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Scale-up and cost analysis of a photo-Fenton system for sanitary landfill leachate treatment

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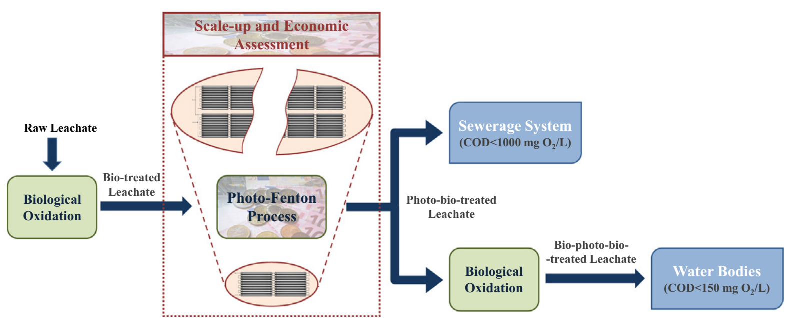
HIGHLIGHTS

- Treatment of 100 m^3/day of a leachate previously oxidized in a biological system.
- Integration of biological/chemical–photo-Fenton/biological oxidations processes.
- Scale-up and cost analysis of the photo-Fenton system.
- Combination of solar radiation and artificial light, as UV–visible photon source.

GRAPHICAL ABSTRACT



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ABSTRACT

This work presents the scale-up and cost analysis of a photo-Fenton process, using solar and/or artificial radiation, for the treatment of 100 m^3 per day of a sanitary landfill leachate previously oxidized in a biological system. The scale-up of the photo-oxidation system, taking into account the CPCs (compound parabolic collectors) area and land requirements for its installation and/or the number of UV lamps (with 4 kW and 20,000-h of lifetime each), was performed considering the following data: (i) the average global UV irradiance and insolation in the specific location of the sanitary landfill; (ii) the amount of UV energy and H_2O_2 necessary for the photo-Fenton reaction in order to achieve two different target COD values, i.e., 1000 and 150 mg O_2/L (values according to the Portuguese discharge regulations into sewerage systems and water bodies, respectively). Regarding the optimal conditions, the plant includes 3836 and 6056 m^2 of CPCs, or 25 and 39 UV lamps, to achieve the above mentioned target COD values. A third plant configuration, combining simultaneous natural and artificial radiation, requires 2446 and 3862 m^2 of CPCs and, 19 and 30 UV lamps, respectively. Total photo-Fenton costs were based on the project's contingencies, engineering and setup and spare parts, personnel, maintenance, electricity and chemicals supply. Thus, the total unitary costs for the optimal conditions aiming to achieve COD values of 1000 and 150 mg O_2/L, were, respectively: (i) 6.8 and 11.0 €/m^3 using only CPCs; (ii) 7.2 and 11.7 €/m^3 resorting just to UV lamps; and (iii) 6.7 and 10.9 €/m^3 combining CPCs and UV lamps. The cost of the H_2O_2 reactant represents more than 30% of the total yearly cost.

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Nomenclature

A_{CPC}	compound parabolic collectors area (m^2)
A_{land}	land area required for the CPCs implementation (m^2)
A_r	illuminated collector surface area (m^2)
BOD_5	biochemical oxygen demand (mg O_2/L)
BTLS	bio-treated leachate samples (BTLS)
COD	chemical oxygen demand (mg O_2/L)
CPC	compound parabolic collector
DOC_f	final dissolved organic carbon concentration (mg C/L)
DOC_i	initial dissolved organic carbon concentration (mg C/L)
E_m	monthly accumulated UV energy (kJ/m^2)
E_y	yearly accumulated UV energy (kJ/m^2)
FCR	fixed charge rate (12%, considering 20-year plant depreciation)
Fe_m	average dissolved iron concentration during photo-Fenton experiment (mg/L)
I_m	yearly average global UV radiation power (W/m^2)
I_{UV}	average UV irradiance power during photo-Fenton experiment (W/m^2)
LTC	lamp total cost (€)
Δm	amount of organic substances removed during phototreatment (g)
N_L	number of UV lamps
N_{ps}	number of photons emitted up to wavelength of 387 nm per unit of time and potency according to the standard ASTM solar spectrum (5.8×10^{21} photons/W/h)
N_{uv}	number of photons emitted up to wavelength of 387 nm
OC	operating cost (€)
PETC	principal equipment total cost (€)
pH_m	average pH value during photo-Fenton experiment
Q_d	daily flow (m^3/day)
Q_{UV}	accumulated UV energy received on any surface in the same position with regard to the sun (kJ/L)
T	temperature (°C)
TCR	total capital required (€)
TDC	total direct cost (€)
T_{fm}	mass treatment factor ($g/h/m^2$)
T_{fv}	volumetric treatment factor ($L/h/m^2$)
t_{ins}	total yearly hours of insolation (h)
T_m	average temperature during photo-Fenton experiment (°C)
TOC	total organic carbon (mg/L)
t_{PF}	phototreatment time (h)
TSS	total suspended solids (mg/L)
TYC	total yearly cost (€)
UC	unitary cost (€/m^3)
V_m	monthly volume of leachate generated from the sanitary landfill (m^3)
VSS	volatile suspended solids (mg/L)
V_t	total reactor volume (L)
V_y	yearly volume of leachate generated from the sanitary landfill (m^3)

