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Integrated bio-electrogenic process for bioelectricity production and cathodic nutrient recovery from azo dye wastewater

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ABSTRACT

Microbial electrochemical treatment (MET) process was designed to evaluate complete mineralization of partially treated dye effluent obtained from anoxically operated Periodic discontinuous batch reactor (PDBR) for simultaneous bioelectricity generation and recovery of nutrients. In MET bioreactor, anode and cathode chambers were fed with designed synthetic wastewater (DSW) and PDBR dye effluents. The dye metabolite (NH_4^+) will be converted to nitrates by the activity of aerobic biocatalyst present in cathode chamber to be used as biofertilizer. Dye removal of 90.2% was observed with good electrogenic activity (voltage (OCV)/current; 395 mV/1.77 mA). The mineralization of dye and its intermediates were assessed by reduction in overall toxicity from 23% to 4%. Chemical oxygen demand (COD) removal efficiency of 75% (anode) and 88% (cathode) were observed in correspondence to higher azoreductase (18.7 U; 48 h) and dehydrogenase (1.66 μg/ml of toluene; 24 h) enzyme activities which correlated well with metabolic activities of biocatalyst. Bioelectrocatalytic behavior of mixed biocatalyst on the basis of redox catalytic currents and prevalence of redox mediators signified the specific function of electron transfer toward dye mineralization. The results obtained suggest that the use of MET can considerably degrade toxic pollutants and provides nitrate rich solution (biofertilizer). Utilization of recovered nutrients directly to farms without any energy intensive methods is reported in this communication.

1. Introduction

Most of the industrial wastewaters are characterized by variety of pollutants ranging from complex to low biodegradable compounds [1]. Textile dye wastewaters are characterized by fluctuating pH, intense color, dissolved solids, high Chemical oxygen demand (COD) and toxic compounds [2]. Normally, azo dye requires sequential integration of anoxic and aerobic processes to facilitate the decolorization and degradation of dye molecule and its intermediates respectively under suitable microenvironments [2–4]. Because of its chemical stability and synthetic nature, azo dyes are not totally degraded and exhibit slow degradation by conventional wastewater treatment methods [5,6]. PDBR is an advanced biological and batch analog process that allows the integration of both anoxic and aerobic redox conditions in a single reactor for the possibility of mineralization by following reductive and oxidative steps in a sequence [2,3,7,8].

Integration strategies enables value addition to wastewater treatment [4]. This integrating strategy also provides a step towards circular bioeconomy advocating sustainability [9,10]. Microbial electrochemical treatment (MET), a typical microbial fuel cell (MFC), has the ability to couple both electrochemical and anaerobic biological processes triggering the redox reactions for the degradation of complex pollutants with simultaneous power generation [10–13]. These reducing equivalents (electrons (e^-) and protons (H^+)) aid in pollutant degradation, bioelectricity generation and facilitate formation of value added products through a cascade of redox reactions [13–15]. The anode respiring bacteria enables effective electron transfer towards pollutant degradation [11,13]. Since the cathodic reduction of reducing powers is also important along with anodic oxidation, biocathode with aerobic bioconsortia will also influence substrate oxidation indirectly [16,17]. Biocathode also has specific function on overall system's performance viz. wastewater treatment, specific pollutant removal. etc. [18–21]. MET processes utilize wastewaters rich in nitrogen sources and generate value added products that has potential advantages in terms of versatility, environmental compatibility and zero chemical usage. Cation exchange membrane (CEM) sandwiched between anode and cathode chambers aids in transfer of protons and cations

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and paves a way towards pollutant removal or salts separation [21,22]. The cations transferred will undergo various process viz., nitrification by the aerobic biocatalyst and aid in formation of simpler compounds (NO_2^- and NO_3^-) [23,24].

An attempt was made in this communication to understand the process of treating textile effluent using microbial electrochemical processes in integration with periodic discontinuous batch reactor (PDBR). In this, the waste (effluent) obtained from one process can be utilized for the other to devour carbon present and recover nutrients for commercial purposes or farming making the overall process sustainable aiming towards zero liquid discharge in the frame work of biorefinery. Studies were also carried out to evaluate the process dynamics with the function of anode and cathode chambers operated with anaerobic and aerobic biocatalysts respectively. The bioreactor performance was assessed by evaluating various parameters viz., pollutant (dye and COD) removal, enzymes (Azo reductase and dehydrogenase) activity, nutrient recovery (Nitrates and ammonical nitrogen), toxicity analysis, bioelectrogenesis (OCV and current), bioprocess (pH and VFAs) parameters and bioelectrochemical (CV, DCV, mediators, Tafel plots and slopes) analysis. This study will help to comprehend few challenges and design effective integration strategy for complete mineralization of high strength wastewater and recovery of nitrates utilizing zero input energy methods and mixed culture as bioconsortia.

