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Electrochemical and bio-electrochemical treatment of baker's yeast effluents

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ABSTRACT

In this study, electrochemical and bio-electrochemical oxidation where examined as possible methods for the treatment of untreated and biologically treated baker's yeast effluents, bearing large amounts of melanoidins. Experimental data showed that electrochemical oxidation, carried out in an electrolysis cell with a boron-doped diamond anode, strongly depends on the current density applied and the organic load is rapidly oxidized to CO_2 without the formation of intermediates leading to almost complete discoloration and COD removal. Color removal of the treated and untreated effluents was almost complete after 200 min of oxidation at a current density greater than 132 A/m^2. COD and TOC of both effluents were also successfully reduced under the same experimental conditions. The acidic pH favours oxidation more than neutral or alkaline one. On the other hand, bio-electrochemical treatment via a microbial fuel cell (MFC) with carbon felt electrodes, was proven less efficient on the discoloration of the untreated effluent, but exhibited a significant effect on the reduction of COD which reached 40%. The addition of 0.4% v/v ABTS$^+$ mediator in the anode chamber enhanced the power output of the cell up to 0.018 W/m^2 and the removal of COD up to 40% but further increase had a negligent effect on MFC's performance.

1. Introduction

Effluents generated from baker's yeast and other fermentation industries, which use molasses as feedstock, are characterized by high concentrations of BOD_5, COD, TKN and dark brown color [1]. The latter is attributed to the presence of high molecular weight colored polymers known as melanoidins which are formed during the non-enzymatic Maillard reaction [2,3].

The most common technology used for the treatment of molasses effluents is a two stage conventional combination of anaerobic/aerobic processes. Anaerobic treatment converts a great amount of the effluent COD into biogas and can be successfully operated at high organic loading rates; also, the biogas thus generated can be utilized for steam generation in the boilers thereby meeting the energy demands of the unit. The post-anaerobic treatment effluent still has a high organic loading and dark brown color, hence it is usually subjected to a secondary, aerobic activated sludge treatment [4,5]. This technology significantly reduces COD and BOD_5 of the wastewater but has a negligent effect on the removal of melanoidins and consequently on the color of the wastewater [6,7]. Melanoidins have antioxidant properties and are toxic to microorganisms that are typically found in wastewater treatment facilities [8]. Therefore, methods alternative to standard biological treatment are needed for the removal of melanoidins either from untreated effluents (pre-treatment) or treated effluent (post-treatment). To that direction, both electrochemical and bio-electrochemical technologies have been used in this work for the treatment of untreated and biologically treated baker's yeast effluents.

In recent years electrochemical treatment has been proven a potentially powerful approach for environmental remediation and in particular for color removal from industrial effluents [9–14]. The primary reagent used is the electron which in principle makes electrochemical treatment a clean technology for addressing environmental problems because there is no necessity for extra addition of reagents [15].

Interest has grown in electro-oxidation as a suitable method for the treatment of industrial wastewaters. There are two modes that

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Fig. 1. Photo of the double chamber MFC unit.

electro-oxidation can be operated. First, the indirect anodic oxidation, utilizing in-situ electrochemically generated oxidizing agents such as, chlorine, hypochlorite, Fenton's reagent, peroxodisulphate, ozone and hydroxyl radicals ($OH^{\bullet}$) [16,17]. The drawback of indirect oxidation is the formation of chlorinated organic intermediates which are considered carcinogenic and mutagenic (this is because most effluents contain chloride ions) [18,19]. In the second mode, direct anodic oxidation, the pollutants are directly oxidized at the surface of the anode. Provided that $OH^{\bullet}$ radicals stay at the surface or the vicinity of the electrode some authors classify the oxidation by $OH^{\bullet}$ radicals as direct too [20]. The parameters that affect direct oxidation are the ability to generate physically or chemically adsorbed hydroxyl radicals occurring in parallel with the oxygen evolution reaction, the applied current and the characteristics of anode material [21]. The electrode is an important parameter when optimizing such processes since the mechanism and the products of several anodic reactions are known to critically depend on the anode material. For example, in search for the best anode, distillery spent wash was treated with planar graphite electrode [22], ruthenium oxide coated titanium mesh [23], and stainless steel (SS) plates [24], while vinasses effluents were treated with titanium alloy anode in a laboratory pilot plant [25]. Boron-Doped Diamond (BDD) electrodes are found to be quite attractive for electrochemical applications due to their high activity towards $OH^{\bullet}$ production and other characteristics including chemical inertness, high hardness, wide electrochemical potential window and electrochemical stability [26–30]. Although synthetic melanoidin solutions were treated with BDD anode electrodes, we are not aware of a similar treatment of a real baker's yeast effluent [31,32].

