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Research article

Enhancement of the performance of a combined microalgae-activated sludge system for the treatment of high strength molasses wastewater

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The treatment of molasses wastewater, by a combined microalgae-activated sludge process, for the simultaneous organics and total nitrogen reduction, was examined. Further enhancement of the performance of the combined process was accomplished, by means of biofilm carriers or electrocoagulation. A LED light tube was immersed into the reactor tank aiming to enhance the growth of photosynthetic microalgae, while in a similar unit, biofilm carriers were added to the system, representing a moving bed bioreactor. Exposure of the activated sludge biocommunity to light source, resulted in the growth of microalgae and photoreactors exhibited higher removal rates of total nitrogen and nitrates. However, operation at longer times resulted in low effluent quality due to the presence of microalgae cells as a result of high growth rates, and potential light shading effect. Nevertheless, the moving bed system was more beneficial than the single photoreactor, as biofilm carriers provided a self cleaning capacity of the light source, reducing the effect of microalgae deposition. Advanced treatment of the biological effluents, by electrocoagulation, increased even more the process efficiency: the combined photobioreactor and electrocoagulation process resulted in about 78% COD removal and more than 35% total nitrogen removal in the effluent, where nitrates represented almost the single form of total nitrogen.

1. Introduction

Molasses is a major by-product of the sugar industry used as raw material in various industrial processes such as production of baker's yeast, bioethanol and in distilleries; however, processing of molasses results in the formation of high strength molasses wastewater, characterized by a dark brown color, extensive odor, very high COD (Chemical Oxygen Demand) up to 60,000 mg/L and BOD (Biochemical Oxygen Demand) values (25,000 mg/L) (Chandra et al., 2008; Robles-Gonzalez et al., 2012). Melanoidins represent a significant component of molasses wastewater, responsible for their poor biodegradability. Melanoidins are non-linear polymers produced through non-enzymatic Maillard and polycondensation reactions (Chandra et al., 2008; Cammerer et al., 2002); they are recalcitrant substances resistant to biological and chemical treatments. Nevertheless, since molasses wastewater covers a wide range of effluents obtained from different processes and raw materials (sugarcane, sugar beetles), the characteristic properties of molasses wastewater, such as pH, organic and nutrients content etc., may greatly vary. Thus, various treatments have been examined for the degradation of molasses wastewater, and it has been reported that the effectiveness of a process depends on the organic content, i.e. COD concentration, of the raw effluent (Asaithambi et al., 2012). It is profound that the disposal of untreated molasses wastewater is associated with significant environmental impacts, and its management is a difficult issue of great interest.

Typical management systems of molasses wastewater include anaerobic digestion followed aerobic-activated sludge treatment (Pant and Adholeya, 2007). However, the efficiency of these biological stages is not adequate depending on raw wastewater origin and properties, resulting to a low quality effluent with a high COD content, up to 5000 mg/L, with low biodegradability, as deduced by the low BOD_5 (5 day BOD) values; therefore, combination of various techniques is examined by several researchers, including electrocoagulation (Asaithambi et al., 2012; Tsioptsias et al., 2015), enzyme treatment (Sangave and Pandit, 2006a), nanofiltration (Meihong et al., 2013), ultrasound irradiation (Sangave and Pandit, 2006b) and ozonation (Asaithambi et al., 2012; Tsioptsias et al., 2016). Usually, these techniques are applied as pre- or post-treatment stages to the biological process and various COD and

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color reduction rates depend on influent properties, the origin of molasses wastewater, and the experimental conditions.

Microalgae and photosynthetic bacteria have been examined for their potential towards the production of biohydrogen and biopolymers (Munoz and Guieysse, 2006; Keskin and Hallenbeck, 2012; Zhou et al., 2014), while their implementation in wastewater treatment processes is usually carried out in membrane bioreactor systems, since photosynthetic bacteria are resistant to sedimentation (Lu et al., 2013). The produced biomass can be safely used as fish food or medium for fertilizer replacement (Lu et al., 2013). Notwithstanding, microalgae are often used for the tertiary treatment of secondary effluents, aiming to the enhancement of nutrients removal, heavy metals, or pathogens (Munoz and Guieysse, 2006). When microalgae are used in the primary or the secondary stage of a wastewater treatment plant, their main role is rather supporting the aerobic microorganisms by providing oxygen through the photosynthetic cycle, than direct degradation of organic compounds (Munoz et al., 2003; Munoz and Guieysse, 2006). This process, called photosynthetic oxygenation, is an alternative method to mechanical aeration for fulfilling of the oxygen demand in an activated sludge system; furthermore, is a low cost method, which in addition, has the advantage of minimizing the evaporation of hazardous volatile substances (Munoz and Guieysse, 2006). Therefore, the efficiency of microalgae as oxygen releasing organisms has been proved, such as the degradation of salicylate through bacteria oxygenated exclusively by photosynthetic bacteria and microalgae (Munoz et al., 2003); however, the utilization of microalgae and photosynthetic bacteria for direct degradation of macromolecules is limited (Lu et al., 2010). Nevertheless, limited studies (Valderrama et al., 2002) have been presented on the utilization of microalgae for molasses wastewater treatment, although these effluents contain high amounts of nutrients. It has been reported that molasses wastewater treatment by microalgae and macrophytes resulted in about 65% COD and 70% NH_4 removal respectively, but under long incubation time, 4 days for microalgae and additional 6 days for macrophyte, and requiring complicated feeding condition modes (Valderrama et al., 2002).

