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Performance of anaerobic baffled reactor (ABR) treating synthetic wastewater containing *p*-nitrophenol

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Abstract

In this study, the effect of increasing *p*-nitrophenol (PNP) concentrations on the performance of anaerobic baffled reactor (ABR) (chemical oxygen demand (COD), removals, volatile fatty acid (VFA), *p*-aminophenol (PAP) and methane gas productions) was investigated through 240 days. The PNP concentrations were raised to 700 from 10 mg/L corresponding to PNP loading rates of 0.97 and 67.9 g/m^3 day. The PNP and COD removal efficiencies were 99 and 90% at PNP loading rates as high as 33.9 g/m^3 day, respectively, through the acclimation of anaerobic granular sludge. After this loading rate, the removal efficiencies decreased to 79%. The COD removal efficiencies were high in compartment 1 (E = 78–93%) while a small amount of COD removal was achieved in compartments 2 and 3. The PNP removal efficiencies were approximately 90% in all PNP loading rates except for loading rate of 0.97 g/m^3 day. The maximum PNP removal efficiency was measured as 99% at a loading rate of 8.32 g/m^3 day. The optimum PNP loading rate for maximum COD, PNP removals and methane yield was 8.32 g/m^3 day. The total, methane gas productions and methane percentages were approximately 2160–2400 mL/day and 950–1250 mL/day and 44–52% for the PNP loading rates varying between 4.36 and 33.9 g/m^3 day, respectively. For PNP loading rates varying between 33.9 and 67.9 g/m^3 day, the total, methane gas productions and methane percentages were approximately 2160 and 960 mL/day and 44%, respectively. The highest total volatile fatty acid (TVFA) concentrations were found in the first compartment with fluctuated values varied between 50 and 200 mg/L indicating the acidogenesis. *p*-Aminophenol was found as the main intermediate through anaerobic degradation of PNP which later was broken down to phenol and ammonia.

Keywords: Anaerobic baffled reactor; Compartmentalization; *p*-Nitrophenol; *p*-Aminophenol; Phenol

1. Introduction

The successful application of anaerobic technology for the treatment of industrial wastewaters depends on the development of high rate bioreactors. Although many high rate designs such as up-flow sludge blanked reactor, anaerobic filter, anaerobic continually stirred tank reactor (CSTR) have been developed, the anaerobic baffled reactor (ABR) has many advantages compared to these anaerobic reactors such as simple design due to no special gas or sludge separation, lower sludge generation, longer biomass retention times, lower hydraulic retention time and higher stability to organic and hydraulic shock loads [1–7]. The most significant advantage of the ABR is its ability to separate acidogenesis and methanogenesis longitudinally down the reactor [1–3]. This can permit different bacterial population to dominate each compartment, acidification predominating in the first compartment section and methanogenesis dominant in subsequent section [1–3]. The separation of acetogenic and methanogenic phases causes an increase in protection against toxic materials and higher resistance to changes in environmental parameters such as pH, temperature and organic loading [4].

Among high rate reactors, the anaerobic baffled reactor was suggested by several researchers as a promising system for industrial wastewater treatment [8–13]. Although there have been many anaerobic high rate designs developed, the ABR were extensively used in the treatment of synthetic tannery wastewater containing sulfate and chromium (III) [4], textile dye wastewater [6], azo dyes containing wastewater [7], swine wastes [8], palm oil mill effluent wastewater [9], treating whisky distillery wastewater [10], sulfate containing

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wastewaters [11], pulp and paper mill black liquors [12], nitrogen containing wastewaters [13], landfill leachate [14] and also domestic wastewaters [5].

Nitrophenols and nitroaromatic compounds are widely used as raw materials or intermediates in the manufacture of explosives, pharmaceuticals, pesticides, pigments, dyes, wood preservatives, leather and rubber chemicals [15–17]. 4-Nitrophenol may get produced in the atmosphere through the photochemical reaction between benzene and nitrogen monoxide and has been detected in rainwater in Japan [16].

