Algal Research 16 (2016) 330–337

Contents lists available at ScienceDirect

Algal Research

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

Using an environmentally friendly process combining electrocoagulation and algal cultivation to treat high-strength wastewater

Rui Chen, Yan Liu, Wei Liao *

Department of Biosystems and Agricultural Engineering, Michigan State University, East Lansing, MI 48824, USA

ARTICLE INFO

Article history:
Received 14 November 2015
Received in revised form 18 March 2016
Accepted 29 March 2016
Available online xxxx

Keywords:
Algae culture
Nutrient removal
Electrocoagulation
Liquid anaerobic digestion effluent
Algal biomass utilization

ABSTRACT

This study investigated an alternative approach to treat a high-strength organic wastewater — anaerobic digestion effluent. Electrocoagulation (EC) and algal assemblage cultivation were integrated to carry out the treatment. An algal assemblage was cultured on the electrocoagulation (EC) treated liquid anaerobic digestion effluent to reduce excess nutrients and turbidity in the effluent as well as to accumulate algal biomass for potential chemical and/or biofuel production. Batch culture demonstrates similar maximum growth rates (0.201–0.207 g TS L^{-1} day^{-1}) from the EC solution with two dilutions (2× and 5×). In addition, communities of the fresh water algal assemblage significantly changed in the media with different dilutions after 9-day cultivation. Semi-continuous culture established steady biomass productivities and nitrogen removal in 2× and 5× EC media. However, both conditions exhibited an increase of phosphorus removal rate which could be explained by the luxury uptake theory. Biomass composition analysis indicates that algae cultured in medium with higher nitrogen concentration accumulated more proteins but less carbohydrates and lipids.

1. Introduction

Technologically and economically feasible waste management is crucial to both municipal and agricultural developments. While many conventional waste treatment practices are still using either landfill or relatively expensive and harsh chemicals to handle organic wastes, cost-effective and environment-conscious approaches attract increasing attention. Anaerobic digestion (AD) as a natural and biological process has been used to convert organic wastes into bioenergy methane-electricity for many decades [1]. The process uses anaerobic microorganisms to degrade organic matter and generate methane gas. Although AD can confine organic wastes and significantly reduce the potential of pathogen export [2–5], nutrients such as ammonium, nitrate and phosphate still remain in the liquid digestate at relatively high concentration [6–9]. The most common application of the liquid digestate is to directly apply in the field as liquid fertilizer [10]. However, since arable soil tends to retain less nutrients from liquid fertilizer than its solid form, such practice must be well regulated and the excess liquid digestate needs to be further processed to reduce its eutrophication potential [8, 10–12].

In addition to the AD process, an increasing number of other eco-friendly methods have also been employed by numerous organic waste management practices. Algal cultivation is one of such methods that has recently been intensively studied as a post-treatment process to further clean up the AD effluent due to its superior capabilities of nutrient removal (nitrogen and phosphorus), dissolved oxygen enrichment, and pH buffer [8,13–16]. Meanwhile, algal biomass collected from the cultivation also has a potential to produce biobased fuel and chemicals. Nevertheless, due to the relatively high turbidity in the AD effluent, the algae cultivation (mostly in raceway open ponds) needs to have much shallower bed than conventional algae cultivation on fresh water to ensure sufficient access to light [8,13,15,17,18], which could raise issues such as excess land use and water evaporation. Therefore, a pretreatment step to remove total solids and improve the clarity of the effluent was recommended prior to algal cultivation [8].

Electrocoagulation (EC) is another technology that has been intensively studied to treat the wastewater [19]. The EC uses electron driven coagulation to remove chemical additives, reduce pathogens, and participate solids in wastewater [6,20,21]. Paper, metal, and mining industries are currently using EC technology to treat their wastewater [22–24]. Several recent studies also reported that EC could significantly reduce chemical oxygen demand (COD), phosphate, and turbidity of liquid digestate [6,20].

