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Biological treatment of hypersaline wastewater in a continuous two-phase partitioning bioreactor: Analysis of the response to step, ramp and impulse loadings and applicability evaluation

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ABSTRACT

The response of a continuous two-phase partitioning bioreactor (C-TPPB) operated with polymeric tubing treating hypersaline wastewater was investigated under dynamic load conditions of step, ramp and impulse inputs of the influent flow rate. Tests were performed with synthetic wastewater consisting of NaCl (100 g L^{-1}) and 2,4-dimethylphenol (DMP) (~1200 mg L^{-1}) to simulate the organic fraction. A biomass specifically acclimatized to the compound was utilized in the tests. The experimental system provides separation of the toxic wastewater flowing inside the polymeric tubing (coiled in the bioreactor) from the microbial culture present in the bulk bioreactor phase with the polymer providing permeability to the organic molecules as well as a barrier to salt transport. These features allowed achieving high performance even in the most severe loading conditions. Removal efficiencies >96% were obtained for DMP under all investigated load conditions (i.e. for influent salt and organic loads up to six times the base case load). A DMP mass balance at the end of the dynamic tests showed that 88% of the removed DMP was biodegraded and only 8% was retained into the polymer tubing itself. No significant variation of the DMP concentration in the bioreactor was observed in all cases thus demonstrating the complete removal of the transferred substrate and the effective performance of the biomass, which was not affected by the applied dynamic loads. A comparative analysis of C-TPPB results with the performance data of the classical technologies commonly applied for saline wastewater treatment has been performed to evaluate the system applicability.

1. Introduction

Saline wastewater originates in many industrial processes, notably the chemical, agro-food, textile and leather industries (Lefebvre and Moletta, 2006). High salt contents are found also in road runoff water (Guesdon et al., 2016) and landfill leachate (Meky et al., 2017). Such saline streams are also characterized by a variety of organic contaminants requiring high removal efficiency of the organic components as well as the removal or recovery of the salt(s). The salt content in the saline wastewater is in the range of 2–15% (Castillo-Carvajal et al., 2014), and, according to Woolard and Irvine (1995), wastewater containing organic compounds and a salt amount greater than 3.5% (w/v) are defined as hypersaline or brines. Treatment methods currently applied to saline wastewater are generally physical-chemical operations including thermal methods (i.e. multiple-effect evaporation), coagulation–flocculation (as a pre-treatment step to remove suspended and colloidal COD), ion exchange, and membrane techniques (i.e. electro-dialysis and reverse osmosis) (Lefebvre and Moletta, 2006). Efficient treatment often requires a multi-step approach including pre and post treatment, in order to achieve high effluent quality. The main drawback of the physical-chemical methods is their high operating cost in that they require frequent maintenance operations, and this explains why biological processes have been, and still are, investigated as an alternative or as an adjunct method used in combination with chemical-physical treatment. The most critical aspect of the biological treatment of saline wastewater is the inhibitory/toxic effect exerted on microorganisms by high salt concentrations (≥5%). Long acclimatization periods are generally required and bio-treatment performance can be seriously compromised by the variation of the influent characteristics in terms of salt content and organic load (Lefebvre and

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Moletta, 2006; Reid et al., 2006). Previous studies on sequencing batch reactors (SBRs) reported that high salt concentrations (~6%) significantly reduced COD removal efficiency (Uygur and Kargi, 2004) and that improved removal efficiencies were obtained only with the addition of halophilic bacteria (Lefebvre et al., 2004).

With the aim of mitigating the negative effect of high salt concentrations on microbial activity, Tomei et al. (2017a) proposed the use of a continuous two-phase partitioning bioreactor (C-TPPB) in which the salt and the organic fraction in the feed stream are differentially retained/transported, by selected polymer tubing. The bioreactor consists of a CSTR (Completely Stirred Tank Reactor) containing acclimated biomass, within which is inserted coiled polymeric tubing through which the saline/organic feed is pumped. The employed polymer tubing is specifically selected to be impermeable to salt transport and to have high affinity for the organic fraction, which diffuses through the tubing walls into the bioreactor where it is biodegraded. The salt sequestration occurs simultaneously with the biological processes and no additional pretreatment for salt removal is required. The system configuration is similar to the extractive membrane bioreactors (EMBs) operated with silicone rubber membranes proposed by Livingston (1993a; 1993b) for saline wastewater treatment, but the use of selected polymer tubing here, whose composition and affinity can be specifically tailored for the organic contaminant to be removed, extends the system applicability to a wider spectrum of compounds. This is of relevance for saline wastewater whose production derives from many industrial sectors, characterized by a wide range of organic contaminants.

