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Spatial variation of electrode position in bioelectrochemical treatment system: Design consideration for azo dye remediation

Dileep Kumar Yeruva[a,b], J. Shanthi Sravan[a,b], Sai Kishore Butti[a,b], J. Annie Modestra[a,b], S. Venkata Mohan[a,*]

[a] Bioengineering and Environmental Sciences Lab, EEFF Department, CSIR-Indian Institute of Chemical Technology (CSIR-IICT), Hyderabad 500 007, India
[b] Academy of Scientific and Innovative Research (AcSIR), Hyderabad, India

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ABSTRACT

In the present study, three bio-electrochemical treatment systems (BET) were designed with variations in cathode electrode placement [air exposed (BET1), partially submerged (BET2) and fully submerged (BET3)] to evaluate azo-dye based wastewater treatment at three dye loading concentrations (50, 250 and 500 mg L^{-1}). Highest dye decolorization (94.5 ± 0.4%) and COD removal (62.2 ± 0.8%) efficiencies were observed in BET3 (fully submerged electrodes) followed by BET1 and BET2, while bioelectrogenic activity was highest in BET1 followed by BET2 and BET3. It was observed that competition among electron acceptors (electrode, dye molecules and intermediates) critically regulated the fate of bio-electrogenesis to be higher in BET1 and dye removal higher in BET3. Maximum half-cell potentials in BET3 depict higher electron acceptance by electrodes utilized for dye degradation. Study infers that spatial positioning of electrodes in BET3 is more suitable towards dye remediation, which can be considered for scaling-up/designing a treatment plant for large-scale industrial applications.

1. Introduction

Untreated dye based wastewaters from textile, paper and food processing industries contain hazardous and toxic compounds, which are not suitable for the existence of biological life. The unrestrained release of these dyes into water bodies diminishes the aquatic life forms by restricting the light penetration and hence pose a serious environmental concern. The breakdown by intermediate products of dye molecule can be toxic and mutagenic that would lead to critical health hazards (Azizi et al., 2015; Kumar et al., 2013). Traditional biological treatment methods suffer from low efficiencies due to microbial dye toxicity and the induction of secondary pollutants that require additional handling and disposal mechanisms (Alventosa-deLara et al., 2012; Firmino et al., 2010; Venkata Mohan et al., 2012). Bioelectrochemical treatment systems (BETs) are suitable alternatives that have been employed to treat wastewater, which permits cleaving of aromatic pollutants such as dyes, nitrosamines, antibiotics and chlorophenol (Sreelatha et al., 2015c; Solanki et al., 2013; Venkata Mohan and Chandrasekhar, 2011). Decolorization of azo dyes was studied by varying abiotic or biotic cathodes, applied potential, electrode materials, reactor configuration and redox condition (Sreelatha et al., 2015a; Liu et al., 2009; Sun et al., 2013; Yang et al., 2016).

Electrodes are key components that play a crucial role in BET operations and have a significant influence on the biotreatability. The spatial arrangement of electrodes and their design considerations play a major role in improving the electrocatalytic activity of system as well as biofilm and thereby might positively influence the remediation. Anodic oxidation, as well as cathodic reduction reactions, are also important to achieve the desired degree of degradation. Electrode assembly induces potential difference by the biocatalytic action of electrochemically active bacteria around the anode that carry out simultaneous redox reactions towards the breakdown of dye molecules. Electrochemical interactions at the microbe-electrode interface of anode also depend on the variations in cathode placement which in turn directly influence the performance of BET. Degradation potential of BET is majorly dependent on the bio-potential development that manifests the breakdown of complex organics. Breakdown of complex pollutants results in the formation of secondary compounds which would help in the transfer of electrons towards electrodes (Venkata Mohan et al., 2014; Modestra et al., 2016).

The spatial arrangement of electrodes involving electrolytic dissociation and electrochemical oxidation is considered as a limiting factor in BET operation and is hypothesized as one of a critical factor that influences the efficiency of azo dye degradation. Several studies

* Corresponding author.
E-mail addresses: svmohan@iict.res.in, vmohan_s@yahoo.com (S. Venkata Mohan).

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reported the effect of cathode towards the treatment of pollutants (Janicek et al., 2014; Wei et al., 2011; Yang et al., 2016; Kong et al., 2014; Cui et al., 2014; Xafenias et al., 2013). Direct influence of varying cathodic position on the biopotential generation for effective treatment of azo dye degradation needs to be studied which influences the anodic reactions. An optimized cathode placement has an influence on both operational efficiency and design simplification for upscaling. In order to overcome this challenge, a specific design has to be made on varying cathode position for utilizing the maximum efficiency of BET system. Therefore, spatial arrangement of cathode as the variant was considered as one of the factor that will have an influence on BET performance in the context of design. An attempt has been made in the present study to comparatively assess the influence of three cathode positions viz., air exposed cathode (BET1), partially submerged cathode (BET2) and fully submerged cathodes (BET3) towards dye degradation. Acid azo dye synthetic wastewater at variable dye loads (50, 250 and 500 mg L^{-1}) was used as the electrolyte to evaluate the relative performance of three systems with respect to dye decolorization. The study is also aimed to look into the understanding of mechanism involved in the reductive nature of spatial variations of cathode placement towards dye degradation.

