Process Biochemistry 51 (2016) 89–94

Contents lists available at ScienceDirect

Process Biochemistry

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

Synergistic integration of electrocoagulation and algal cultivation to treat liquid anaerobic digestion effluent and accumulate algal biomass

Zhiguo Liu, Yan Liu*

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

ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form 19 October 2015
Accepted 3 November 2015
Available online 10 November 2015

Keywords:
Anaerobic digestion liquid effluent
Electrocoagulation
Chlorella vulgaris
Algal biomass
Nitrogen
Phosphorus

ABSTRACT

An integrated system of electrocoagulation and algal cultivation was developed to treat a high strength wastewater—anaerobic digestion liquid effluent for reclaimed water and value-added algal biomass production. The integrated system synergistically takes advantages of both electrocoagulation and algal cultivation to enhance the efficiencies of wastewater treatment. The electrocoagulation treated wastewater had low turbidity with better light penetration (108 NTU) to enable algal growth. The algal cultivation had high removal efficiencies of phosphorus (99.4%) and nitrogen (88.2%). The dissolved iron in the electrocoagulation treated wastewater enhanced lipid accumulation of the algae. The results present that total phosphorus and nitrogen in the reclaimed water were 0.78 g L^{-1} and 35.5 mg L^{-1} respectively, and the harvested algal biomass had 35% of lipid, 53% of protein, and 6.4% of carbohydrate. This study concluded a new route for agricultural wastewater treatment that turns wastewater from an environmental liability into a valuable asset.

1. Introduction

It has been reported that 335 million dry tons of farm organic wastes and 60 million tons of food wastes are generated annually in the U.S. [1]. Proper handling of these wastes is critical to alleviate their environmental impacts such as, greenhouse gas emission, surface/ground water contamination, and odor problem. Anaerobic digestion (AD) as a natural biological process has been widely used in organic waste management practices, which simultaneously confines the wastes and produces methane for energy generation [2]. However, the main drawback of AD technologies is that they do not possess adequate efficiency to remove nutrients (phosphorus and nitrogen) in the wastes. Therefore, the liquid effluent from anaerobic digestion (liquid digestate) needs to be further treated before discharging.

Various approaches have been developed to treat liquid digestate, such as active carbon adsorption [3], coagulation [4] and ozone treatment [5]. These approaches have demonstrated efficient nutrient removal from the liquid digestate, while chemical supplement, secondary contamination and low solid content requirement are the main barriers that limit their applications [6]. Electrocoagulation (EC) as an electron driven coagulation method overcomes the disadvantages of the aforementioned chemical and physical approaches. Since it simultaneously coagulates and floats solids in the solution, EC is very good at handling relatively high-strength wastewater, and represents a promising method to treat liquid digestate [7]. As a matter of fact, EC has been widely used in industry to treat wastewaters from paper and pulp [8], mining and metal processes [9]. Our previous study demonstrated that EC has an outstanding performance on removing chemical oxygen demand (COD), phosphorus, and turbidity from liquid digestate [10]. However, the study also showed that EC has limited capability to remove nitrogen. It is mainly due to high solubility of ammonium/ammonia (NH_4^+/NH_3) in the liquid digestate.

Meanwhile, algal culture has been reported as a biological process that is able to efficiently remove nitrogen from wastewater. *Chlamydomonas reinhardtii* can remove 55% of nitrogen from municipal wastewater [11]. *Chlorella vulgaris* can uptakes 88% of nitrogen from the ammonia rich wastewater [12]. Other algal species such as *Scenedesmus obliquus* [13], *Scenedesmus dimorphus* [14], and *Nannochloris* sp. [15] also demonstrate good nitrogen removal capability. Besides nitrogen removal, algal biomass is also a good feedstock for biofuel and chemical production, which could create a win–win situation for both wastewater treatment and bioenergy industries. Nevertheless, photosynthetic algae need light to support their growth, so that light penetration into the culture medium is a critical factor for a healthy algal cultivation. Due to

* Corresponding author at: Department of Biosystems & Agricultural Engineering, Michigan State University, 203 A.W. Farrall Hall, East Lansing, MI 48824-1323, USA. Fax: +1 517 432 2892.
E-mail address: liuyan6@msu.edu (Y. Liu).

http://dx.doi.org/10.1016/j.procbio.2015.11.003
1359-5113/

Table 1
Maximum biomass concentration (B_{max}), biomass productivity (P_{max}) and specific growth rate (μ_{max}) of *C. vulgaris* under different CO_2 levels.

CO_2 level (%)	B_{max}	P_{max} (g L^{-1} d^{-1})	μ_{max} (d^{-1})
0.04	0.37	0.05	0.36
5	1.71	0.22	1.03
10	1.26	0.18	0.83

Data are average of two replicates.

high turbidity and solid content of liquid digestate, directly culturing algae on the liquid digestate is impracticable. Combining EC and algal cultivation could be a good solution to address this issue.

Therefore, in order to effectively treat liquid digestate and utilize nutrients for valuable chemical production, this study developed a new liquid digestate utilization process that integrates EC and algal cultivation. The new process applied the EC to first reduce turbidity of the liquid digestate and increase light transmission for algal growth, and then used algal cultivation to remove remained nutrients, accumulate algal biomass, and reclaim water.

