Microalgae as the solution for nutrients recovery from black water: pilot scale study

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Abstract
Nutrients recovery from anaerobically treated black water by microalgae in a pilot-scale photobioreactor (PBR) has been studied. A 211 L tubular PBR was operated under Dutch natural light conditions in batch and continuous mode of operation. Four batch runs were operated until P depletion. Nitrogen and phosphorus removal and biomass yield were followed. During batch operation all phosphorus was removed while it remained quite high during continuous. Nitrogen was removed up to 77% during batch and 50% during continuous. Biomass yield on light was higher during batch than continuous. The growth of *C. sorokiniana* during the continuous run was most likely light limited.

Keywords
Decentralized sanitation; Nutrient recovery; *Chorella Sorokiniana*; Photobioreactor

INTRODUCTION
The time has come to rethink the toilet and redesign our wastewater treatment facilities. Current wastewater treatment technologies can no longer merely clean wastewater but they need to recover the valuable energy and resources that are present in it.

One of the valuable resources is phosphorus – a depleting resource within the coming century (Cordell et al., 2011). Of all domestic wastewater produced in a household, urine has 40% of phosphorus and 69% of nitrogen, while faeces has 28% of phosphorus and 13% of nitrogen (Kujawa-Roeleveld & Zeeman, 2006). Therefore when able to recover that phosphorus, human excreta could supply 22% of the world phosphorus demand (Mihelcic et al., 2011).

Current state-of-the-art wastewater treatment technologies can recover phosphorus (Bio-P, struvite), but in most cases in an insufficient way. Moreover, other nutrients such as nitrogen and potassium are not recovered. Microalgae, on the other hand, can uptake not only phosphorus, but also nitrogen and other macro-/micro-elements, transforming them into a valuable algae product (e.g. fertilizer, bioplastic, added value products).

The Netherlands Institute of Ecology (NIOO-KNAW) in Wageningen, The Netherlands, has implemented decentralized wastewater treatment in its new office building. The vacuum collected black water (BW) is treated in a UASB. The liquid effluent, known as anaerobically treated black water (AnBW), contains the major part of the nutrients, and will be treated in a microalgae photobioreactor (PBR). Our results from bench scale experiments under batch conditions have shown that microalgae *Chlorella sorokiniana* can recover all phosphorus and nitrogen from the AnBW (Vasconcelos Fernandes et al., 2015). In the now submitted work we will show the results of our pilot PBR for nutrient recovery and biomass yield under Dutch natural light conditions in batch and continuous mode.

MATERIALS AND METHODS

A 211 L tubular PBR consisting of 50m of horizontal tubing and two 3m vertical air lift columns complemented with two 3m vertical columns was used. The PBR was located in a greenhouse at NIOO-KNAW. pH was controlled automatically at 6.7 ±0.1. Temperature, pH and light intensity (3 sensors) was continuously measured and logged in NIOO logger V1.0 custom made software. The content was homogeneously mixed by air bubbling enriched with 10% CO2 at a flow of 10 $L.min^{-1}$. The PBR was illuminated only by natural light. For the batch mode, four runs were operated, between April and June 2015, and statistically compared with univariate ANOVA. For the continuous mode of operation one continuous run with a dilution rate of 0.2 d^{-1} (HRT=5d) was operated between July and October 2015.

The AnBW had the following average characteristics: pH 7.5, 1.1 $gTN{\cdot}L^{-1}$, 1.0 $gNH_4^+\text{-}N{\cdot}L^{-1}$, 100 $mgTP{\cdot}L^{-1}$ and 80 $mgPO_4\text{-}P{\cdot}L^{-1}$. *C. sorokiniana* CCAP 211/8K was obtained from CCAP (Oban, UK).

NH_4^+-N, PO_4-P, NO_3-N and NO_2-N were measured in a Seal QUAATRO Auto Analyzer (Beun de Ronde, Abcoude) according to the standard methods (APHA, 2005). Algae biomass was followed by algal biovolume with a CASY®1 Model TTC system (Schärfe System GmbH). At the end of the experiment, algal dry weight was determined according to standard methods.(APHA, 2005)

RESULTS AND DISCUSSION

Phosphorus was 100% removed in all batch runs while in continuous the residual phosphorus remained at about half of the AnBW concentration. The nitrogen in the batch runs (operated up to depletion of P) was removed up to 77%. In continuous mode the residual nitrogen remained, like for the phosphorus, at about half of the AnBW concentration. The yield of biomass for the batch runs was on average 2.5 $g.L^{-1}$ while for the continuous it was significantly higher due to the appearance of cyanobacteria. The yield on light for the batch runs was on average 0.8 gD.W..mol $photon^{-1}$ while for the continuous mode it was a factor 10 lower. The growth of *C. sorokiniana* during the continuous run was most likely limited by light. This was due to the excess of biofilm growth on the inner walls resulting in lower incident light and lower natural light availability from September.

CONCLUSIONS

Chlorella sorokiniana can remove all phosphorus and nitrogen from AnBW in a tubular PBR, under Dutch natural light conditions in batch mode. This was however not the case when operated in continuous mode, due to light limiting conditions.

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