Bioresource Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Bioresource Technology

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

Review

Microalgal cultivation with biogas slurry for biofuel production

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HIGHLIGHTS

- Current technology for microalgal cultivation with biogas slurry is summarized.
- A scale-up scheme for simultaneous biogas upgrade and algal cultivation is proposed.
- Uncertainties that might affect this practice are explored.

ARTICLE INFO

Article history:
Received 26 July 2016
Received in revised form 29 August 2016
Accepted 30 August 2016
Available online xxxx

Keywords:
Microalgae
Cultivation
Biogas slurry
Biofuels
Bioproducts
Scale-up
Biogas upgrading

ABSTRACT

Microalgal growth requires a substantial amount of chemical fertilizers. An alternative to the utilization of fertilizer is to apply biogas slurry produced through anaerobic digestion to cultivate microalgae for the production of biofuels. Plenty of studies have suggested that anaerobic digestate containing high nutrient contents is a potentially feasible nutrient source to culture microalgae. However, current literature indicates a lack of review available regarding microalgal cultivation with biogas slurry for the production of biofuels. To help fill this gap, this review highlights the integration of digestate nutrient management with microalgal production. It first unveils the current status of microalgal production, providing basic background to the topic. Subsequently, microalgal cultivation technologies using biogas slurry are discussed in detail. A scale-up scheme for simultaneous biogas upgrade and digestate application through microalgal cultivation is then proposed. Afterwards, several uncertainties that might affect this practice are explored. Finally, concluding remarks are put forward.

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http://dx.doi.org/10.1016/j.biortech.2016.08.111
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Please cite this article in press as: Zhu, L., et al. Microalgal cultivation with biogas slurry for biofuel production. Bioresour. Technol. (2016), http://dx.doi.org/10.1016/j.biortech.2016.08.111

1. Introduction

The global energy demand and consumption continue to rise. The duration of fossil fuels for consumption is not optimistic at all (Sindhu et al., 2016), and some recent studies have suggested that the global crude oil reserves will be exhausted by 2030 (Chowdhury and Freire, 2015). Some researchers suggest that the world oil extraction will reach a peak in near future, while others claim that the peaking of oil has already occurred in the past years (Abas et al., 2015). Greenhouse gas (GHG) emissions as a result of fossil fuel combustion during anthropogenic activities are ever-increasing. According to the investigation by the Mauna Loa Observatory in Hawaii, the global carbon dioxide concentration level has climbed up to 400.26 ppm in middle 2015 from about 320 ppm at preindustrial time. It is widely accepted that GHGs emissions trigger global warming and climate changes, which directly or indirectly increase the probability of extreme weather events such as hurricanes and floods (Zhu and Ketola, 2012).

An increased concern over the energy crisis, global warming and climate changes has led to an increased interest in the search for renewable and sustainable energies to replace fossil fuels. Biofuels derived from biomass such as oily crops and lignocellulosic plants have been considered as feasible substitutes. Nonetheless, first generation biofuels have confronted serious ecological, economic and policy challenges, especially in a debate on *Fuel vs. Food* issues (Lohman et al., 2015). As an alternative and renewable biomass feedstock, microalgae offer many advantages, such as non-competition for farmlands, efficient productivity per unit area per unit time, rapid growth, and capability of mitigating waste CO_2 released from a point source like power plant (Singh et al., 2011; Kobayashi et al., 2013; Yuan et al., 2015; Zhu et al., 2015). In spite of these advantages, microalgal biofuels encounter evident challenges in economic inconvenience. One particularly main challenge lies in the easy access to nutrients with a low cost and low energy-intensiveness (Zhang et al., 2013). It is suggested that the energy consumption of nutrient procurement can account for up to 50% of the total during the microalgal production when fertilizers are applied (Stephenson et al., 2010). In that context, nutrient-rich wastewater can replace inorganic fertilizers, since it can decrease the costs and create environmental benefits via wastewater treatment.

