Treatment possibilities of electrical discharge non-thermal plasma for industrial wastewater treatment- review

Ramya Suresh1*, Baskar Rajoo2, Maheswari Chenniappan3 and Manikandan Palanichamy4

1,2School of Food and Chemical Sciences, Kongu Engineering College, Perundurai, Erode-638060, India.
3Department of Mechatronics Engineering, Kongu Engineering College, Perundurai, Erode-638060, India.
4School of Science and Humanities, Kongu Engineering College, Perundurai, Erode-638060, India.

*Corresponding Author: ramya24591@gmail.com

Abstract: The effluent remedy is ordinarily to allow human and commercial effluents to be disposed of whilst now no threat to human health or unacceptable damage to the natural ecosystem. Industrial effluents (in general from factories) comprise numerous substances, counting on the change. Industries have long discharged their effluents into close move courses, public sewers, and fields or the ocean, leading to environmental and fitness problems. Plasma is an innovative method to modify the properties of surface of material with atmospheric pressure. When electrical discharge takes place between the two electrodes the high intensity of plasma arc formed which produces highly active reactive radicals. Here, this paper represents the review of non-thermal plasma and its application, techniques and up to date undergoing development on the utilization of non-thermal plasma in numerous industrial wastewater treatment.

Keywords: Non-thermal plasma, DBD, Electrical discharge, Pollution, Wastewater treatment, Reactor, Corona Discharge, Arc discharge

1. Introduction
The primary approach of wastewater disposal in large towns is discharged into a body of surface water. Suburban and rural regions depend on subsurface disposal [1]). In both cases, wastewater should be purified or treated to some degree with a view to guard public fitness to make quality water [2]). In many locations, it will likely be higher to layout the reuse machine to accept a low-grade of effluent as opposed to depending upon greater remedial strategies producing a reclaimed effluent which constantly meets a stringent supreme prevalent [3]. The layout of sewer water remedy plants is working based on the requirement to minimize natural and suspended solids.

Generally, the primary, secondary and tertiary wastewater treatments are available. Tertiary and/or advanced wastewater remedy is employed whilst specific wastewater ingredients, which cannot be eliminated by secondary treatment, ought to be removed [4, 5]). Nowadays, superior treatment methods such as chlorination and ozonation techniques are used in the remedy of wastewater treatment [6]. Occasionally the presence of chlorine in water after chlorination method ends with the impurity
again it pollutes the environment [7]. Ozonation is the most advantageous technique, however; the technology of ozone in a normal approach is not always adequate [8]. The main benefit in the usage of ozone instead of chlorine is in the very rear built-up of harmful compounds within the case of bromine presence. Ozone provides advantages like high redox potential, higher degradation efficiency, and providing a spontaneous transition to oxygen.

Based on the advantages of ozone, plasma technology is the revolutionary approach for the generation of ozone to treat wastewater in an effective way [9]. Plasma technology is a cost-effective method because it does not require any expensive vacuum and cooling systems in the wastewater treatment [10]. Plasma discharges effectively eliminate the substances such as phenols, anilines, and naphthols [11], halogenated substances [12], pesticides, cyanides, organic micro pollutants [13], antibiotics [14] Acid Black 1 [15], and other pharmaceutical compounds [16]. Hence the plasma technology is considered to be an alternate and effective method for wastewater treatment. The present review paper summarizes the introduction to plasma, types of plasma technology, and types of reactors and industrial application of Non-thermal plasma.

2. Plasma Process

2.1 Plasma

It is one of the four fundamental states of count number except for solid, liquid, and gas and they are intently applicable to the human life and present-day enterprise. It is formed by ionization of gaseous molecules, which contains excited atoms, superb oxides, negative electrons, potential radicals, ultraviolet radiation and electronic field [17].

![Figure 1. Stages of plasma](image)

As shown in figure 1, Plasma is the fourth state of matter created by applying some energy [18]. When applying heat or electrical energy into the solid matter, it converted into a liquid called melting process. Further the application of energy into liquid, it converted into a gas called vaporization process. Further energy is applied, then the gas state changed into plasma called ionization process [19].

