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Removal of Maxilon Yellow GL in a mixed methanogenic anaerobic culture

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Abstract

Degradation of dye Maxilon Yellow GL (MY GL) (Basic Yellow 45) was investigated with anaerobic mixed culture using glucose (3000 mg l^{-1} COD) as carbon source and electron donor throughout batch experiments. Zero-, first- and second-order reaction kinetics were used to find out the suitable substrate removal and decolorization kinetics. The substrate removal (COD) process is suitable for second-order reaction kinetics among the kinetic models studied. Decolorization process also approximates to second-order kinetics between 50 and 1000 mg l^{-1} of MY GL concentration. Substrate and color removal rates (mg l^{-1} h^{-1}) were found to be 6.38, 5.98, 4.6, 4.16, 3.64, 2.86, 2.34 and 0.075, 0.0149, 0.0265, 0.0303, 0.0426, 0.053, respectively, in all serum bottles throughout the incubation period. Color removal efficiencies decreased as the influent dye concentration increased. The highest removal efficiency (80%) was obtained with 50 and 100 mg l^{-1} of MY GL dye concentrations. However, the lowest removal efficiency (28%) was found with a 1000 mg l^{-1} of MY GL dye concentration. Complete dye reduction was not found for this basic dye. The results indicate that anaerobic mixed culture can decolorize low concentration of this basic dye.

Keywords: Dye removal; Anaerobic mixed culture; Substrate removal; Kinetic constant

1. Introduction

Most of the industries, such as textiles, paper, plastics, leather, food, cosmetics, etc use dyes or pigments to color their final product. Effluents from these industries are generally highly colored. Therefore they are main sources of water pollution [1].

Dyes include a broad spectrum of different chemical structures, primarily based on substituted aromatic and heterocyclic groups such as aromatic amine (C_6H_5–NH_2) and phenyl (C_6H_5–CH_2) [2]. Azo dyes constitute the largest class (60–70%) of dyes used in industry [2,3]. They are characterized by their typical –N=N– nature [4]. Basic dyes are cationic compounds that are used for dyeing acid group-containing fibres, usually synthetic fibres like modified polyacryl. They bind to the acid groups of the fibres. Most basic dyes are diarylmethane, triarylmethane, anthraquinone and azo compounds. Basic dyes represent approximately 5% of all dyes listed in the Color Index [5]. The acute toxicity of dyestuffs is generally low. The most acutely toxic dyes for algae are – cationic – basic dyes. Many dyes and their breakdown products have toxic as well as carcinogenic and mutagenic effects on living organisms [1,6,7]. Therefore, decolorization of dyes is an essential aspect of wastewater treatment before discharge. Dyes are not easily degradable and are generally not removed from wastewater treatment systems [3]. Several physical, chemical and biological pretreatment, main treatment and post-treatment techniques can be employed to remove color from dye containing wastewaters [5]. Physico-chemical techniques include membrane filtration, coagulation/flocculation, precipitation, flotation, adsorption, ion exchange, ion pair exctraction, ultrasonic mineralization,

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electrolysis, advanced oxidation (chlorination, bleaching, ozonation, Fenton oxidation and photocatalytic oxidation), and chemical reduction [1,5,8]. Biological techniques include bacterial and fungal biosorption and biodegradation in aerobic, anaerobic, anoxic or combined anaerobic/aerobic treatment processes. Biological processes provide a low cost and efficient means to treat the textile effluent [4,9,10]. Generally biological aerobic wastewater systems are not successful for decolorization of majority of dyes [1]. However, under strict anaerobic conditions, decolorization of dye can be achieved and is well documented [9,11]. Especially, anaerobic wastewater treatment is superior to aerobic treatment for azo dye removal [3,12,13]. Several researchers have reported that a low redox condition kept in the bioreactor by the methanogenic culture is responsible for color removal [9,11]. Decolorization of azo dye in the anaerobic batch culture has been studied by several researchers [3,9,11,13,14].

The objective of this study was to evaluate the use of anaerobic mesophilic culture for color removal from a basic dye (MY GL).