p-Nitrophenol is toxic to plant, animal and human health [17]. It is a high-priority pollutant and poses significant health and environmental risk due to its mutagenic and carcinogen activity [18]. Among the nitrophenols, 2-nitrophenol (2-NP), 4-nitrophenol (PNP), 2,4-dinitrophenol (2,4-DNP) are listed on the US Environmental Protection Agency's (USEPA's) "Priority Pollutants List" [15,16,19,20]. Nitrophenols and other nitroorganic compounds are generally considered to be highly resistant to microbial degradation [20]. The purification of wastewaters contaminated with these pollutants is very difficult since they are resistant to the conventional treatment techniques [20]. Although several investigators have used physical and chemical methods such as volatilization, photodegradation, photo-catalysis and advanced oxidation [20–22] to treat the wastewater containing nitrophenol, anaerobic biodegradation is the ultimate degradation mechanism [23]. Anaerobic biological treatment systems may have promising applications for the removal of nitrophenol pollutants because the anaerobic microorganisms are able to degrade these compounds [23]. The conjugation of unstable nitroso and hydroxylamine intermediates results into the formation of complex azo or azoxy compounds under aerobic conditions. The high electron withdrawing properties of the nitro group is the main factor that makes the *p*-NP recalcitrant to the oxidative cleavage of the aromatic ring during aerobic processes [18]. However, under anaerobic conditions, nitrophenols readily transformed to their corresponding amines. On average, aromatic amines are 500-fold less toxic than their corresponding nitroaromatics. This suggests that anaerobic conditions detoxify the nitrophenolic wastewater although are not completely mineralized them [16–23].

Most of the degradation studies on PNP have focused on aerobic and advanced oxidation processes providing high amount of sludge and are costly [21,22]. The literature survey shows that there is a lack on the anaerobic treatment of nitrophenol by anaerobic baffled reactor. In other words, no study was found in the literature for the ABR reactor treating the nitrophenol containing wastewaters. Therefore, the purpose of this study is to determine the feasibility of a laboratory-scale ABR on the treatment of synthetic wastewater containing PNP. The present study aims to investigate the effect of increasing *p*-NP loading rates on COD and *p*-NP removal efficiencies, total gas, methane gas productions in ABR reactor. The variations of pH, VFA and *p*-aminophenol (PAP) productions were monitored in the each compartment of ABR. Furthermore, the PAP transformation pathway through the PNP degradation was investigated.

2. Materials and methods

2.1. Experimental setup

The reactor was rectangular box having the dimensions 20 cm wide, 60 cm long and 40 cm high as shown in Fig. 1. The ABR reactor with the active reactor volume (38.4 L) was divided into four equal compartments by vertical baffles. Nevertheless, only three compartments were used throughout this study (effective volume = 28.8 L). Each compartment was further divided into two by slanted edge (45 °C) baffles to encourage mixing within each compartment, and within each compartment down-comer and up-comer regions were created. The liquid flow is alternatively upwards and downwards between compartment partitions. This provided effective mixing and contact between the wastewater and biomass at the base of each upcomer [2,24]. In other words, during upflow, the waste flow contact with the active biomass and it is retained within the reactor providing the homogenous distribution of wastewater. An additional mixing was not supplied to the compartments of the reactor. The width of the down-comer was 4 cm and the width of the up-comer was 11 cm. The passage of liquid from one compartment to another was through an opening measuring 40 mm × 10 mm located about 80 mm from the top of each compartment. The liquid sampling ports were located at 40 mm back of the effluent opening of each compartment. The sludge sampling ports were also located in the center and 80 mm above from the bottom of each compartment. The influent feed was pumped using peristaltic pump. The outlet of ABR was connected to a glass U-tube for controlling the level of wastewater and to trap the solids. The produced gas was collected via porthole in the top of reactor. The operating temperature of the reactor was maintained constant at 37 ± 1 °C by placing the ABR reactor on a heater. This provided a homogenous temperature in whole compartments of ABR reactor. A digital temperature probe located in the middle part of the second compartment provided the constant operation temperature.

2.2. Seed sludge

The reactor was seeded with granulated anaerobic sludge taken from anaerobic upflow anaerobic sludge blanket reactor containing acidogenic and methanogenic partially granulated biomass from the Pakmaya Yeast Beaker Factory in Izmir, Turkey. The granulated anaerobic sludge was introduced into all four compartments of ABR. Each compartment having a volume of 12 L contained 6 L granular sludge and a suspended solids composition of 40 g SS/L in the start-up period. The SS concentration of the compartments varied between 45 and 55 g/L through 240 days of continuous operation period with PNP. The SS concentrations did not affect