2.2 Plasma treating

Plasma has a tendency to modify the physical/chemical properties of a surface material [20]. Plasma are generated by different methods like plasma jet, plasma electrolysis, plasma glid arc discharge, corona discharge, microwave frequency and Dielectric Barrier Discharge (DBD) [21]. The high reactive radicals such as nitrogen, ozone, H⁺, etc. are produced from ionization of ambient air to generate plasma by applying electrical current [22].

2.3 Thermal plasma and Non-thermal plasma

Plasma technology parted into as thermal and nonthermal plasma based on electron temperatures and heavy debris such as ions, metastable, excited atoms, molecules and neutrals as shown in figure 2. When electron temperature is more or less equal to the gaseous temperature is referred to the thermal plasmas (i.e. electrons in thermal equilibrium) [23].
On the other hand, in non thermal plasmas, the electrons temperature is greater than the ionic temperature (i.e. Non equilibrium condition of electron). The difference between thermal and non thermal plasma is shown in Table.1 [24].

| Thermal plasma                                                                 | Nonthermal plasma                                                                 |
|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Created by heating the gas until electrons have enough energy to get out free from the atoms. | Created by an electrical discharge with less heat energy that can kick out an electron from an atom. |
| Ions are hot, i.e. ions have a lot of energy.                                   | Ions are cold, i.e. ions have not very much energy.                                |
| Electrons/Ions are in thermal equilibrium.                                     | Electrons/Ions are not in thermal equilibrium.                                    |
| Produced by plasma torch or high-pressure discharges.                         | Generated by low-pressure discharge or short pulse discharges as DBD.             |
| Ionic temperature: $T_{ele} = T_{ion/gas}$                                    | Ionic temperature: $T_{ele} > T_{ion/gas}$                                        |

Where, $T_{ele}$ = temperature of the electron, $T_{ion/gas}$ = temperature of the ion.

The efficiency of nonthermal plasma depends upon the initial concentration of organic pollutant and on the solution of pH [25]. Nonthermal plasma is a quite new non-thermal era that successfully inactivates microorganisms, consisting of bacteria, bacterial spores, fungi, and biofilms [26]. The principal gain of Nonthermal plasmas is their high chemical performance. As very little heat is produced, almost all input strength is transformed into lively electrons. A kinetic scheme for non-equilibrium discharge in nitrogen-oxygen combinations is evolved, which almost completely describes chemical amelioration of debris inside the cold (200 ok $t < 500 k$) vibrational unexcited gas [26].

2.4 Collision process in Non-thermal plasma

Normally two stages are available in nonthermal plasma collision process are electron collision and heavy particle collision. In electron collisions, a huge number of collisions proceeds between the electrons, atoms and molecules are accelerated by an electric field through a gaseous medium in the plasma. Due to the collisions, electrons are dissipated into the different directions and a large variety of physical processes occurred in atoms or molecules. In heavy particle collision reactive radical species formed by ionization, dissociation, and excitation in the electron collisions [27]. As a result of inelastic collisions between electrons, the free oxygen radicals are produced. Ozone and OH Radicals are the important secondary free radicals in nonthermal plasma. The ionization, electron attachment, dissociation, elastic scattering, total scattering, excitation of rotational, vibrational, and electronic states, and emission of radiation progression are created in electron collision with a water molecule [28, 29].

2.5 Breakdown Process in Non-thermal plasma

The breakdown process of Nonthermal plasma is described as the sector wherein impact ionization and electron attachment can be produced by better electric powered fields. Turner [30] probed the physics of plasma, increasing the background of electrons in the gaseous state require the electric field.
to break down the electrons. Even as the collapse is started in a single electronic pair, the ionization process starts as soon as the electron drifts near the cathode. In the ionization process, the primary electrons enlarge the number of group of electrons. The breakdown of electrons depends on the gap between the electrodes and the voltage applied. The 100-500V electric field required to break down the electrons pair in the gaseous state [31].