The feasibility of the proposed bioreactor for the remediation of xenobiotic compounds in contaminated streams has been demonstrated in previous studies focused on phenolic (Tomei et al., 2016; 2017a) and tannery wastewater (Mosca Angelucci et al., 2017). In addition, the applicability of the C-TPPB prototype on a synthetic saline wastewater in a recent study (Tomei et al., 2017b) focused on the basic aspects of mass transfer, substrate partition coefficients (PCs), and solute diffusivity, which were used in polymer tubing selection.

Previous studies examining the dynamic response of TPPBs utilizing polymer pellets or immiscible solvents as sequestering phases for organic contaminants, when applied to the treatment of contaminated streams, demonstrated their high resilience to input load variations. Boudreau and Daugulis (2006) reported better performance of TPPBs with respect to single-phase bioreactors in treating a toluene contaminated gas in the presence of step influent loads. Similarly, Nielsen at al. (2005) reported a rapid recovery of a liquid-liquid two-phase partitioning bioscrubber treating a benzene vapour stream subjected to step and spike loading. With regard to synthetic wastewaters, Hagesteijn and Daugulis (2012) demonstrated a consistent increase in treatment efficiency with the addition of a small amount (3–10% w/v) of polymer beads when severe phenol step-change organic surges were intentionally applied. In the specific case of 2,4-dimethylphenol (DMP), i.e. the target compound employed in this study, the beneficial effect of granular polymers added to suspended biomass, has been reported for batch kinetic tests on phenolic mixtures (Tomei et al., 2011).

However, no previous studies have been undertaken utilizing such tubing-based TPPB systems in which dynamic organic loadings were considered. Even better performance in facing increasing loads is expected in C-TPBBs, in comparison to other TPBB configurations, because of the separation of the microbial culture from the toxic wastewater. This feature can be advantageously exploited in the treatment of hypersaline wastewater.

The objective of the current work was to test the proposed continuous bioreactor configuration with a synthetic hypersaline wastewater (10% of NaCl) containing DMP to simulate the organic fraction, under dynamic organic loading conditions. The bioreactor was subjected to different loading rates with the same substrate feed concentration by applying the “classical” dynamic inputs of step, impulse and ramp, and the system response was analysed in terms of removal and biodegradation efficiency of the organics. Oxygen consumption rates were also continuously measured to evaluate the effects of the different organic loading dynamics on the biomass activity. Furthermore, a comparative analysis with other conventional and more recent proposed technologies applied to saline wastewater treatment was performed with particular focus on the response to dynamic overloading conditions, in order to highlight the feasibility of the C-TPPB technology and to assess its competitiveness in critical operating conditions occurring in real plants.

2. Material and methods

2.1. C-TPPB bioreactor

The C-TPPB system, described in detail in a previous study (Tomei et al., 2017a), consisted of a completely stirred bioreactor (work volume 2 L) equipped with a metallic grid support completely immersed in the liquid phase on which the polymeric tubing (length 3.5 m; internal and external diameter equal to 6 and 7 mm, respectively) was coiled. A magnetic stirrer provided mixing, and temperature (28 °C), pH (7.5) and dissolved oxygen (DO) were monitored on-line (time interval 15 s) and controlled via a Labview programme. DO values were precautionary selected within the range 3–4 mg L^{-1} to ensure that no limiting conditions for the biomass growth (due to lack of oxygen) occurred in the bioreactor. Recorded DO data were employed to evaluate the respiration rate, i.e. the Specific Oxygen Uptake Rate (SOUR) under the different tested loading dynamics.

Wastewater was fed into the tubing through a micro pump (Watson-Marlow, UK), suitable for flow rates in the range of 0.001–0.24 L h^{-1}. The tubing effluent was collected in sealed glass flasks for analysis and mass balance calculation.

2.2. Tubing

Polymeric tubing made of Hytrel G3548, kindly provided by DuPont (Canada), was employed in the experiments. The polymer density is 1.15 g cm^{-3} while other details of the tubing characteristics are reported in Tomei et al. (2017b). Tubing suitability for the investigated organic compound and its efficient transfer in presence of salt has been demonstrated in the same study with dedicated screening tests.

2.3. Wastewater

The synthetic saline wastewater consisted of a tap water solution of ~1200 mg L^{-1} of DMP (~3000 mg COD L^{-1}) and 100 g L^{-1} of NaCl. Both reagents were analytical grade and were purchased from Sigma-Aldrich (USA). Concentrations of organic and salt in the synthetic wastewater have been chosen according to previous studies (Juang et al., 2009; Tan et al., 2017).

2.4. Analysis

DMP concentration was measured by UV/VIS spectrophotometer (PerkinElmer, Lambda 25) at λ = 280 nm on centrifuged samples (10 min at 13000 rpm).

Biomass concentration in the bioreactor was evaluated as Volatile Suspended Solid (VSS) concentration measured according to Standard Methods (APHA, 2012).