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Biological treatment of polychlorinated biphenyls (PCBs) contaminated transformer oil by anaerobic–aerobic sequencing batch biofilm reactors

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ABSTRACT

Concern about the environmental fate of PCBs contaminated transformer oils has increased recently. Therefore, there is a real need to develop and improve treatment methods of transformer oils to minimize their environmental side effects. This study was carried out to evaluate the efficiency of sequential anaerobic–aerobic batch biofilm reactors for the biological treatment of transformer oil containing PCBs. The process performance was studied by increasing the organic loading rate (OLR) in the range of 0.9 –32.2 g COD/L.d. Average chemical oxygen demand (COD) removal efficiencies of 99.8% were achieved in the system at OLR of 21.5 g COD/L.d. Also, high PCBs biodegradation percentages 96.5 were observed. Analysis of common indicators for the monitoring of anaerobic and aerobic processes confirmed the high ability of the anaerobic–aerobic process for treatment of PCBs contaminated transformer oil, characterized by high COD concentration and by highly chlorinated biphenyls content. The Stover–Kincannon model found to be the most appropriate model for predicting transformer oil biodegradation in anaerobic–aerobic SBBR. This biological system as an environmentally friendly and cost effective method has proved to be a suitable technology for treatment of PCB contaminated transformer oil with high efficiency in organic matter and PCBs removal.

1. Introduction

In recent decades, there has been an increasing concern about the fate of industrial chemicals and wastes such as transformer oils (Haus et al., 2001). Transformer oil is used in transformers as a cooling and insulating medium (Lucas et al., 2001). Mineral oils have traditionally used as the major compounds of transformer oil due to their superior dielectric properties. Mineral oils, complex hydrocarbon mixtures with three main chemical groups including parafins, naphthenes and aromatics, are produced from crude petroleum by various processing steps. These chemical groups are known to differ in their microbial degradation with range varies from 15 to 75% (Haus et al., 2001). Aromatic hydrocarbons and polar compounds with high resistance to biodegradation (Haus et al., 2001) are a major concern for environment and human health. Furthermore, since 1929, polychlorinated biphenyls (PCBs) have been widely used for transformer oils formulation due to their excellent chemical and physical stability and electrical insulating properties (Pieper, 2005; Furukawa and Fujihara, 2008). PCBs, a family of synthetic organic chemicals with toxigenic, carcinogenic and reproduce effects pose a great risk to human health and the environment safety (Hatamian-Zarmi et al., 2009). The high chemical stability and superhydrophobicity of PCBs cause them to bioaccumulate in cells and pass by the food chain (Borja et al., 2005; Pieper and Seeger, 2008). At present, there are large amounts of end-of-life transformer oils all over the world, which actual or potential release of them to the environment seriously threats human and ecosystem (Rojas-Avelizapa et al., 1999). Therefore, it is urgent to develop and improve treatment methods of transformer oils to minimize their environmental side effects. Different physical and chemical methods such as incineration and direct dechlorination for the disposal of transformer oils and destruction of PCBs have been proposed (Sobiecka et al., 2009). However, incineration as a conventional disposal method with high efficiency; could emit toxic compounds and is extremely costly (Kaštánek and Kaštánek, 2005). Since, bacteria play a fundamental role in the removal of waste chemical compounds (Pieper and Seeger, 2008); recently, biological methods of PCBs degradation as an environmentally friendly solution were applied (Sobiecka et al., 2009). However, the number of chlorine atoms per

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molecule is a critical feature for biodegradation of PCBs (Furukawa, 2000; Field and Sierra-Alvarez, 2008). Highly chlorinated biphenyls are persistent under aerobic condition, but anaerobic dechlorination of highly chlorinated congeners generates lower chlorinated congeners which are easily degraded under aerobic conditions (Abraham et al., 2002). Since, the main mixture of PCBs in transformer oils is high chlorinated compounds including Aroclor 1260 and 1254 (Rojas-Avelizapa et al., 1999; Martínez et al., 2005), sequential anaerobic–aerobic treatment is expected to provide complete biodegradation of PCBs contaminated transformer oils (Tartakovsky et al., 2001). There are several study about the biodegradation and bioremediation of PCBs (Fedi et al., 2001; Borja et al., 2006; Adebusoye et al., 2008; Dercová et al., 2008; Hatamian-Zarmi et al., 2009; Bertin et al., 2011). Most of the studies focused on batch cultures involving pure cultures or mixture of bacteria in laboratory media containing a single PCBs congener or an individual Aroclor. Sobiecka et al. (2009) reported the ability of commercial mixtures of microorganisms in biological treatment of transformer oil using glass tubes in batch mode for several days. They observed PCB congeners biodegradation in the ranges of 0–99%, 2–97% and 40–94% under anoxic, oxic and anoxic/oxic treatments. Tartakovsky et al. (2001) evaluated degradation of Aroclor 1242 by coupled anaerobic–aerobic bioreactors and a near complete mineralization of Aroclor 1242 was observed in this study. Hatamian-Zarmi et al. (2009) reported biodegradation of highly chlorinated biphenyl and Aroclor 1242 by *Pseudomonas aeruginosa* TMU56. Gas chromatograph analysis of Aroclor 1242 following 4 days incubation showed about 73% degradation of PCBs. In the other study, Borja et al. (2006) investigated biodegradation of polychlorinated biphenyls using biofilm grown in a fluidized bed reactor. Based on our knowledge, however, there is no study about the biological treatment of PCBs contaminated transformer oils in biological reactors. In this study, for the first time, we evaluated the efficiency of sequential anaerobic–aerobic batch biofilm reactors for the biological treatment of transformer oil containing PCBs.