2.6 Reaction of nonthermal plasma

The high potential chemical species are formed during the primary and secondary collision process such as electron collision and heavy particle collision. These species are very strong oxidizing reactive than untreated gas fed to the discharge as collisions of heavy debris [32]. The oxygen and nitrogen radicals are formed during the reaction are H₂, O₂, O₃, H₂O₂, NO₂, N₂O, HNO₂ and HNO₃ [13]. Among those, hydroxyl radicals are strong oxidizing species which generate further chemical species. These radicals are formed by the process of dissociation of water, neutralization of ions and by reactions of molecular nitrogen and excited states of atomic oxygen [27]. Chemical reaction between Reactive Nitrogen Species (RNS) and Reactive Oxygen Species (ROS) are as shown in table 2. [33].

| CHEMICAL SPECIES            | REACTION                                      |
|-----------------------------|-----------------------------------------------|
| Hydrogen peroxide           | H₂O₂+2H+2e → 2 H₂O                           |
|                             | H₂O₂+ 2 e → 2OH                               |
| Hydroxyl Radical            | OH+H → H₂O                                   |
| Dissolved Oxygen            | O₂+4H + 4e → 2H₂O                            |
|                             | O₂+2H₂O+4e → 4OH                             |
| Superoxide                  | O₂+ H+e → HO₂                                |
|                             | O₂+4e → O₂                                   |
| Ozone                       | O₂+2H+2e → O₂+H₂O                            |
| Singlet Oxygen              | O₂+4H + 4e → 2H₂O                            |
| Nitrogen Dioxide Radicals   | N₂ + e → NO₂                                 |

Figure 3. Schematic demonstration of a nonthermal plasma progression.

From figure 3, when applying the power or electric field to the reactor the electrical discharges takes place. The ionization process occurs after the application of gas by the dispersion of electrons and collision between heavy debris, are accelerated by an electric field. When an electric field exceeds a critical value, plasma generated in a reactor. The plasma generates the heavy reactive species, it reacts with an organic matter present in wastewater and converted into inorganic matters [34].

2.7 Types of reactors used in nonthermal plasma

In trendy, [35] plasma reactors are gadgets which generate plasma. Based on the electrical discharge between electrodes, the NTP reactors are classified as [36]:

Table 2. The reaction of ROS and RNS.
• Corona Discharge (CD)
• Dielectric Barrier Discharge (DBD)
• DC glow discharge (DC-GD)
• Glidarc discharge (GD)

In Corona discharge, the small curvature of electrical arc is discharged between an electrode producing a voltage of about 50 to 100 kV and current of $10^{-6}$-$10^{-4}$ [A] [11].

In DBD discharges, plasma arc developed between two metallic electrodes/dielectric material which are made by quartz, glass, pyrex, ceramic and poly-tetrafluoroethylene [37, 38, 39].

In DC glow discharge, the electric arc developed between electrode and solution electrolyte. In this discharge, the solution or wastewater acts as an another electrode [40, 41].

Glidarc discharge is an electrical discharge between two divergent electrodes. After the introduction of high electrical power, the larger yields of short-lived active species formed [42].

3. Application of Non-thermal Plasma in Industrial Wastewater Treatment

3.1 Rubber Wastewater Industry

3.1.1COD removal. Syakur, Zaman [43] developed a DBD plasma reactor to remove COD from rubber wastewater. Fig.4 represents the configuration of a dielectric-barrier discharge reactor.

![Common dielectric-barrier discharge configurations](image)

Outcome of the result shows that higher the voltage inflicting the decrease of COD in DBD reactor. Likewise, increase of plasma duration time also conflicts the COD reduction. Increase of Voltage of electric arc and time duration of plasma eventually increases the COD reduction.

3.1.2 BOD removal. Syakur, Zaman [43] studied by increasing the voltage and contact time directly influence the ionization of energetic species to degrade the impurities to the extreme. Rubber wastewater naturally contains raw fabric rubber ie. latex and solids which requires horizontal filtration as a pretreatment technique. As from statistical analysis, 88.7% BOD reduction of rubber wastewater at 13 kV voltage and 25 minutes is achieved.