2. Materials and methods

2.1. MET construction

Microbial electrochemical treatment (MET) was constructed by assembling two equal cylindrical glass bottles (as anode and cathode) with total volume of 100 ml each (Fig. 1). The cylinders were fixed together by using bolted assembling unit and leak proof sealing was ensured by inserting rubber sheets between two cylinders. A cation exchange membrane (CEM; Ultrex CMI-7000, Membranes International, U.S.) was sandwiched between two electrodes. The total/working volume of the each cylinder is 100/90 ml and was operated in suspended mode with fed-batch for 6 cycles with a hydraulic retention time (HRT) of 48 h. Non-catalyzed graphite plates (4 cm × 2.4 cm; 5 mm thick) with surface area of 25.6 cm^2 were used as electrodes in both the anode and cathode compartments. Prior to use, graphite plates were washed to eliminate the interfering particles which may have influence on the reactor performance. Copper wires sealed with an epoxy sealant at the joints were used to transfer electron flow by maintaining contact with the electrodes. The wastewater in the anode chamber was recirculated by employing peristaltic pump. The aeration provided at the bottom of the chamber will aid in recirculation of the whole contents in the cathode chamber. The anodic and cathodic electrodes were connected through an external resistor with variable resistance to close the circuit and measure current generated during the process.

2.2. Biocatalyst

Anaerobic and aerobic consortium acquired from an effluent treatment plant (HMT Nagar ETP, Hyderabad, India) and full-scale activated sludge processes were used as biocatalysts in the anode and cathode compartments respectively. Prior to inoculation, parent inoculums were washed twice with phosphate buffer saline (PBS) and re-suspended in designed synthetic wastewater (DSW (without dye); glucose- 3 g/l; NH_4Cl- 0.5 g/l, KH_2PO_4- 0.25 g/l, K_2HPO_4- 0.25 g/l, $MgCl_2$- 0.3 g/l, $CoCl_2$- 25 mg/l, $ZnCl_2$- 11.5 mg/l, $CuCl_2$- 10.5 mg/l, $CaCl_2$- 5 mg/l, $MnCl_2$- 15 mg/l, $NiSO_4$- 0.16 g/l, $FeCl_3$- 0.03 g/l) overnight at ambient room temperature under requisite microenvironment (100 rpm; 48 h). For aerobic consortia air supply was provided through an air-pump to maintain dissolved oxygen (2.5 ± 0.5 mg/l). Culture (15% of total volume) was inoculated into the respective chambers by re-suspending through feed (VSS, 4660 mg/l) to facilitate the initial adaptation and stabilization of the microorganisms in the respective chambers. During SETTLE phase, the retained biomass (10%) was used in subsequent cycle operations with a water exchange of 90%.

2.3. Wastewater

Outlet from periodic discontinuous (sequencing) batch reactor

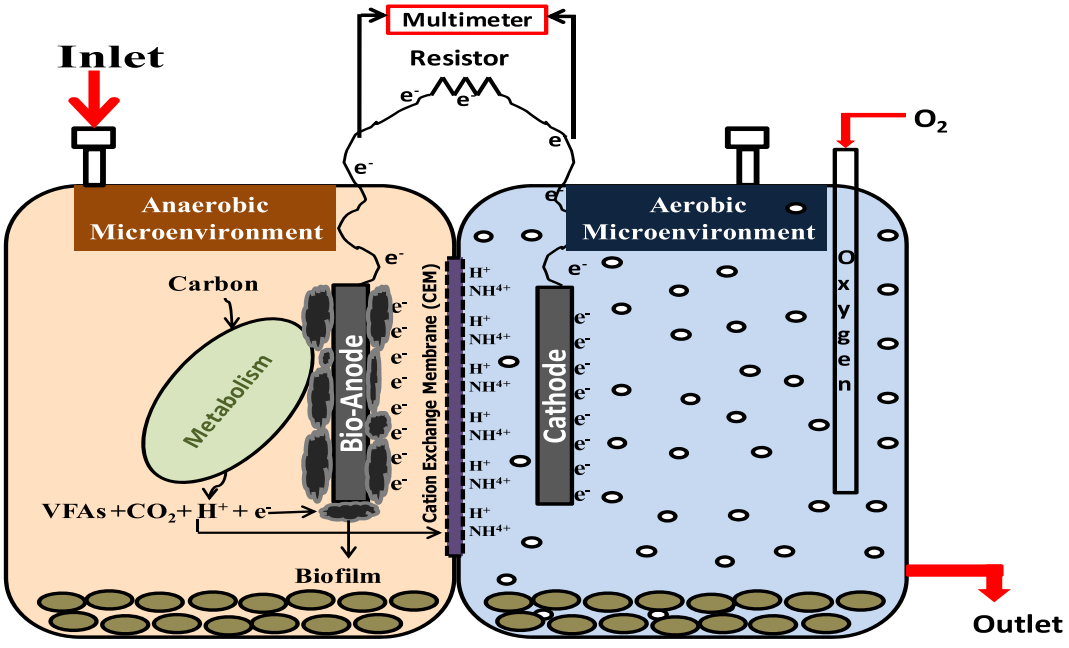

Fig. 1. Schematic Representation of MET bioreactor.