2. Material and methods

2.1. SBBR reactors

The coupled anaerobic–aerobic bioreactors consisted of 7 L anaerobic sequencing batch biofilm reactor (ASBBR) connected to 14 L aerobic sequencing batch biofilm reactor (SBBR) as shown in Fig. 1. The reactors were made of Plexiglas and placed into water bathes heated by aquarium heaters for keeping the operational temperature at 37 ± 1 °C. The anaerobic reactor was fed with synthetic wastewater from a storage tank using an aquarium pump. A reciprocal pump and a peristaltic pump were also used to transfer effluent from anaerobic to aerobic reactor and to discharge final effluent, respectively. The SBBR reactors were filled with 1 cm polyurethane foam cubes (initial porosity of 85%) as immobilizing support. These cubes were contained in glass baskets inside the reactors. In order to minimize the air pollution from PCBs, granular activated carbon was used on the top of aerobic reactor.

Table 1
Operational parameters of the anaerobic–aerobic sequencing batch biofilm reactors.

Anaerobic-SBBR				Aerobic-SBBR		
Influent COD (g/L)	OLR (g COD/L.d)	HRT (d)[a]	Concentration of influent PCBs (mg/L)	Influent COD (g/L)	OLR (g COD/L.d)	HRT (d)[a]
4.7	0.9	5	0.034	0.12	0.01	10
7.8	1.6	5	0.041	0.25	0.03	10
10.7	2.1	5	0.055	0.24	0.02	10
13.5	2.7	5	0.068	1.09	0.11	10
14.5	2.9	5	0.082	1.18	0.12	10
18.9	3.8	5	0.102	1.55	0.15	10
23.7	4.7	5	0.136	1.66	0.17	10
28.4	5.7	5	0.205	1.09	0.11	10
31.1	6.2	5	0.273	1.10	0.11	10
36.2	7.2	5	0.341	0.84	0.08	10
39.4	7.9	5	0.478	1.14	0.11	10
53.7	10.7	5	1.854	0.98	0.10	10
53.7	21.5	2.5	3.709	2.09	0.42	5
53.7	32.2	1.7	5.563	12.26	3.7	3.3

[a] HRT = $V_{Reactor}/V_{Feed}t_C$, t_C: cycle period (Siman et al., 2004).

2.2. Experimental setup

Both reactors were inoculated with a mixture of wastewater sludge and transformer contaminated soil microbial consortium have already been acclimatized to PCB contaminated transformer oil in a batch experiment .The anaerobic reactor was fed with synthetic wastewater containing PCB-contaminated transformer oil at a rate of 1 L/cycle. The synthetic wastewater was supplied

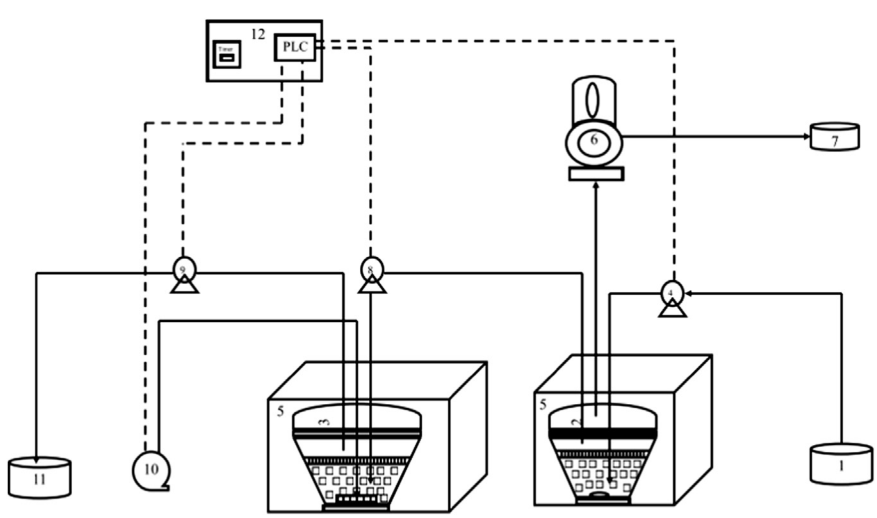

Fig. 1. Scheme of anaerobic–aerobic sequencing batch biofilm reactors containing immobilized biomass: (1) substrate tank, (2) ASBBR, (3) SBBR, (4) feed pump, (5) water bath, (6) wet gas meter, (7) gas bag, (8) reciprocal pump, (9) discharge pump, (10) air pump, (11) treated effluent, (12) Programmable logic controller (PLC) and timers.