ENHANCED CARBON, NITROGEN AND PHOSPHORUS REMOVAL FROM DOMESTIC WASTEWATER IN A NOVEL ANOXIC-AEROBIC PHOTOBIOREACTOR COUPLED WITH BIOGAS UPGRADING

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INTRODUCTION

Algal bacterial processes have received an increasing attention as a cost-efficient technology for wastewater treatment as a result of their low-cost oxygenation, enhanced nutrient recovery and carbon dioxide mitigation potential. However, this technology only exhibits consistent carbon, nitrogen and phosphorous removal efficiencies at high C/N ratios (≈100/18), values not typically encountered in domestic or livestock wastewaters. This limitation entails the need for development of advanced photosynthetic processes capable of supporting nutrients removal under carbon limiting conditions.

This work evaluated the performance of an innovative photosynthetic technology for the treatment of real domestic wastewater based on an anoxic bioreactor for carbon and nitrogen removal via denitrification interconnected with a biogas-supplemented algal-bacterial photobioreactor supporting nitrification and nutrients assimilation. The experimental set-up also incorporated a biomass settling step followed by biomass recirculation to the anoxic tank.

MATERIAL AND METHODS

The system was composed of a 0.9 L anoxic tank coupled with 2.7 L photobioreactor interconnected to a 60 cm tall 0.3 L absorption column and a 1 L conical settler (Fig.1). The system was operated for 208 days at 25 ºC, at a hydraulic retention time of 2 days and a sludge retention time of 10 days, under a 12h/12h light/dark irradiation regime at 400 µE m^{-2} s^{-1}. The internal and external recirculation were maintained constant at 2.8 L/day and 0.5 L/day (corresponding to 1.55 and 0.27 folds the influent wastewater flowrate, respectively). During the first operational stage, the system was operated without additional inorganic supplementation, while in stage II biogas ($CH_4/CO_2/H_2S$ =70%/29.5%/0.5%) was supplied at 1.8 ml/min via a 10 µm metallic sparger located at the bottom of the absorption column (co-currently with a cultivation broth flow rate of 18 ml/min) to overcome inorganic carbon limitation and promote nitrification. The average composition of the influent wastewater was: TOC=176.4 mg C/L, IC=106.41 mg C/L, TN=104 mg N/L, PO_4^{3-} =32.87 mg P/L, N-NH_4^+ = 92.6 N/L. Daily measurements (twice a day) of pH, dissolved oxygen concentration (D.O) and T were carried out. On the other hand, the aqueous concentration of TN, TOC, IC, TSS, N-NH_4^+, N-NO_3^-, N-NO_2^-, PO_4^{3} in the anoxic tank and photobioreactor, and the gas concentration of CO_2, CH_4, O_2, H_2S and N_2 in the inlet and outlet of the absorption column were measured twice a week. A sample of the cultivation under each steady state was drawn to monitor the dynamics of microalgae and bacterial population.

Analytical procedures

pH was determined using a pH meter instruments pH510, D.O and T were recorded using an O_2 meter WTW Oxi 330*i*, while the photosynthetic active radiation was measured using a LI-250A. CO_2, CH_4, O_2, N_2 and H_2S were measured using a Bruker 430 GC-TCD. The concentration of TOC, IC and TN were measured using a Shimadzu TOC-VCSH analyzer equipped with a TNM-1 module. NH_4^+ was determined using the Nessler method, phosphate by HPLC-IC, while nitrate and nitrite analyses were analyzed via the cadmium reduction column method. The concentration of TSS was determined according to APHA, (2005). The composition of the microalgae population was determined by microscopic examination Olympus IX 70 using the Sournia protocol (Sournia, 1978) while bacteria population structure was carried out by DGGE analysis. Finally, a mass balance calculation was performed.

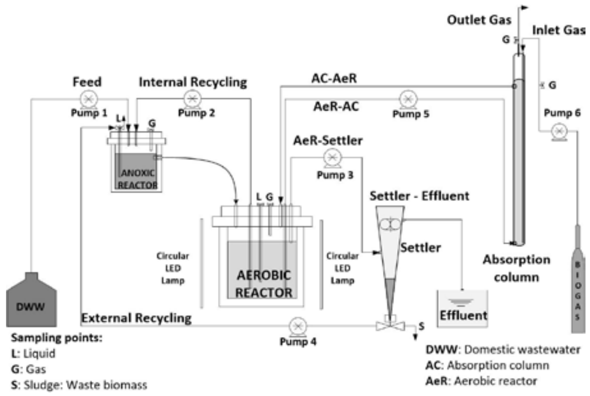

Fig. 1. Anoxic aerobic algal-bacterial photobioreactor modified with absorption column for biogas upgrading.

RESULTS AND DISCUSSION

The mass balance calculations over the 208 days of operation showed recoveries for TN of 100±5 %, TOC of 100±1 %, IC of 99±4 % and P-PO_4^{3-} of 100±14 %, which validated the analytical and instrumental methodologies used. An increase in the removal efficiency of TN from 48% to 79%, N-NH_4^+ from 58% to 92%, and P-PO_4^{3-} from 47% to 63% was recorded when additional CO_2 was supplied to the photobioreactor via biogas supply in the bubble column (operated at a L/G of 10 v/v) to support an almost complete nitrification of the N-NH_4^+ to N-NO_3^- and to promote microalgae growth. During stage I, process operation under inorganic carbon limitation resulted in nitrite concentrations of 8.8±7.2 N-NO_2^- mg/L and nitrate concentrations of 0.6±0.6 N-NO_3^- mg/L, while nitrate concentration averaged 10.6±5.2 N-NO_3^- mg/L and nitrite decreased to 1.1±2.0 N-NO_2^- mg/L from day 120 onward. Orthophosphate concentration decreases from 20.5±9.8 P-PO_4^{3-} mg/L to 10.7±3.9 P-PO_4^{3-} mg/L, concomitantly with an increase in biomass concentration in the photobioreactor from 1183±274 mg TSS/L to 2507±573 mg TSS/L due to phosphorus bioassimilation.

TOC removal remained constant at 89±6 % regardless of the addition CO_2, while the effluent TSS achieved an average value of 26±12 mg TSS/L by the end of the experiment. On the other hand, a DGGE analysis of the bacterial community revealed the occurrence of 11 phyla, Proteobacteria being the dominant phylum with 17 of the 33 bands sequenced. Finally, the morphological characterization of the microalgae population dynamics revealed a gradual dominance of the genus *Scenedesmus*, which accounted for 46 % of the total microalgal population in the absence of biogas supply, and for 94-100 % when biogas was supplemented to the wastewater treatment process.

CONCLUSIONS

The novel algal-bacterial anoxic-aerobic photobioreactor here evaluated exhibited consistent carbon and nutrients removal efficiencies. CO_2 supplementation from biogas was required to sustain the nitrification-denitrification process and also increased phosphorus bioassimilation.

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