1. Introduction

Mature leachates present a high non-biodegradable organic fraction mainly due to the presence of humic and fulvic acids. The best treatment strategy to reach the required level of purification to fully reduce environmental negative impacts and to meet discharge regulations, at comfortable prices, consists in a multi-stage treatment process. This strategy may include primary, secondary and tertiary processes, as those reported in UK Environment Agency guidance [1].

Advanced oxidation processes (AOPs) have been reported to significantly enhance the biodegradability of mature landfill leachates [2–4] and, therefore, are particularly suitable to be combined with biological oxidation systems [5–7]. Amongst AOPs, the solar photo-Fenton process has been selected as the best option for the pre-oxidation of mature leachates [4,8].

The photo-Fenton reaction consists of the Fenton reaction ($H_2O_2 + Fe^{2+} \rightarrow Fe^{3+} + OH^- + OH^\cdot$) in the presence of UV–Vis radiation. The radiation has a positive effect on the reaction rate by promoting the photoreduction of ferric ions to ferrous ions, producing additional hydroxyl radicals. The regenerated Fe^{2+} ions react with H_2O_2, generating more hydroxyl radicals. Thus, low amounts of iron are needed for the treatment of wastewaters using a photo-Fenton process [9].

During the last years, our research group in collaboration with a multinational company (*Efacec Engenharia e Sistemas S.A.*), has been developing a multistage treatment system for raw leachate from sanitary landfill, which includes: (i) lagooning with an anoxic and aerobic zones – biological denitrification and nitrification of the raw leachate with recycling in order to take advantage of the biodegradable organic matter required for denitrification, adding external carbon source if needed, such as, methanol (complete removal of nitrogen compounds, alkalinity and biodegradable organic carbon fraction); (ii) solar/UV photo-Fenton oxidation process (degradation of the most recalcitrant compounds and enhancement of the leachate biodegradability); (iii) aerobic biological oxidation (complete removal of the remaining biodegradable organic compounds) [10–12].

Silva et al. [11] presented the first pre-industrial plant for leachates treatment from a sanitary landfill located in the North of Portugal, combining: (i) an aerobic/anoxic biological system (3.5 m^3 capacity); (ii) a solar photo-Fenton oxidation process, using 39.52 m^2 of compound parabolic collectors (CPCs), and (iii) a further aerobic biological treatment. This multistage treatment system lead to a final effluent with COD and total nitrogen concentrations below 150 mg O_2/L and 15 mg N/L, respectively, which is in agreement with the discharge limits into receiving water bodies, imposed by the Portuguese Legislation. Given the promising results and in order to scale-up the process, a cost analysis must be performed to assess the economic viability of the process.

Few studies have reported cost analysis for AOPs applied to water/wastewater treatment (see Table 1). Durán et al. [13] presented an operating cost of 6.0 €/m^3 for the treatment of a real wastewater by a solar photo-Fenton process. Jordá et al. [14] reported a treatment cost of 0.74 €/m^3 for a paracetamol-containing wastewater (~1 mM; 100 mg DOC/L) using a photo-Fenton system. Cassano et al. [15] reported the operating costs for the combination of a sequential batch biofilter granular reactor (SBBGR) and a solar photo-Fenton (SphF) process for the treatment of municipal landfill leachate (COD_i = 2.8–3.6 g/L; DOC_i = 0.9–1.2 g/L; $N\text{-}NH_{4,i}$ = 1.5–2.0 g/L). The operating costs were 3.26 €/m^3 (2.54 €/m^3 for SBBGR and 0.72 €/m^3 for SphF) and 4.13 €/m^3 (2.54 €/m^3 for SBBGR and 1.59 €/m^3 for SphF) for a final COD of 500 and 160 mg O_2/L, respectively. Pérez et al. [16] carried out an economic assessment on a solar photo-Fenton/membrane bioreactor (MBR) combined process, to treat industrial ecotoxic wastewaters (mixture of five commercial pesticides, ranging from