Journal of Environmental Management 182 (2016) 651–666

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Treatment of an actual slaughterhouse wastewater by integration of biological and advanced oxidation processes: Modeling, optimization, and cost-effectiveness analysis

Ciro Fernando Bustillo-Lecompte [a], Mehrab Mehrvar [b, *]

[a] Graduate Programs in Environmental Applied Science and Management, Ryerson University, 350 Victoria Street, Toronto, ON M5B 2K3, Canada
[b] Department of Chemical Engineering, Ryerson University, 350 Victoria Street, Toronto, ON M5B 2K3, Canada

ARTICLE INFO

Article history:
Received 3 June 2016
Received in revised form
13 July 2016
Accepted 14 July 2016
Available online 29 August 2016

Keywords:
Slaughterhouse wastewater
Anaerobic digestion
Activated sludge
Advanced oxidation processes
Process optimization
Combined processes

ABSTRACT

Biological and advanced oxidation processes are combined to treat an actual slaughterhouse wastewater (SWW) by a sequence of an anaerobic baffled reactor, an aerobic activated sludge reactor, and a UV/H_2O_2 photoreactor with recycle in continuous mode at laboratory scale. In the first part of this study, quadratic modeling along with response surface methodology are used for the statistical analysis and optimization of the combined process. The effects of the influent total organic carbon (TOC) concentration, the flow rate, the pH, the inlet H_2O_2 concentration, and their interaction on the overall treatment efficiency, CH_4 yield, and H_2O_2 residual in the effluent of the photoreactor are investigated. The models are validated at different operating conditions using experimental data. Maximum TOC and total nitrogen (TN) removals of 91.29 and 86.05%, respectively, maximum CH_4 yield of 55.72%, and minimum H_2O_2 residual of 1.45% in the photoreactor effluent were found at optimal operating conditions. In the second part of this study, continuous distribution kinetics is applied to establish a mathematical model for the degradation of SWW as a function of time. The agreement between model predictions and experimental values indicates that the proposed model could describe the performance of the combined anaerobic–aerobic–UV/H_2O_2 processes for the treatment of SWW. In the final part of the study, the optimized combined anaerobic–aerobic–UV/H_2O_2 processes with recycle were evaluated using a cost-effectiveness analysis to minimize the retention time, the electrical energy consumption, and the overall incurred treatment costs required for the efficient treatment of slaughterhouse wastewater effluents.

1. Introduction

Slaughterhouse wastewater (SWW) effluents are becoming one of the major agribusiness concerns because of the elevated amounts of water used during slaughtering, processing, and cleaning of the abattoir facilities. Although physical, chemical, and biological treatment can be used for SWW degradation, each treatment process has different benefits and drawbacks depending on the SWW characteristics, best available technology, jurisdictions, and regulations (Tabrizi and Mehrvar, 2004; Barrera et al., 2012; Franke-Whittle and Insam, 2013; Bustillo-Lecompte and Mehrvar, 2015; Valta et al., 2015; Bustillo-Lecompte et al., 2015, 2016a, 2016b). However, adopting combined processes for SWW treatment is considered operationally and economically advantageous because it incorporates and optimizes the advantages of different technologies to achieve high-quality effluents from industrial and high-strength wastewaters (Kurian et al., 2006; Mehrvar and Tabrizi, 2006; De Nardi et al., 2011; Bustillo-Lecompte et al., 2013, 2014; Bustillo-Lecompte and Mehrvar, 2015; Mowla et al., 2014).

Anaerobic treatment is the preferred biological treatment because of its effectiveness in treating high-strength wastewater such as SWW with less complex equipment requirements. Nevertheless, anaerobically treated effluents of SWW require post-treatment to comply with required discharge limits (Cao and Mehrvar, 2011; Bustillo-Lecompte et al., 2013, 2014). Therefore, aerobic treatment systems are more frequently used in wastewater treatment since they operate at higher rates than conventional anaerobic treatment methods in the case of lower strength wastewaters. Taking into account that oxygen requirements and

* Corresponding author.
E-mail address: mmehrvar@ryerson.ca (M. Mehrvar).

http://dx.doi.org/10.1016/j.jenvman.2016.07.044

treatment time are directly proportional to an increase in wastewater strength, the aerobic treatment are commonly used for further treatment and nutrient removal following physicochemical and anaerobic treatment methods (Bustillo-Lecompte and Mehrvar, 2015).

Furthermore, the SWW may contain toxic and non-biodegradable organic substances, making biological treatment alone insufficient. Thus, advanced oxidation processes (AOPs) are used to improve the biodegradability of wastewaters containing non-biodegradable organics and inactivate both pathogenic and non-pathogenic microorganisms without adding additional chemicals to the SWW, avoiding the formation of hazardous by-products. Consequently, AOPs are an attractive alternative to conventional treatment systems and a complementary treatment method to biological processes for the treatment of slaughterhouse effluents (Oller et al., 2011; Barrera et al., 2012; Bustillo-Lecompte and Mehrvar, 2015; Bustillo-Lecompte et al., 2016a, 2016b).