3.2 Slaughterhouse industry

Gongwala, Fotio [44], investigated the acidified/non-acidified samples of slaughter house wastewaters. Fig.5 depicts the experimental setup of glidarc type reactor. Operating parameters such as reaction time, plasma voltage, gas flow rate of 800 L/h and pH are greatly influence the pollutants removal. After 20 min treatment for gliding discharge method, the phosphates of 41.55% and nitrates of 86.24% are abated. Comparing to non-acidifying sample, acidifying sample gives more phosphates and nitrates removal and it removal efficiency are increased with treatment time.
3.3 Palm oil mill effluent (POME)

Nur. Amelia [8] investigated the POME contains a water of 96%, oil of 0.7% and general solids of 5%. DBD plasma reactor are comprises stainless-steel electrode and dielectric barrier of pyrex tube as shown in fig.6. This DBDP become generated by an excessive voltage. Influent gas of argon gas with a flow rate of 1-10 l/min is continuously feed into the rector.

The result shows that the COD 18% of COD and 85% of TSS removal is attained at a voltage og 4kV and argon flow rate of 4 l/min. Voltage and argon gas, and its flow rate greatly influence the COD and TSS removal on POME. As per the Modified Robinson Equation, charge carrier mobility of gas is higher in samples than without samples.

3.4 Coke-Plant industry

Aristova [35] examined the purification of coke-plant wastewater by means of nonthermal plasma. Statistics concerning wastewater purification by the way of nonthermal plasma in the biochemical department at Nizhny Tagil metallic works are analyzed in the light of new statistics concerning the chain oxidation of hydrocarbons and their products.
The oxidation kinetics of phenol underneath the motion of a corona discharge creating a nonthermal plasma. The sample extent is 300 ml; the release current of the nonthermal plasma generator is 0.5 mA. The initial chemical oxygen demand for (COD) of the solution is 2000 mg O/L. The chain reaction is initiated by way of a generator of ozone–hydroxyl mixture.

If the COD before biochemical treatment is 1500–2000 mg/l, the rate of the oxidation chain reaction must be 300–400 mg O/L. This is, in reality, the amount after biochemical treatment. In itself, the 20–30% lower within the chemical oxygen minimal due to the controlled plasma generator it is not always great.

Diverse techniques must be blended which will ensure first-rate wastewater treatment. Consequently, nonthermal plasma remedy of wastewater may additionally expediently be employed at coke plants as a supplement to biochemical treatment. The characteristics of plasma improve the reliability and stability of the biochemical system and extensively reduce the chance of its disruption with a surprising spike in the pollutant content.

3.5 Food Processing Industry

Patange, Boehm [45] investigated the eco-toxicological and disinfection capacity of dairy effluent which consists pH of 6.0, milk fat of 0.2% (w/v), NaOH of 0.015%, phosphorus, proteins, magnesium, calcium, carbohydrates which are toxic to the environment. DBD reactor are operated at 60-80 kV voltage at 50 Hz and 0-10 min detention time at 16 °C to 18 °C temperature. The Advanced technology of nonthermal plasma shows potential for deduction of microorganisms in dairy and meat industry effluent. Elimination of monoculture bacteria is effective at 10 min retention time of 80 kV voltage supply for the nonthermal plasma treatment.

3.6 Other Applications

Jović, Dojić [47] investigated the treatment of potable and wastewater using coaxial DBD reactor. Performance of direct water ozone is measured in bi-distilled water in an effort to keep away from the influence of ozone intake at the feasible impurities oxidation. They concluded that ozone awareness is an increasing feature of time throughout the reactor operation. The ozone concentrations are decreased for larger water flow quotes. The wastewater is contaminated by using the oil derivate (COD of the non-dealt with wastewater pattern turned into 400 mg/l). Within the wastewater treatment, an extensive lower of chemical oxygen and potassium permanganate demands. It is observed that just after one skip treatment via DBD the COD of wastewater decreased by 30% and the coloration change from dark to shiny also observed. At some stage, in the first 48 hours, COD and potassium permanganate continually decrease by 70 % of its preliminary value.