This paper focused on combining electrochemical technology and algal assemblage cultivation to treat a high-strength wastewater — liquid AD digestate. The objectives of this study were to: (1) demonstrate the impact of EC treated liquid AD digestate (EC medium) on the fresh water algal assemblage; (2) determine an appropriate dilution of EC medium to achieve maximum nutrient removal and algal growth; and (3) analyze chemical composition of algal biomass cultured in the EC medium.

* Corresponding author at: Department of Biosystems & Agricultural Engineering, Michigan State University, 203 A.W. Farrall Hall, East Lansing, MI 48824-1323, USA.
E-mail address: liaow@msu.edu (W. Liao).

http://dx.doi.org/10.1016/j.algal.2016.03.032
2211-9264/

2. Material and methods

2.1. EC treatment of liquid AD digestate

Liquid digestate was collected from the commercial anaerobic digester at Michigan State University (N42°41′55″, W84°29′18″). The digester is a continuously stirred tank reactor (CSTR) and has an effective volume of 1800 m^3. Feedstock of the digester consisted of roughly 60% dairy manure and 40% food waste (wet mass): dairy cows were fed on an alfalfa and corn silage blend diet according to the standard Total Mixed Rations (TMRs) for dairy cattle by Natural Research Council [25], and food waste was mainly collected from campus cafeterias. The digester was operated at 35 °C with a hydraulic retention time of 25 days, and the digestate was separated into liquid and solid portions using a screw press with 2 mm screen. The liquid digestate containing 4.8% total solids (TS, w/w), 3.1 g L^{-1} total nitrogen (TN), 1.5 g L^{-1} total phosphorus (TP), 21.5 g L^{-1} chemical oxygen demand (COD), and a pH of 8.0, was used as the feed for the EC treatment.

The EC treatment of the liquid digestate was carried out according to previous studies with minor modification [6,26]. The original liquid digestate was diluted 4 times using tap water and treated in a 50 L column EC reactor with anode surface area/volume ratio as 0.124 cm^2 cm^{-3}. A DC power supply (XPOWER™ 30 V, 20 A) was used to power the reaction, the current was maintained at 20 A, and the retention time was 4 h. The diluted liquid digestate contained 0.87% TS (w/w), 470 mg L^{-1} TN, 210 mg L^{-1} TP, 3200 mg L^{-1} COD, and pH of 7.2. After EC treatment, the effluent was centrifuged at 3500 rpm for 10 min and the supernatant (EC medium) was collected for algal culture. The EC medium contained 0.03% TS (w/w), 350 mg L^{-1} TN, 25.4 mg L^{-1} TP, 907 mg L^{-1} COD, 5.41 mg L^{-1} total iron (Fe), and pH of 8.5.

2.2. Preparation of algal inoculum

A freshwater algal sample was collected from a pond located near the dairy farm at Michigan State University (N42°41′54″, W84°29′17″). The pond water was initially poured through a sheet of one-layer cheesecloth four times (~250 μm pore size) to screen out stones, debris, invertebrate larva (i.e. mayfly larva), and aquatic plants (i.e. duckweeds). The screened pond water was then centrifuged at 3750 rpm for 10 min to concentrate algal biomass. The final algae concentrate was stored at 4 °C briefly before being applied as the inoculum for following kinetic study and semi-continuous cultures; the inoculum contained 0.34 g L^{-1} algal biomass (dry weight) and the community composition of the original algal assemblage is shown in Fig. 3.

2.3. Kinetic study of algal culture in EC medium

The effects of three EC medium concentrations: original (1×), twice dilution (2×) and five-time dilution (5×), were investigated in the algal kinetic study with a set of two biological replicates. A 3 mL algal inoculum and 50 mL EC medium of each concentration were added to a 125 mL Erlenmeyer flask; a total of 12 flasks of each EC medium concentration were prepared and two were randomly sampled on days 1, 2, 3, 5, 7, and 9. The culture was conducted on orbital shakers (2.33 Hz, 150 rpm) at 22 ± 2 °C under continuous illumination using fluorescent lamps (100 μE m^{-2} s^{-1}), and all culture media had a slightly alkaline pH (8.1 ± 0.4) due to the nature of AD effluent and EC process. A culture using only deionized water and the same algal inoculum was applied as blank for comparison (Fig. S.3), and a set of EC media in three concentrations without algal inoculation was also prepared as controls to eliminate nutrient loss due to the non-biological processes (i.e. volatilization) during culture (Fig. S.4–6).