As a result, considering the eventual reduction in operation and maintenance costs, high removal efficiency requirements, potential energy recovery from biogas production, and enhanced quality for water reuse purposes, combined biological processes and AOP systems are recommended for the SWW treatment if the system were optimized at an appropriate residence time in each reactor. (Tabrizi and Mehrvar, 2004; Oller et al., 2011; Bustillo-Lecompte and Mehrvar, 2015).

Combined processes for wastewater treatment are multifactor systems due to the interactions of different parameters on the overall process efficiency including the concentration of organic matter, the reaction time, the pH, the light source intensity, the oxidant concentration, and the output power, among others, which have not been widely evaluated. Therefore, the optimization of such systems requires the consideration of both single-factor and cross-factor effects through a design of experiments (DOE) to identify the factors that influence the multivariable system while overcoming the limitations of traditional experimental methods in terms of the number of experimental trials, time, and materials. (Ghafoori et al., 2012, 2014, 2015; Bustillo-Lecompte et al., 2016a, 2016b). On the other hand, the available information on the reaction mechanisms and detailed kinetic modeling of combined biological and AOP systems involving all free radicals and molecular species for the degradation of SWW is limited (Ghafoori et al., 2012; Bustillo-Lecompte and Mehrvar, 2015).

In this study, the effects of the influent concentration of TOC, the flow rate, the pH, the inlet concentration of H_2O_2 to the photoreactor, and their interactions on the overall efficiency of the anaerobic–aerobic–UV/H_2O_2 processes, the effluent H_2O_2 residual concentration at the photoreactor outlet, and the CH_4 yield for the treatment of SWW were investigated. The DOE was used to optimize the SWW treatment using a combined system of an anaerobic baffled reactor (ABR), followed by an aerobic activated sludge (AS) reactor, and a UV/H_2O_2 photoreactor with recycle in continuous mode at laboratory scale. The CH_4 yield and the removal of the TOC and the TN were maximized while minimizing the H_2O_2 residual in the effluent of the photoreactor. The optimal parametric values from the DOE were obtained using a central composite design (CCD) with four factors at five levels combined with the response surface methodology (RSM). Statistical models were also developed to predict the percentual TOC and TN removals, the effluent concentration of H_2O_2, and CH_4 yield as response variables by the combined anaerobic–aerobic-UV/H_2O_2 processes. The statistical models were validated by an additional set of experiments at the optimum conditions in line with the DOE results.

In the second part of this study, the reactors in the combined processes were analyzed to find the degradation models for the prediction of the percentual TOC removal as the output variable as a function of time. The degradation models were validated by another set of experimental data carried out under the optimized operating conditions based on the results of the experimental design.

Finally, the optimized combined ABR–AS–UV/H_2O_2 system with recycle was evaluated using a cost-effectiveness analysis (CEA), minimizing the incurred treatment costs, the electrical energy consumption, and the retention time required for the efficient treatment of slaughterhouse effluents. The results from this study contribute towards the cost-effective use of combined biological and advanced oxidation processes for the treatment of actual wastewater from the meat processing sector.

2. Materials and methods

2.1. Materials

Actual SWW samples, with an average TOC concentration of 862 mg/L, were taken from selected provincially licensed meat processing plants (Ontario, Canada) directly from their source (OMAFRA, 2016). The overall SWW characteristics from the selected meat processing plants are shown in Table 1. Five sample sites were used in this study due to the wide TOC range of the slaughterhouse effluents obtained from the meat-processing plants. Anaerobic and aerobic sludge seeds in concentrations of 38000 and 3000 mg/L, respectively, were obtained from the Ashbridges Bay Wastewater Treatment Plant, a municipal wastewater treatment plant in Toronto, Canada. A hydrogen peroxide solution (30% w/w) was purchased from Sigma-Aldrich (Oakville, ON), whereas NaOH (50% w/w) and H_2SO_4 (98% w/w) were obtained from EMD Millipore (Etobicoke, ON) for pH adjustment. All purchased chemicals were used as received.

2.2. Experimental setup

Fig. 1a illustrates the schematic diagram of the experimental setup for the combined ABR–AS–UV/H_2O_2 processes. The combined system consisted of a 36-L ABR with five equal-volume chambers integrated with individual headspaces and biogas collection piping, a 12.65-L aerobic AS bioreactor with a monitored air flow rate to maintain dissolved oxygen (DO) concentrations over 2.0 mg/L, and a 1.35-L photoreactor with recycle and uniform light distribution. The stainless steel cylindrical photoreactor (Barrier SL-1S – Siemens Inc., Markham, ON) had an external diameter of 8 cm, a length of 34 cm, and a 2.5 cm diameter UV-C lamp inserted into the center of the photoreactor with an output power of 6 W and a 254 nm wavelength. A quartz sleeve covered the lamp to protect it from fouling and maintain a uniform UV-C radiation emission.

Table 1
Characteristics of the actual slaughterhouse wastewater from selected provincially licensed meat processing plants with study range values for the combined ABR–AS–UV/H_2O_2 system.

Parameter	Range
BOD (mg/L)	65.15–1831
COD (mg/L)	76.43–2166
TN (mg/L)	101.1–366.1
TOC (mg/L)	48.91–1691
TP (mg/L)	0.1430–31.38
TSS (mg/L)	0.2870–124.3
pH	6.800–7.000