Nonthermal plasma technology is used in medical wastewater treatment. It is noticeably effective in eliminating E.coli within handiest 90s. It may also decompose the organic compounds, compounds from dye product as well as chlorine compound and benzene nucleus. Moreover, plasma famous to be incredibly effective in decomposing as much as 98% oil molecules and surfactants, as well as an extensive discount in heavy metals such as Pb, Cd, Fe, and Mn.

Sarangapani, Dixit [48] established the optimizes the degradation of a cocktail dyes methyl orange and bromothymol blue in wastewater by employing Box-Behnken design with RSM methodology. Response Surface Methodologies (RSM) are used to analyze the efficacy of the plasma method parameters on degradation performance. A Box Behnken Design (BBD) and ANOVA confirmed that the coefficients of the polynomials for the portion degradation and ozone concentration responses indicated tremendous linear results (p<0.001) whereas, a terrible linear effect are determined for pH. The positive linear effect of variable emphasizes that voltage and treatment time have been the maximum dominant elements (p<0.001) meaning that higher degradation efficiencies are performed which will increase in the remedy period.

Magureanu, Piroi [49] probed the plasma technology for the treatment of waste which includes chlorinated compounds. The electron-beam is used in the generation of plasma to decompose
numerous chlorinated compounds in air streams. For chlorinated compounds like carbon tetrachloride and trichloroethylene, the decomposition manner seems to be electron-attachment-brought on decomposition. Carbon tetrachloride implies that round 60 eV of electricity is needed in line with molecule decomposed for 75 percent decomposition of CCl₄ in air streams with concentrations within the 300-600 ppm range. About a 100 eV is wanted for 95% decomposition because of competition for electrons from the decomposition merchandise. It is used to decompose CCl₄ inside the 300-ppm attention range in vacuum-extracted air streams. For trichloroethylene, which is possibly the most extensively encountered solvent in remediation activities, about 10 times much less electricity is needed per decomposition relative to the quantity required for the decomposition of CCl₄. The energy expense is normally 10 eV according to molecule decomposed. It appears that the cause for this lower in energy price is because of the presence of a sequence reaction wherein chlorine ions released within the decomposition, in turn, create greater decompositions.

Li, Liu [50] using a TiO₂ catalyst to improve the degradation efficiency of thiamethoxam. The DBD reactor are operated by 1-100 kHz frequency and power range of 1-200 W. The result shows that applying a discharge power of 150 W by the time period of 160 min, thiamethoxam are removed by 85.9%. Fe³⁺ and Cu²⁺ to improve the degradation process by adding n-butyl alcohol and degradation decrease with the increase of pH and electrical conductivity.

Sarangapani, Dixit [48] experimented by using atmospheric nonthermal plasma to reduce the humic acid in trihalomethane. After the 15 min treatment with nonthermal plasma, 93% of humic acid removed from the wastewater. Wang, Sun [51] Wang and D.Z. Chen (2014) inquired that an increase in electrical conductivity which decreases of silica content, pH and hardness of viscous oil wastewater. Jiang, Zheng [52] explored the electrical discharge plasma has an effective method to degrade the pesticides present in the effluent, coloring matter, and odor.

Patil, Bourke [53] studied the nonthermal plasma is a latent refinement approach in food, medical, and healthcare sectors. Plasma approach involves a complicated collection of organic interactions in microorganisms due to the motion of generated reactive plasma retailers. Reactive species play a substantial function in dictating antimicrobial product. Krugly, Martuzevicius [54] investigated the decomposition of 2-naphthol in water and its decomposition efficiency of pollutant increased as 98.6% after the 6 min plasma treatment under the 33W power supply. Li, Ma [55] examined generation of OH radicals in the plasma reactor decreased with increasing the dosage of Na₂B₄O₇. The 83.48% abasement of acetamiprid achieved by the power supply of 170 W with a 200 min contact time of plasma. Summary of the effluent factors is presented in table 3. Most of the authors pointed out the significance of falling film DBD reactor and its summary is given in table 4.

