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Strategies for Reducing Disinfection By-Products Formation during Electrocoagulation

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Abstract

During the last three decades, the electrocoagulation (EC) process has known an exemplary renaissance in the field of water and wastewater treatment. Several researchers focused on applying this electrochemical technology in removing diverse pollutants such as pathogens and organic matters. During EC application, the hazards of formation of highly toxic disinfection by-products (DBPs) are more and more proved especially in water containing organic matter and halogens especially chloride. This work presents a brief view on the questions related to such issues and challenges. Great efforts remain to be accomplished towards the comprehension of the inherent phenomena related to removing both microorganisms and organic matters in the EC method. Using granular activated carbon post-treatment could hugely diminish the levels and toxicity of DBPs. Further, safe multi-barrier methods, such as distillation and membrane processes, have to be adopted.

Subject Areas

Environmental Sciences, Hydrology

Keywords

Electrocoagulation (EC), Disinfection By-Products (DBPs), Wastewater Treatment, Organic Matter, Chemical Oxygen Demand (COD)

1. Introduction

Landfill leachate remains one of the most defying liquid wastes and is formed by

the degradation of solid wastes and the percolation of rainfall through landfill [1] [2]. Leachate greatly changes in features and includes complicated constituents like organic amalgams, inorganic chemicals, heavy metals, and emerging contaminants, that way making a dangerous ecological effect and public health worry if it is not treated completely [1] [3] [4] [5]. For dealing with leachate, largely examined techniques comprise biological treatment [6]-[12], advanced oxidation [13] [14] [15], membrane filtration [16]-[21], physical separation (involving adsorption, coagulation and flotation), and electrochemical treatment [22] [23] [24] [25]. More importantly, electrochemical techniques are of brilliant attention thanks to their inherent benefits of plain running, ecological affinity, and validity with regard to the variability of the quality and quantities of leachate [1] [26] [27] [28] [29].

As one of the electrochemical techniques, electrocoagulation (EC) [30] has been tested for dealing with landfill leachate [31]. Through an EC method, a sacrificial anode generates metal ions *in situ* via electrolytic oxidation below an applied electrical potential. Such metal ions attach with water molecules to constitute hydrated metal ions, which may form polymeric hydroxides that act as the coagulants and neutralize the ionic species in leachate to generate flocs. The pathways of pollutant elimination implicate chemical reactions, absorption, precipitation, and flotation [32]. Since the EC technique produces the coagulants *in situ*, it does not need an external introduction of chemicals [1]. Further, it is more efficient in separating suspended solids and organic matters than traditional coagulation [33]-[38]. With a large success, the EC technology has been implemented to remedying leachate thanks to its capacity of eliminating both color [39], turbidity [40], and a set of pollutants in the complicate leachate [41] [42] [43] [44]. For instance, it was noted that the EC technique could attain almost 70% of the decolorization in landfill leachate employing stainless steel as the electrodes below the situation of 10 V and 120-min reaction time [43]. Eliminating performance of chemical oxygen demand (COD) and ammonia is hugely changing, for example among 17% and 70% (COD reduction) and 0% - 16% (ammonia reduction), as it is touched via the parameters like electrode materials, residence period, and current density [22].

Since landfill leachate frequently includes an elevated level of chloride ions, the response of chloride oxidation to chlorine gas would take place as a secondary influence at the anode of EC. This reaction is accompanied by additional production of active chlorine species like free chlorine and integrated chlorine [33]. The co-presence of such active chlorine species and organic matters may conduct to the generation of greatly carcinogenic disinfection by-products (DBPs) [45]-[52]. Numerous investigations have mentioned the formation of active chlorine [53] [54] [55] [56] in the electrochemical devices like electroflotation [57] [58], electrochlorination, and electrodisinfection [33] [59] [60] [61]. For instance, chloroform, dichloroacetic acid (DCAA) and trichloroacetic acid (TCAA) were found in the water samples treated by the merged EC and electrooxidation device [62]; however, it was possible that most DBP generation was

provoked via electrooxidation [63] [64] [65]. Until now, scarce researches have frankly followed the generation of DBPs through the EC remediation of landfill leachate. Moreover, the importance of the discrete DBP category towards their poisoning contribution has not been shown until now. Consequently, there is a requirement for these studies [1].

This work presents a brief view on the DBBs generation throughout EC of landfill leachate, dye and humic acid.

2. DBBs Generation throughout EC of Landfill Leachate

As discussed above, in the course of the EC handling of landfill leachate, the generation of chlorine species may conduct to the production of poisonous DBPs. This production was followed by Xu *et al.* [1] via observation of five classes of DBPs (haloacetic acids-HAA, trihalomethanes-THM, haloacetonitriles-HAN, haloketones-HK, and halonitromethanes-HNM) in two leachate samples remedied by EC (**Figure 1**). They proved that the applied current has catalyzed the production of DBPs, which were prevailed by unregulated DBPs. Applying a current density of 100 mA/cm^2, the unregulated HK prevailed the weight-based DBP concentration (96% in Leachate A and 44.3% in Leachate B), while the unregulated HAN contributed to >80% of the DBP additive toxicity in both leachates. The *in situ* formation of active chlorine has conducted to the DBP production, as proved in the scavenging test. Employing granular activated carbon as a post-treatment stage could efficiently minimize the total DBP concentration from 295.33 to 82.04 μg/L in Leachate A, conducting to a total DBP abstraction of 72.2% and a toxicity elimination of 50% (**Figure 2**). Considering the prevailing concentration and shortage of toxicity data, the unregulated DBPs should attract more focus [1].