Apart from pollutant biodegradation by microorganisms, nutrient uptake by algal cells during the culturing period contributes to the nitrogen (N) and phosphorus (P) removal from wastewaters (Patel et al., 2012; Liu and Vyverman, 2015; Zhu, 2015a; Zhao et al., 2016). Currently, a lot of on-going studies suggest that microalgae can be grown in wastewaters from different sources, including municipality, industry and agriculture at no or low cost (Su et al., 2012; Arita et al., 2015; Lu et al., 2015). The removals of about 80–85% TP and 60–80% TN, respectively, were obtained by Kothari et al. (2012), who used *Chlorella pyrenoidosa* to treat dairy wastewater and accumulate microalgal biomass simultaneously. Gentili (2014) investigated the potential application of three algal strains for the bioremediation of mixed municipal and industrial wastewater, and found that 96–99% ammonia (NH_4–N) and 91–99% phosphate (PO_4–P) were reduced. Selecting *Chlorella* sp. to treat meat processing wastewater, Lu et al. (2015) achieved the removals of ammonia nitrogen and total nitrogen at 68.75–90.38% and 30.06–50.94%, respectively. Lee et al. (2016) achieved the most efficient nutrient removals (92.3% COD, 95.8% TN, 98.1% TP), when they carried out the two-phase photoperiodic cultivation of algal–bacterial consortia with municipal wastewater. Recently, application of biogas slurry to cultivate microalgae for biofuel production has also received a great deal of interest. It is suggested that microalgal cultivation in biogas slurry can not only realize nutrient management but also accumulate biomass for the production of biofuels. In this article the authors are going to review this technology and propose an integrated biorefinery approach for up-scaling.

1.1. Objective and structure of this study

Numerous original research papers dealing with microalgal cultivation with wastewater have been published, and there are already several published review articles available on the topic. However, no systematized review on microalgal cultivation with biogas slurry has been found in the existing literature, although a visible number of relevant research articles have been written. Hence, this review aims to help fill this gap. The objective is to present the current knowledge on microalgal cultivation with biogas slurry for biofuel production, and propose an integrated scale-up system to seek for a path forward for the research & development and commercialization of microalgal biofuels. There is hope that this review will offer a worthwhile and practical guideline to researchers, authorities and potential stakeholders, in an attempt to promote this industry for sustainable development. In the coming sections, the authors first explore the current technologies on microalgal cultivation in biogas slurry in Section 2. Afterwards, an integrated biorefinery approach is proposed in Section 3, followed by the discussion of the uncertainties that affect the technology in Section 4. Finally, a summary of this study is concluded in Section 5.

2. Microalgal cultivation with biogas slurry

2.1. Anaerobic digestion as a solution to waste management

Anaerobic digestion is a controllable, biological process, where a variety of anaerobic microorganisms use organic matters as the substrates to produce methane (CH_4) and/or hydrogen (H_2) in the absence of oxygen (Jain et al., 2015). Anaerobic digestion is treated as an effective measure for the management of organic wastes, since it reduces landfilling and thus odor, pathogens and GHG emissions, recovers nutrients, and generates bioenergy in the form of biomethane (Stowe et al., 2015). Four consecutive biological processes occur in anaerobic digestion: hydrolysis, acidogenesis, acetogenesis and methanogenesis (McKennedy and Sherlock, 2015). During the hydrolysis, complex organic matters such as carbohydrates, proteins and lipids are broken down into soluble derivatives with the help of extracellular enzymes which are excreted by various bacteria. In the following stage, the hydrolyzed molecules including sugars and amino acids are converted into CO_2, H_2, NH_4–N and organic acids by acidogenic bacteria. Then, the resulting organic acids are continuously converted into acetic acid, along with additional NH_4–N, H_2 and CO_2. In the final phase, methanogenic archaea use the intermediate products of the previous stages and convert them into CO_2, water and CH_4. This technology has been widely applied in the disposal of kitchen wastes, agricultural wastes and wastewater sludge (Kwietniewska and Tys, 2014). Apart from methane and/or hydrogen, the end products

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