Table 3. Summary of the wastewater parameter analysis.

| Type of effluent Removed | Type of Reactor Used | Parameter Analyse | Result | References |
|--------------------------|----------------------|-------------------|--------|------------|
| Rubber Wastewater        | DBD                  | COD               | Voltage variation: 13 Kv (6 min) – 365 mg/l (75%) | [43] |
|                          |                      |                   | Time variation: 25 min (5 Kv) – 365 mg/l (75%) | |
| Slaughterhouse Discharge | Glidarc              | BOD               | Voltage variation: 13 Kv (25 min) – 200 mg/l (88.7%) | [44] |
|                          |                      |                   | Time variation: 25 min (13 Kv) – 200 mg/l (88.7%) | |
|                          |                      | Phosphates        | Non-acidified Phosphates (pH= 7.8)- 41.55% (After 20 min) | |
|                          |                      |                   | Acidified phosphates (pH= 2.2) - 26% increased (after 30 min) | |
|                          |                      | Nitrates          | Non-acidified Nitrates (pH=7.8) – 86.24% | |
Acidified Nitrates (pH=2.2) – 24% increased (after 30 min) [8]

Palm oil mill effluent DBD COD 4kV – 115.62 mg/L or 18% [8]

Coke-Plant Corona Discharge COD 0.5 Ma- 20 to 30% [35]

Potable and wastewater treatment Coaxial DBD COD and Potassium permanganate 48 hours – 70% [56]

Food and leather processing plant DBD wastewater bacterial community 85.34 Ma- 60 and 90s (deterioration of entire bacteria in both plants) [57]

Phenol Contact glow discharge electrolysis Phenol 90 minutes – 99.6% [58]

Degradation of toxic compounds Plasma electrolysis(PE) or CGDE Methyl Blue 99% [59]

Food Wastewater DBD e- and i-mecA genes 2.6 and 0.8 logs [60]

Decomposition of 2-naphthol DBD 2-naphthol 98.6% in 6 minutes at 33W power supply [54]

Degradation of acetamiprid DBD Acetamiprid 83.48% in 120 min at the 170W power supply [55]

Textile Dyes Gliding arc COD 42% at 30 min [61]

Dye mixtures Gliding arc discharge plasma (GAD) Alizarin red S, azo dye Orange G 80% [62]

| Experimental Configurations | Conditions | Removal efficiency | References |
|-----------------------------|------------|-------------------|------------|
| Cylinder type, L_o= 100mm, Φ_e=16 mm, stainless steel, Barrier=quartz, Φ_b= 19 mm and L_b = 210 mm | Q_p = 30mL/min, air or oxygen, Q_g = 600sccm, DC, Capacitor = 1nF, P< 1W | Oxacillin -TC, TIC and TOC = 25% at 120 min. Amoxicillin-TC, TIC, TOC=22.5%, COD=43% at 120min.Ampicillin =29%,COD =53% at 120 min | [14, 63] |
| Coaxial geometry, L_o= 12cm, Φ_e =8 mm, aluminum alloy, Barrier =pyrex tube, Φ_b = 12 mm , t_b= 1.7mm, catalyst=TiO₂ | liquid rate adjusted, , Q_p =3.2 cm³/s , V= 16 kV, f=50 Hz, C =0.56 mA, P= 9 W | Oil hydrocarbons, phenols and synthetic surfactants (with catalyst) =98% | [64] |
| Cylindrical geometry , Φ_e =0.25 mm, tungsten wire ,Barrier= glass, Φ_b = 15.5 mm and L_b = 210 mm, t_b=2mm | Q_p = 6 mL/min, G= 2mm, Dry air flow, Q_g = 60 mL/min, V=14 to 16 kV, AC, f= 40 kHz | Phenol, Chlorophenol, dyes=35% | [65] |
| co axial, L_o= 400mm, Φ_e=30 mm, aluminum foil, Φ_b=20mm, L_b = 500 mm, | Q_p = 210 mL/min, G=3.5mm, f=500 Hz, V=17kV,P= 150W | Decolorization = 97% , Energy Density = 45 kJ/L at 24 h | [56] |