3. DBBs Generation throughout EC of Dye and Humic Acid

Keyikoglu *et al.* [66] compared the effects of different supporting electrolytes on the treatment of a dye solution by EC technology [67] [68] [69]. They mentioned the likely hazard of the formation of DBPs which must be considered.

There is no doubt that the chloride (Cl^-) ions in water containing humic acid may induce formation of carcinogenic chemicals (DBPs) [33]. For this reason, the favorable supporting electrolyte type would be sodium sulfate [70] [71].

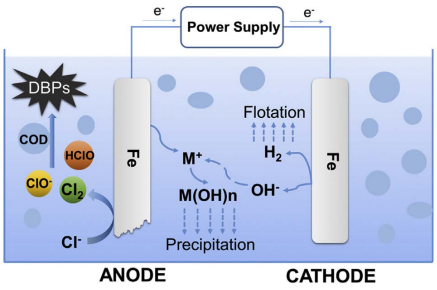

Figure 1. The schematic of an EC cell with DBP formation [1].

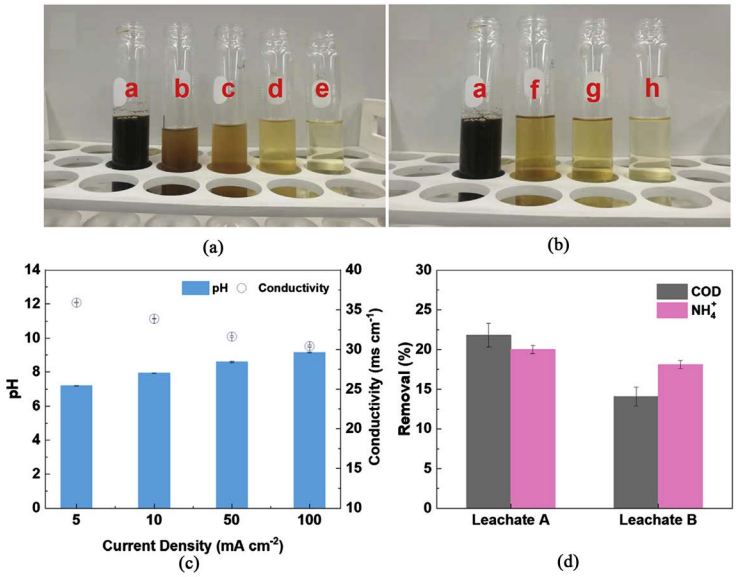

Figure 2. Leachate treatment by EC: (a) the change of color in Leachate A with different current densities applied after 60-min EC treatment (a: raw leachate, b: 5 mA/cm^2, c: 10 Ma/cm^2, d: 50 mA/cm^2, e: 100 mA/cm^2); (b) the change of color in Leachate A with different reaction times under the current density of 100 mA/cm^2 (f: 15 min, g: 30 min, h: 60 min); (c) pH and conductivity changes in Leachate A with different current densities applied after the 60-min EC treatment; and (d) chemical oxygen demand (COD) and ammonium removal efficiency in two leachates when current density was 100 mA/cm^{2}and reaction time was 60 min [1].

4. Conclusions

From this work, the following conclusions can be drawn:

1) During the last three decades, the EC process has known an exemplary renaissance in the field of water and wastewater treatment. Several researchers focused on applying this electrochemical technology in removing diverse pollutants such as organic matters. During EC application, the hazards of formation of highly toxic DBPs are more and more proved especially in water containing organic matter and halogens especially chloride.

2) An investigation has uncovered the possibility of DBP production in the EC handled leachates, where unregulated DBPs prevailed both concentrations and toxicity [1]. Higher current densities encouraged the generation of unregulated DBPs. HKs prevailed the weight based DBP concentration while HANs prevailed the DBP additive toxicity in most of the situations. Scavenging trials proved that free chlorine possessed a fundamental contribution in producing DBPs. Using granular activated carbon post-treatment could hugely diminish the levels and toxicity of both regulated and unregulated DBPs.

3) The EC method fully eliminated the largest molecular size part of humic acid; nevertheless, the lowest molecular size portions of humic acid were a little diminished at tried pHs levels [72]. As a result, the EC reactor was performed in eliminating humic acid [73] [74] [75] [76].

4) Great efforts remain to be accomplished towards the comprehension of the

inherent phenomena related to removing both microorganisms and organic matters in the EC method. Further, safe multi-barrier methods, such as distillation and membrane processes, have to be adopted.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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