Moving bed bioreactors and biofilm carriers (Nicolella et al., 2000; Munoz et al., 2009; Luo et al., 2014) offer certain advantages in wastewater treatment systems, such as high contact surface between wastewater and microorganisms associated to compact reactors, high biomass age, and enabling clarification and separation stages either by reducing settling time (Nicolella et al., 2000) or by easily floating if no mixing or aeration is applied, depending on the form of carriers. For nutrients removal, requiring anoxic stages for the reduction of N-NO_3 to molecular N_2, these systems provide an additional advantage, since both oxic and anoxic regions exist upon the carriers (Luo et al., 2014). Biofilm photo-bioreactors are less common (Munoz et al., 2009); combination of a moving bed with a photo-bioreactor has not been reported for the treatment of high strength wastewaters; such a system could be beneficial for the treatment of molasses wastewater and the removal of nitrogen.

The objectives of this study were the examination of the degradation of an alkaline baker's yeast molasses wastewater, and the investigation of alternative methods for the enhancement of nitrogen removal rate, simultaneously to organic compounds reduction, by using a combined microalgae and activated sludge process in a sequencing batch photobioreactor system (Tsioptsias et al., 2016). The beneficial role of microalgae was twofold: a) oxygen source to the heterotrophic bacteria through photosynthesis, and b) direct degradation of the pollutants. In addition, enhancement of the removal process took place by the examination of two different approaches: a) moving bed sequencing photobioreactor by the addition of biofilm carriers into the aeration tank and b) a rapid post-treatment step of the effluent by electrocoagulation.

2. Experimental

2.1. Materials and instruments

Sugar beet molasses wastewater was collected from the outlet stream of the anaerobic wastewater treatment plant of a baker's yeast industrial plant. Wastewater mixtures were prepared containing 90% v/v molasses wastewater in tap water and these mixtures were used in the experimental systems. Activated sludge was collected from the sludge recycling stream of a full scale activated sludge wastewater treatment plant, located in Thessaloniki, Northern Greece.

The examination of the treatment of molasses wastewater took place in three identical Sequential Batch Reactors (SBR) consisted of 10 L plexiglass cylindrical units with ID (internal diameter) 0.206 m and height 0.3 m. Each system was equipped by the required devices i.e. two peristaltic pumps (type PR7, SEKO) for the introduction of the influent and the removal of effluent; needle and solenoid valves for the supply and the adjustment of air flow rate into the reactors; magnetic stirrers for stirring the content of each reactor (Fig. 1a).

Dissolved oxygen concentration into the reactors, during the aeration stage, was adjusted to 2.5 mg/L using a Greisinger dissolved oxygen meter and a proportional-integral-derivative (PID) controller. A strip with 10 low emitting diodes (LED), was immersed into the photo-bioreactor tank as a light source; total power consumption of the LEDs estimated to 17 W and luminous flux was 600 lumens. The light source consisted in LEDs emitting in various wavelengths, red, blue, yellow and green, in order to obtain a white light. The LED bar was placed inside a glass tube and the glass tube was immersed and fixed in the center of the reactor by using laboratory clamps and support stand. An image of the LEDs module and the glass tube are presented in Fig. 1b. AnoxKaldness™ were used as biofilm carriers (Fig. 1c).

A variable voltage transformer (Yokoyama Electric Works Ltd) was used for the electrocoagulation experiments using copper and iron electrodes. The aim of this work was the treatment of a strong industrial wastewater by a cost efficient method: therefore, efforts were paid towards the utilization of low cost materials. As a result, materials used as electrodes were of industrial composition, obtained from the local cable market (copper sheets and copper cables) or from iron related processes (i.e. sheets from lathe machine works).

For the determination of COD, nitrogen (nitrate, ammonium and total) and phosphorous content the respective Hach-Lange LCK kits were used, along with a DR-2800 spectrophotometer. Total and volatile suspended solids were measured according to standard methods (APHA, 1998). Light absorption measurements at 475 nm were performed by a Helios UV–Vis photometer (Thermo Electron Corporation).

Two alternative independent series of experiments were carried out using the following treatment processes: a) utilization of biocarriers in the moving bed SBR photobioreactor and b) electrocoagulation as a rapid post treatment step followed by biological treatment in the SBR photobioreactor.

2.2. Microalgae-activated sludge treatment in SBR photobioreactors with biofilm carriers

Three identical SBR reactors were used for the examination of molasses wastewater treatment. Startup of the SBR systems carried out by the addition of 0.5 L of recycled activated sludge and 5.5 L of the molasses wastewater mixture. The three reactors were operated in subsequent 12 h cycles consisted in the following stages: 1)