2. Material and methods

2.1. Liquid digestate

The liquid digestate was collected from a 2500 m^3 anaerobic digester in the Anaerobic Digestion Research and Education Center (ADREC) in Michigan State University. The feed of the anaerobic digester was a mixture of 60% of dairy manure and 40% of food wastes. The dairy manure was from the MSU dairy teaching and research farm. The animal feeds of the dairy farm were alfalfa and corn silage blended based on the Natural Research Council (NRC)'s standard Total Mixed Rations (TMRs) for dairy cattle. [16] The food wastes were from MSU cafeterias. The digester is a completely stirred tank reactor (CSTR) operated at temperature of 35 °C and retention time of 25 days. A screw press separator with 2 mm screen was used to separate liquid and solid fractions of the digestate. The liquid fraction was diluted 10 times and then used as the liquid digestate for this study. The liquid digestate had 0.5 (w/w) of total solids, 300 mg L^{-1} of total nitrogen, 140 mg L^{-1} of total phosphorus, and 2100 mg L^{-1} of COD. The pH of the liquid digestate is 8.0.

2.2. EC treatment

A 3 L column EC reactor was constructed with anode surface area/volume ratio (S/V) as 0.124 cm^{-1}, which was reported as the most effective S/V ratio from a previous study [10]. A steel rod was fixed in the center of the column reactor as anode, and a surrounding steel pipe was placed against the inner wall of the reactor as cathode. The sketch of the reactor is presented in Fig. 1. A DC power supply (XPOWER™ 30 V 5 A) was used to power the EC reactor. The current was maintained at 5 A. The retention time of the EC treatment was determined by nutrients and turbidity that satisfy the requirements of algae cultivation. The EC effluent was centrifuged at 460 g for 10 min, and the supernatant (EC water) was collected for algal cultivation.

2.3. Selection of algal strain

Three algae strains of *C. reinhardtii* 18798, *S. dimorphus* 1237 and *C. vulgaris* 395 (purchased from UTEX Culture Collection of Algae at the University of Texas at Austin) were selected and cultured on the EC water to evaluate and compare their capacity of nutrient uptake. Tris–Acetate–Phosphate (TAP) medium was prepared for activation of algae strains [17]. 50 mL sterilized TAP medium was used to culture the seed of each strain in 250 mL flask, and the flask

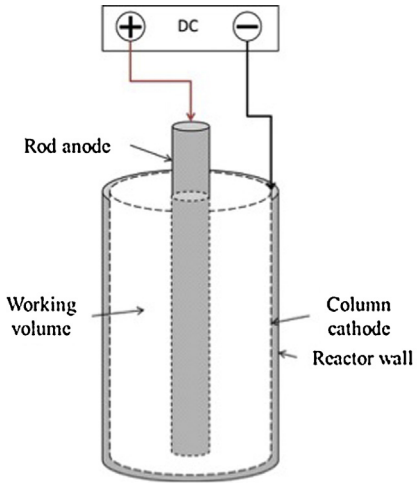

Fig. 1. Sketch of column EC reactor.

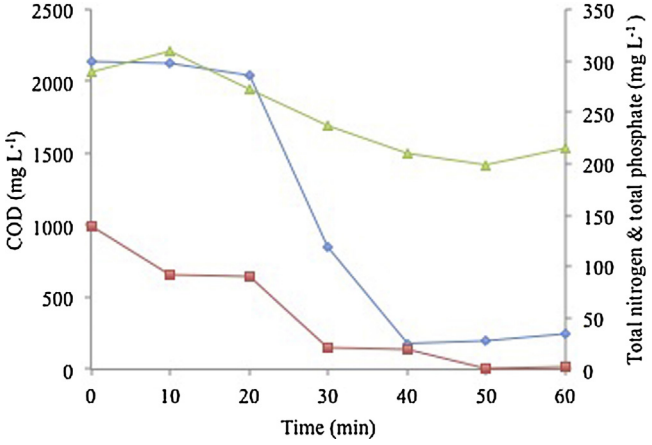

Fig. 2. Dynamic change of nutrients during the EC process in cylindrical reactor. Blue diamond stands for COD, red square stands for total phosphate, and green triangle stands for total nitrogen. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

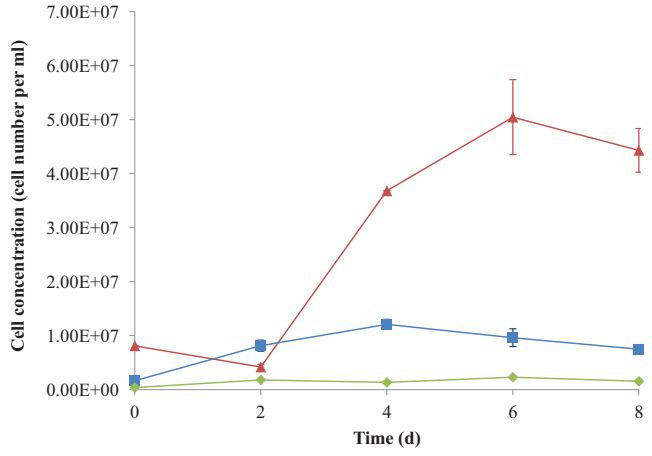

Fig. 3. Growth of different algae on the EC water. Blue square stands for *Scenedesmus dimorphus*, red triangle stands for *Chlorella vulgaris*, green diamond stands for *Chlamydomonas reihardtii*. Data are average of two replicates with standard errors. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)