An aliquot of 1 mL algal culture solution was collected to determine the optical density (OD_{750nm}) of biomass, cell count, standardized biovolume, and algal community. An aliquot of 50 mL was centrifuged at 8000 rpm for 15 min to separate algal biomass from medium; biomass was dried overnight at 78 ± 3 °C, and the liquid medium was collected for measurements of TN, TP, Fe, and turbidity (OD_{600nm}) [8,27].

To determine growth rate, polynomial curve fitting based on the coefficient of determination (R^2) was applied to TS data. The concavity of fitted polynomial equation was measured by its second derivative, and the slope at inflection point of the polynomial was used to estimate the maximum growth rate.

2.4. Semi-continuous algal culture in EC medium

The optimal EC medium dilution based on the kinetic study was chosen for semi-continuous culture. Two 2-L Erlenmeyer flasks were used to prepare biological replicates; each flask contained 60 mL algal inoculum and 1 L EC medium at the beginning of the culture. The culture flasks were placed on orbital shakers (2.33 Hz, 150 rpm) at 22 ± 2 °C under continuous illumination using fluorescent lamps (100 μE m^{-2} s^{-1}). The lag and log growth phases were also determined by kinetic result; when algal growth reached to its maximum rate, an aliquot of 100 mL algal culture from each flask was sampled daily, and the same amount of diluted EC medium was added back into the flasks. Cell count, community assemblage, dry biomass weight, and biomass optical density (OD_{750nm}) of the culture medium were monitored according to the method described in the previous section. TN, TP, Fe and turbidity (OD_{600nm}) of the liquid medium after centrifugation were tested using the same methods stated in previous section as well. Dry biomass collected at the end of the semi-continuous culture was ground using mortar and pestle for chemical composition analysis.

2.5. Analytical methods

Cell density (cell per mL culture) was determined using a compound microscope (Nikon Eclipse 50i, 40× objective, 400× total system magnification) and a microscopic hemocytometer. The average biovolume (mL biomass per cell) of algal cells was measured using imaging software NIS-Elements D 3.00 (Nikon Instruments Inc., Melville, NY). Standardized biovolume (mL biomass per mL culture) was calculated as the product of cell density and average cell biovolume. TN, TP, and Fe were analyzed using HACH testing reagent sets (HACH, Loveland, CO. Product #: 2714100, 2767245, 2415915, and TNT858, respectively). Carbohydrates in algal biomass were determined based on the analytical procedure by National Renewable Energy Laboratory [28]. Protein content was measured using a bicinchoninic acid assay kit (BCA1, Sigma-Aldrich, St. Louis, MO). Crude lipid was measured using the chloroform-methanol extraction method [29].

3. Results and discussion

3.1. Kinetic study

Algal growth in EC medium with different dilutions was recorded based on dry weight, biomass density, and standardized biovolume (Fig. 1, Fig. S.1–2, Table S.1–7). There was no significant growth for the culture on the 1× EC medium (Fig. 1). It has been reported that the optimal algal culture medium made by the chemical treated AD effluent had a OD_{600nm} of 0.92 [8], in comparison, OD_{600nm} of the 1× EC medium in this study was 0.48, which indicates that light penetration might not be sufficient for algal growth in the 1× EC medium. On the other hand, the ammonia (NH_3) concentration in the 1× EC medium was relatively high, which could have the inhibitory effect on the algal growth [30–32]. Compared to the culture on the 1× EC medium, the cell growth on both 5× EC and 2× EC media showed much better growth (Fig. 1). The cell growth in the 5× EC medium had the shorter lag phase (less than 1 day) than the 2× EC medium (2–3 days), which suggests that the freshwater algae preferred relatively balanced and mild nutrient concentration.