Table 4. A comparative report on Falling Film DBD reactor.
Barrier=Pyrex, $\Phi_e = 27$ mm and $L_o = 600$ mm, $t_b = 1.5$ mm

$\Phi_o = 16$ mm, $\Phi_e = 10$ mm, copper, Barrier=quartz, $\Phi_b = 80$ mm and $L_o = 600$ mm, $t_b = 2$ mm

| vol=2L, $G=4$ mm, $Q_e = 14.5$ L/min, $V=20$ kV, $P=5$ W - $33$ W. | 2-naphtol = 98.6% at 6 min at 33W, Energy Density = 18.7 to 866 kJ/g. | [54, 66] |

Coaxial, copper mesh =120 cm$^2$

$Q_e = 125$ mL/min, $G=3$ mm, air or oxygen, $Q_g = 5$ L/min, $V=17$ kV, DC, Capacitor = 1nF, $P=1$ W flow rate, capacitor = 470 nF.

| $O_3 = 6$ mg/l at 80 ml/min and 1.5 mg/l at 250 ml, 0.6 mg/l at 580 ml/min, COD = 70 % at 48 hrs | [46] |

Planar falling film reactor, Dielectrics = 5 cm dia, 68 cm ht and 29 cm width

| $O_3 = 6$ mg/l at 80 ml/min and 1.5 mg/l at 250 ml, 0.6 mg/l at 580 ml/min, COD = 70 % at 48 hrs | [46] |

Coaxial-double DBD plasma reactor, $L_o = 120$ mm, $\Phi_e = 5$ mm, aluminium, Barrier = quartz, $\Phi_b = 25$ mm and $t_b = 2$ mm

| AIR, $f=0$–$30$ kHz, AC power source, $V=250$ V | DEET = 76.8% at 27 min, TOC = 24%. | [70] |

Where, $Q_s = $ solution flow rate, $Q_g = $ gas flow rate, $G = $ gap between electrodes, $P = $ Power, $V = $ Voltage, $C = $ Current, $f = $ frequency, $L_o = $ length of outer electrode, $\Phi_e = $ diameter of external electrode, $L_i = $ length of inner electrode, $\Phi_o = $ diameter of inner electrode, $\Phi_b = $ diameter of dielectric barrier, $L_o = $ length of barrier, $t_b = $ thickness of barrier

From the analysis shown in table 4, the increased flow rate of gas does not influence the degradation rate of toxic pollutants. The degradation rate and energy efficiency of pollutants depend upon the treatment time, applied voltage and liquid flow rate. At a short time, less liquid flow rate gives the best result as compared to the longer treatment time. In the DBD reactor, when introducing the oxygen as a gas molecule leads to the generation of more ozone production. The recirculation of liquid and gas into the reservoir forms the bubbles; which tend to increase the 20% of ozone production. The pH and electrical conductivity of wastewater are increased rapidly with time. But sometimes, during plasma generation, the formation of nitrogen oxides is to acidify the liquids leads to an increase in the conductivity of the solution.

4. Conclusion

In recent a long time, the utility of NTP plasma method for treatment of pollutants has appreciably accelerated. Overview of the review paper describes the utility of nonthermal plasma in the remedy of wastewater in distinctive industries. In this review paper, most of the authors describing dielectric barrier as a reactor to create the nonthermal plasma to remedy of wastewater. The growing touch time of wastewater in the reactor improved with the awareness of COD, BOD, phenol and chlorinated...
compounds has been reduced. When wastewater containing acidified phosphates and nitrates after the remedy of plasma the attention of phosphates and nitrates content material seemingly multiplied. The increase of microorganism become identically reduced while wastewater insurance in nonthermal plasma. Plasma method will considerably improve the aspects of health and safely and devastation of harmful and venomous compounds. Although a big wide variety of experimental consequences are stated, concerning usage of electrical discharge plasma for contaminant remedying, application of this technology for commercial contaminant elimination nevertheless involves overwhelming huge technological problems. For enormous amount of effluents in numerous productions, adopting the plasma procedure entails methodical solutions in chemical aspects, fabrication and energy.

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