2. Kinetic models

2.1. Kinetic model for co-substrate (glucose) degradation and decolorization

Monod-type kinetics has been used for dye biodegradition and decolorization. However, some researchers showed that it was not successful to use these in their anaerobic systems. Hence, removal of co-substrate during decolorization of dyes can be expressed by zero-, first- and second-order reaction kinetics in an anaerobic batch reactor by the following equations [3,8]:

$$S_t = S_0 - k_0 t \tag{1}$$

$$S_t = S_0\, e^{-k_1 t} \tag{2}$$

$$\frac{1}{S_t} = \frac{1}{S_0} + k_2 t \tag{3}$$

Similarly, zero-, first- and second-order reaction kinetics have been used to find out color removal rate constants by using the equations below:

$$C_t = C_0 - K_0 t \tag{4}$$

$$C_t = C_0\, e^{-K_1 t} \tag{5}$$

$$\frac{1}{C_t} = \frac{1}{C_0} + K_2 t \tag{6}$$

3. Materials and methods

3.1. Batch experiments and experimental procedure

In the batch anaerobic experiments, 500 ml glass serum bottles sealed with rubber screw cap were used. Each of the serum bottles consisted of 18.5 ml anaerobic mixed culture to provide sludge concentration as 3000 mg MLVSS l^{-1} taken from UASB reactor treating the wastewaters of Pakmaya Yeast Factory in İzmit, Turkey, 3000 mg COD l^{-1} of glucose and the necessary Vanderbilt mineral medium for macro- and micronutrients. Table 1 gives the conditions of batch test.

This mineral medium was used in all batch experiments and contains the following inorganic composition (in mg l^{-1}): NH_4Cl, 400; $MgSO_4 \cdot 7H_2O$, 400; KCl, 400; $Na_2S \cdot 9H_2O$, 300; $(NH_4)_2HPO_4$, 80; $CaCl_2 \cdot 2H_2O$, 50; $FeCl_3 \cdot 4H_2O$, 40; $CoCl_2 \cdot 6H_2O$, 10; KI, 10; $(NaPO_3)_6$, 10; L-cysteine, 10; $AlCl_3 \cdot 6H_2O$, 0.5; $MnCl_2 \cdot 4H_2O$, 0.5; $CuCl_2$, 0.5; $ZnCl_2$, 0.5; NH_4VO_3, 0.5; $NaMoO_4 \cdot 2H_2O$, 0.5; H_3BO_3, 0.5; $NiCl_2 \cdot 6H_2O$, 0.5; $NaWO_4 \cdot 2H_2O$, 0.5; Na_2SeO_3, 0.5 [15]. The alkalinity and neutral pH were kept constant by the addition of 5000 mg l^{-1} $NaHCO_3$. Temperature controlled incubator was used at 35 °C for all batch experiments. The serum bottles were shaken at 150 rpm during determined intervals. Syringe was used to take supernatant samples from bottles for analysis. λ_{max} of dye was found to be 430 nm (Fig. 1).

A control without dye and a seed blank sample were used to determine and compare COD measurements in all batch serum bottles. Substrate removal and decolorization experiments in all batch studies were performed in duplicates to control the accuracy of the experimental results. Experimental data were detected both from COD and dye measurements. The methane gas to COD conversion was considered as follows: 0.395 ml methane gas was produced from the removal of 1 mg of COD^{-1}.

The microbial cultures were autoclaved at 121 °C for 15 min to measure the adsorption or abiotic removal of dyes.

Table 1
Experimental conditions of anaerobic batch study

Stock	Seed control (ml)	Abiotic control (ml)	Control (dye-free) (ml)	1 (50 mg l^{-1})	2 (100 mg l^{-1})	3 (250 mg l^{-1})	4 (500 mg l^{-1})	5 (750 mg l^{-1})	6 (1000 mg l^{-1})	Resulting control
Sludge, 32.5 g MLVSS l^{-1}, 40 g MLSS l^{-1}	18.5	–	18.5	18.5	18.5	18.5	18.5	18.5	18.5	3000 mg MLVSS l^{-1}
Glucose, 30 g COD l^{-1}	–	20	20	20	20	20	20	20	20	3000 mg COD l^{-1}
$NaHCO_3$, 50 g l^{-1}	20	20	20	20	20	20	20	20	20	5000 mg l^{-1}
Vanderbilt	20	20	20	20	20	20	20	20	20	Desired comp.
Dye, 10 g l^{-1}	–	1.0	–	1.0	2.0	5.0	10	15	20	Desired comp.
Total	200	200	200	200	200	200	200	200	200	1