for acid red 17 degradation, Journal of Industrial and Engineering Chemistry, 2017, 50, pp. 86-95.

[53] Zhang Qianrou, Qu Guangzhou, Wang Tiecheng, et al., Humic acid removal from micro-polluted source water in the presence of inorganic salts in a gas-phase discharge plasma system, Separation and Purification Technology, 2017, 187, pp. 334-342.

[54] Piskarev I. M., Effects of cold plasma and UV-C radiation on isotonic solution, High Energy Chemistry, 2017, 51(4), pp. 297-301.

[55] Jiang X., Lee S., Mok C., Lee J., Sustainable Methods for Decontamination of Microcystin in Water Using Cold Plasma and UV with Reusable TiO(2) Nanoparticle Coating, International journal of environmental research and public health, 2017, May 5,14(5), pp.

[56] Prakash R., Hussain A. M., Pal U. N., Kumar N., Khairnar K., Mohan M. K., Dielectric Barrier Discharge based Mercury-free plasma UV-lamp for efficient water disinfection, Scientific reports, 2017, Dec 12, 7(1), pp. 17426.

[57] Khataee Alireza, Taseidifar Mojtaba, Khorraram Sirous, Sheydaei Mohsen, Joo Sang Woo, Preparation of nanostructured magnetite with plasma for degradation of a cationic textile dye by the heterogeneous Fenton process, Journal of the Taiwan Institute of Chemical Engineers, 2015, 53, pp. 132-139.

[58] Khataee A., Rad T. S., Vahid B., Khorraram S., Preparation of zeolite nanorods by corona discharge plasma for degradation of phenazopyridine by heterogeneous sono-Fenton-like process, Ultrasonics sonochemistry, 2016, Nov, 33, pp. 37-46.

[59] Wang J., Yao Z., Yang M., Wang Y., Xia Q., Jiang Z., A Fe3O4/FeAl2O4 composite coating via plasma electrolytic oxidation on Q235 carbon steel for Fenton-like degradation of phenol, Environmental science and pollution research international, 2016, Aug, 23(15), pp. 14927-14936.