



Performance of passive aerated immobilized biomass reactor coupled with Fenton process for treatment of landfill leachate



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ABSTRACT

The passive aerated immobilized biomass (PAB) reactor was investigated for the treatment of landfill leachate. Reactor performance was affected by hydraulic retention time (HRT), organic loading rate (OLR), volatile suspended solids to total suspended solids ratio (VSS/TSS) and $\text{COD}_{\text{total}}/\text{NH}_4\text{-N}$ ratio. $\text{COD}_{\text{total}}$ and $\text{NH}_4\text{-N}$ removal efficiency dropped from 55 ± 6 to $33 \pm 2\%$ and from 93 ± 8 to $80 \pm 11\%$, when the HRT was decreased from 16 to 4 h, respectively. Ammonia oxidation increased from 69 to 94% at decreasing the VSS/TSS ratio from 0.54 to 0.24, respectively. Fenton pre-treatment substantially improved the removal efficiency of $\text{COD}_{\text{total}}$ ($83 \pm 4\%$) and $\text{COD}_{\text{soluble}}$ ($83 \pm 5\%$). The simple empirical model designed to assess the performance of PAB reactor treating landfill leachate showed good agreement between predicted and experimental parameter values.

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1. Introduction

Landfills are widely used for solid waste disposal in developing countries. However, landfill leachates which are generated by chemical and biological decomposition of solid wastes are important sources for aquifer and surface water contaminants (Zhao et al., 2010). The composition of landfill leachate varies depending on the types of disposal of solid wastes, soil characteristics, rainfall patterns and landfill age. Landfill leachate is usually characterized by offensive odor, high ammonia-nitrogen content, inorganic salts, heavy metals and complex chemical composition (Cassano et al., 2011). Consequently, treatment of landfill leachate is essential to reduce the environmental impacts and meet legislated standards for discharge into natural water streams. Several technologies have been proposed for treatment of landfill leachate, such as biological processes i.e. anaerobic (Kawai et al., 2012), aerobic suspended carrier biofilm (Welander et al., 1997) and combination of anaerobic-aerobic processes (Kettunen et al., 1996), physical and/or chemical processes i.e. adsorption by activated carbon (Foo and Hameed, 2009), advanced oxidation process (Rocha et al., 2011) and coagulation–flocculation (Boumechhour et al., 2013) and a

combination of biological and physicochemical treatment methods i.e. a combination of photo-chemical oxidation with biological processes (Koh et al., 2004) and adsorption with biological processes (Kargi and Pamukoglu, 2003). Generally, application of biological treatment alone is not satisfactory due to the leachate characteristics. A combination of different processes is preferred. Moreover, it is necessary to develop and create a novel treatment system which is reliable, simple and less energy consuming. Recently, immobilized biomass reactors have been considered one of the most advantageous technologies for treatment of wastewater containing organic and inorganic compounds (Tawfik and ElBatrawy, 2012). This is mainly due to high removal efficiencies of carbonaceous and nitrogenous organic compounds present in wastewater in addition to the relatively low cost in comparison with other treatment techniques (El-Kamah et al., 2011). Several researchers have investigated the treatment of landfill leachate using attached growth systems such as trickling filters (Knox, 1985), submerged aerobic biological filters (Pedersen, 1992) and rotating biological contactors (Spengel and Dzombak, 1991). These systems have the advantage of not suffering from loss of active biomass due to poor separability, and nitrification in attached growth systems has been shown to be less affected by low temperatures than in suspended growth systems (Knox, 1985).

In this study, a passive aerated immobilized biomass (PAB) reactor was developed for treatment of landfill leachate, a technology not yet reported in the literature for treatment of landfill

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leachate. The PAB reactor was composed of polyurethane carriers (sponge) as packing media where heterotrophic and autotrophic bacteria were attached. The main advantages of PAB reactor over trickling filter are long sludge retention time (SRT), short HRT, low excess sludge production and small bioreactor footprint. In order to increase the leachate biodegradability and degrade the wide variety of refractory organic compounds present in landfill leachate a pre-treatment process was required to improve subsequent PAB reactor performance. Advanced oxidation processes (AOPs) have been reported to be efficient for the treatment of high strength wastewater (Zhang et al., 2005). Fenton reagent's process is one of the most common AOPs for treatment of landfill leachate where ferrous ion reacts with hydrogen peroxide producing hydroxyl radicals ($\bullet\text{OH}$) (Alalm et al., 2015).

The objectives of this study were to (1) assess the performance of the PAB reactor for treatment of landfill leachate at different HRTs with emphasis on COD fractions, TSS, VSS and ammonia removal, (2) study the effect of Fenton reagent as a pre-treatment process on the efficiency of PAB reactor, and (3) develop an empirical model of PAB reactor treating landfill leachate.

2. Materials and methods

2.1. Source of Landfill leachate and its characteristics

Landfill leachate used in this study was collected weekly from Nasreya hazardous solid wastes landfill situated in Borg EL-Arab, Egypt. The harvested landfill leachate was stored at 4 °C before feeding to the treatment processes in accordance with the standard methods (APHA, 2012). The main characteristics of landfill leachate are summarized in Table 1.