2. Materials and methods

2.1. BET configuration

Three single chambered membraneless cylindrical BET systems (dia, 7 cm; height, 15 cm) were fabricated using borosilicate with a total/working volume of 0.5/0.45 L. Reactors were designed to have specific ports to accommodate the electrodes in different spatial arrangements. Graphite (dia, 2.5 cm) was used as both anode and cathode after pretreatment with 0.1 N HCl for 1 h followed by washing with deionized water. Electrical connections for measuring electrochemical parameters were made using a double insulated copper wire to prevent direct contact with the liquid. Based on the positioning of cathode, bioreactors were classified as BET1 (air cathode placed at right angles to the anode with an inter-electrode distance of 4 cm), BET2 (partly submerged cathode placed vertically parallel to the anode with an inter-electrode distance of 4 cm) and BET3 (completely submerged cathode placed vertically and parallel to the anode at same height with an inter-electrode distance of 4 cm) (Fig. 1). Anodes were completely submerged in all the bioreactors and were maintained constant with a vertically submerged position in BET2 and 3 and horizontally submerged in BET1. The surface area of anode and cathode were 19.63 cm^2, and the liquid contact of cathode was 9.86 cm^2 in BET1 and BET2 and 19.63 cm^2 in BET3.

2.2. Biocatalyst

Prior to startup, BET reactors were inoculated with anaerobic sludge (collected from sewage treatment plant (STP)). Parent inoculum procured was washed twice with phosphate buffer saline (PBS) to remove debris and grit. The washed biomass was re-suspended in DSW with chemical oxygen demand (COD) of 3 g L^{-1} (without dye) and allowed to grow overnight at 28 °C. The overnight grown culture was inoculated into the bioreactor by re-suspending through DSW (VSS-4870 mg L^{-1}) with a dye concentration of 50 mg L^{-1}.

2.3. Wastewater

Acid Black 10B [(4-amino-5-hydroxy-3-[(4-nitrophenyl) azo]-6-(phenyl azo)-2,7-naphthalene disulfonic acid disodium salt); ($C_{22}H_{14}N_6O_9S_2Na_2$)] related to azo group was used as standard dye for the study. Simulated dye wastewater (SDW) was prepared by dissolving dye concentrations of 50, 250 and 500 mg L^{-1} in designed synthetic wastewater (DSW (g L^{-1}): glucose-3.0, NH_4Cl-0.5, KH_2PO_4-0.25, K_2HPO_4-0.25, $MgCl_2$-0.3, $CoCl_2$-0.025, $FeCl_3$-0.025, $ZnCl_2$-0.0115, $NiSO_4$-0.050, $CuCl_2$-0.0105, $CaCl_2$-0.005 and $MnCl_2$-0.015). Prior to feeding, pH of SDW was adjusted to 7.1 ± 0.1 using 1 N HCl/NaOH.

2.4. Operation

Performance of BET reactors with the function of azo dye degradation was assessed at three varying cathode positions viz., air exposed (BET 1), partly submerged (BET 2) and fully submerged (BET 3) for three different dye concentrations of 50, 250 and 500 mg L^{-1} with a constant organic load of 3 g L^{-1} glucose. All the systems were operated in batch mode with a hydraulic retention time of 48 h. An external load of 500 Ω was used for closed circuit operation in all the systems. Periodic sampling of the reactor contents was performed at every 6 h interval to evaluate the system performance and dye degradation.

2.5. Analysis

To determine the decolorization efficiency, samples were withdrawn from BET systems at periodic time intervals during reactor

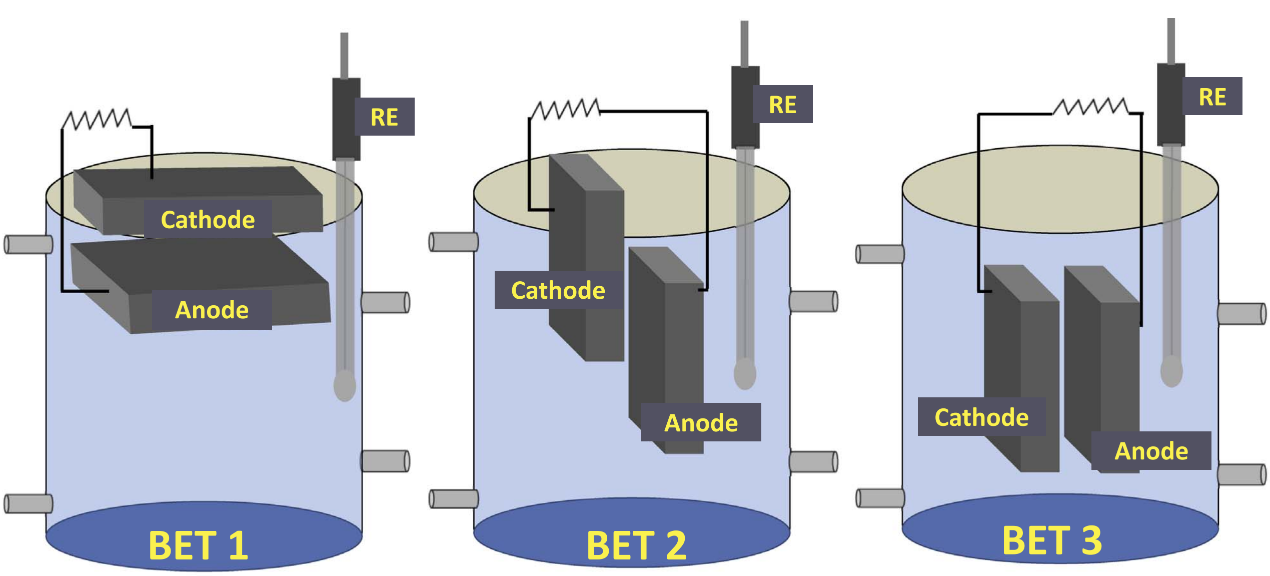

Fig. 1. Schematic representation of BET reactors and varied electrode placement used in the study.