At the same time, microbial fuel cells (MFCs) are also an emerging bio-electrochemical technology that is examined for simultaneously treating wastewater and producing energy since the early 90′s [33–35]. The construction and analysis of MFCs requires knowledge of different scientific and engineering fields, ranging from microbiology and electrochemistry to materials and environmental engineering. Constructing efficient MFC systems therefore involves an understanding of these different scientific and engineering principles [36]. Although MFC technology still lacks standard procedures and methods for the analysis of the system performance, it is considered to be a promising sustainable technology to meet increasing energy needs, especially using wastewaters as substrates [36,37]. MFC's can generate electricity by converting the energy stored in chemical bonds of organic compounds present in the substrate, to electrical energy through catalytic reactions triggered by microorganisms and coupled to electron transfer at electrodes, while simultaneously accomplishing wastewater treatment. In this way, MFCs may offset the operational costs of wastewater treatment plants [37–39].

Various designs of microbial fuel cells have been reported. A typical MFC consists of an anodic and a cathodic chamber separated by a proton exchange membrane or a salt bridge which allows electrolyte movement while blocking the diffusion of oxygen into the anode compartment and that of the effluent into the cathode compartment of the MFC [40].

Among the studies related to the MFC technology, there are few that use alcohol distillery effluents containing melanoidins as the MFC substrate and even fewer that encompass dark fermentation wastewater [41–45]. To the best of our knowledge there is no study yet available that uses baker's yeast wastewater as a substrate in a dual chamber MFC for the production of electricity with simultaneous wastewater treatment.

This study aims to investigate the removal of color, COD and TOC, from real baker's yeast effluents, either by electrochemical (EC) or bio-electrochemical (MFC) methods. The novelty of the current research is the comparison of the studied methods as pre or post treatment complementary to conventional applied aerobic-anaerobic biological treatment. The EC evaluation was done in an electrolytic cell with BDD electrodes. The effect of pH and current density was studied. The bio-electrochemical treatment was realized in a two compartment MFC and the effect of substrate, mediator concentration and pH was investigated.

2. Materials and methods

2.1. Baker's yeast effluents

Baker's yeast effluents were taken from a local yeast manufacturing factory. The latter has a two-staged biological treatment facility. Raw molasses effluent is initially mixed in a buffer tank before being fed to anaerobic-aerobic biological treatment. Samples were collected from the buffer tank, referred to as "untreated", and from the exit of biological treatment referred to as "treated". Samples of effluents collected stored and analyzed over an extended period of two years on a weekly basis from the local yeast manufacturing factory. The characteristics of the untreated effluent were COD = 15000 mg/L (±300), TOC = 4800 mg/L (±100), TDS = 19500 mg/L (±500), pH = 8-8.5 and color content ADMI = 17200-17860. The characteristics of the treated effluent were COD = 3500 mg/L (±200), TOC = 4300 mg/L (±200), TDS = 18600 mg/L (±500), pH = 8-8.5 and ADMI = 18200-18650. The background electrolyte concentration, a measure of TDS, of the samples was sufficient to provide conductivity (~5 mMho) for carrying oxidation current and extra addition of electrolyte salt was deemed unnecessary. All samples were kept in refrigerator at 5 °C before use [46].

2.2. Electro-oxidation

Batch electro-oxidation experiments were carried out in a single compartment electrolytic cell, with total volume of 50 mL, using boron doped diamond (BDD) electrode coating on a polycrystalline silicon substrate (BDD/Si, NeoCoat, Lot N°: LD1170_G1) as the anode. The electrode substrate was 50 mm high, 25 mm wide, 1 mm thick and the resistivity of the coating was 100 m Ω·cm. The electrode comprised of a single coated side. The thickness of the BDD coating was 2.5 μm while boron concentration was 700 mg/L. A stainless steel grid was used as the cathode. Both electrodes were rectangular, with a nominal area of 8.75 cm^2, placed vertically 5 cm apart in the cell. The experiments were carried out using 30 mL samples under constant magnetic steering at 200 rpm using a 1.5 cm long and 0.5 cm wide stirring bar. Similar experimental set-up has been extensively used by other researchers [47–51]. Temperature and pH were continuously monitored but without adjustment. Electrolysis was conducted by applying