2.2. Passive aerated immobilized biomass reactor

Fig. 1 shows a schematic diagram of the lab scale PAB reactor treating landfill leachate or Fenton's reagent effluent. The reactor was made of polyvinyl chloride with a working volume of 21.2 l, height of 1.8 m and an internal diameter of 0.25 m. The reactor consisted of three segments separated by open spaces (10 cm height) for diffusion of natural oxygen from ambient air avoiding energy consumption and created fully aerobic conditions where the dissolved oxygen concentration exceeded 5.0 mg l⁻¹ in the bulk liquid. Landfill leachate flowed from the top of the reactor and trickled downwards by gravity contacting the immobilized biomass on the sponge surface. The volume of cylindrical shaped packing sponge material (polyurethane foam with specific surface area of

256 m² m⁻³, density of 30 kg m⁻³, void ratio of 0.9, and pore size of 0.63 mm packed into a net-like cylindrical polyvinyl chloride ring of 3 cm diameter and 3 cm length) was 11 l which represented 51.8% (V/V) of the total reactor. The carrier sponge was randomly distributed in the reactor to facilitate the oxygen diffusion into the packing material. Three circular perforated plates, one per segment, were used to support filling sponges, separate the reactor segments and allow the water flows between the segments.

2.3. Fenton pre-treatment

Landfill leachate Fenton oxidation was performed for 15 min at pH 3.5, with a molar ratio H₂O₂/Fe⁺² of 5 and a H₂O₂ dosage of 25 ml l⁻¹ (Ismail and Tawfik, 2015). The pre-treated effluent was fed to passive aerated immobilized biomass reactor.

2.4. Operational conditions

The reactor was continuously fed with landfill leachate initially at an OLR of 0.5–5.0 gCOD l⁻¹ d⁻¹ and HRT of 24 h. No inoculum was used for seeding the reactor. The reactor attained steady state after 30 days as indicated by constant effluent concentrations of COD and NH₄-N within 5% variation for five consecutive daily measurements. After 30 days, startup period, the HRTs were adjusted to 16, 8 and 4 h, corresponding to average OLRs of 5.7, 9.9 and 16.6 gCOD l⁻¹ d⁻¹, respectively (1st scenario). In the 2nd scenario, the PAB reactor feed was switched to Fenton pretreated effluent for 75 days at an HRT of 10 h, and OLR of 7.5 gCOD l⁻¹ d⁻¹. COD fractions, NH₄-N and coarse suspended solids were analyzed in samples from effluents and collected from the various sections of the reactor.

2.5. Total and volatile solids retained in the sponge, excess sludge and scanning electronic microscopy

Three sponge pieces were sampled monthly from each segment of the PAB reactor and replaced with new ones. The harvested sponges were carefully squeezed and washed with distilled water until the sponges were completely cleaned. The eluted biomass was concentrated by centrifugation for determination of total solids (TS), volatile solids (VS) and biofilm density (biomass weight (g) per volume of sponge (l)). TS and VS were calculated considering the sponge volume of the reactor. The excess sludge (mainly precipitated coarse suspended solids and detached biomass) was discharged daily from the settler located at the bottom of the PAB reactor. The discharged sludge was analyzed for total solids, volatile solids and sludge volume index. However, the PAB reactor produced less excess sludge compared to classical aerobic attached-growth processes due to long sludge retention time (Onodera et al., 2013).

Sponge with immobilized biomass was harvested at day 160 from PAB reactor for scanning electronic microscopy (SEM) as described earlier by Tawfik et al. (2010). The collected sponge media were fixed in 0.1 M phosphate buffer (pH 7.0) containing 2.5% glutaraldehyde for 12 h at 4 °C. Samples were rinsed three times in 0.1 M phosphate buffer (pH 7.0) and dehydrated gradually after successive immersions in ethanol solutions (10, 30, 50, 70, 80, 90 and 95%). Each rinsing and dehydrating step took 10 min. Afterwards, the samples were washed in 100% ethanol solution before adding hexamethyldi-silazane for 30 s. Drying process was completed by incubating the samples for 2 h at 30 °C. The sponge samples were coated with a piece of gold and attached on the microscope supports with silver glue. SEM resolution was at beam energy of 0.4 nm at 30 kV.

Table 1
Characteristics of landfill leachate used in the experiments.

Parameters	Unit	Range	Average ± SD
pH-value	–	^a 7.6–9.0	8.5 ± 0.4
COD _{total}	(mg l ⁻¹)	2645–5900	3909 ± 985
COD _{soluble}	(mg l ⁻¹)	1920–4975	3352 ± 970
COD _{particulate}	(mg l ⁻¹)	140–1508	570 ± 258
BOD ₅	(mg l ⁻¹)	735–950	847 ± 79
BOD/COD	–	0.16–0.27	0.22 ± 0.04
NH ₄ -N	(mg l ⁻¹)	15–203	74 ± 48
TKN	(mg l ⁻¹)	60–235	114 ± 46
TDS	(mg l ⁻¹)	13,845–26,150	21,654 ± 2114
TSS	(mg l ⁻¹)	755–4000	1878 ± 761
VSS	(mg l ⁻¹)	220–1700	596 ± 285
Cl ⁻	(mg l ⁻¹)	1335–2030	1631 ± 271
Iron (Fe ⁺²)	(mg l ⁻¹)	0.14–0.50	0.33 ± 0.16
Copper (Cu ⁺²)	(mg l ⁻¹)	8.0–12.0	10.5 ± 1.8
Nickel (Ni ⁺²)	(mg l ⁻¹)	0.41–0.89	0.75 ± 0.25

^a Values represent Mean ± STD.

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