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Effect of light intensity on the capability of different microalgae species for simultaneous biogas upgrading and biogas slurry nutrient reduction

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ABSTRACT

In this study, we investigated the ability of microalgae to remove biogas slurry nutrients and upgrade biogas simultaneously under various light-emitting diode light intensities. Three green algae, namely, *Scenedesmus obliquus*, *Chlorella* sp., and *Selenastrum bibraianum*, were selected and cultivated in photobioreactor bags. The capacity of each microalga to reduce the chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) of wastes was investigated. The growth rate and CO_2 uptake of each microalga were also examined. Compared with *S. bibraianum*, *S. obliquus* and *Chlorella* sp. showed better combined results and were more suitable for simultaneous biogas upgrading and biogas effluent nutrient reduction. Results showed that the best results for biogas slurry nutrient reduction, CO_2 removal, and upgrade effects were obtained from the treatment under moderate light intensity (150–170 μmol m^{-2} s^{-1}) for *S. obliquus*. The highest reduction values of COD, TN, TP, dry weight, and CH_4 concentration obtained were 93.08% ± 4.62%, 84.12% ± 4.37%, 86.76% ± 4.58%, 465.31 ± 19.44 mg L^{-1}, and 94.41 ± 3.16 (v/v), respectively.

1. Introduction

Green algae can be used in economic development and environmental management activities, which include fine chemical production, atmospheric nitrogen fixation, methane fuel production, solar energy conversion, and wastewater treatment (Chakdar et al., 2012; El-Sheekh et al., 2009). Accordingly, considerable attention has been focused on the development of microalgal value-adding products over recent decades, allowing biogas upgrading and biogas effluent nutrient reduction using microalgae, especially green algae (Zhao et al., 2013; Yan et al., 2013a). Crude biogas is an environment-friendly fuel obtained from anaerobic fermentation; however, this fuel must be upgraded to meet the requirement of efficient combustion (i.e., CH_4 concentration >90%, v/v) (Ryckebosch et al., 2011).

The total amount of livestock poultry manure and agricultural solid waste produced in China is approximately 40 hundred million tons per year. Therefore, these wastes can be utilized as raw materials to produce biogas through anaerobic fermentation to meet the energy demand of the country. However, their biogas grade is low, their CO_2 content is high, and their CH_4 content is low to meet the actual demand (Ryckebosch et al., 2011). Therefore, the use of anaerobic fermentation for biogas production is unsustainable. In this study, we focused on biogas upgrading using three green microalgae, which are characterized by high growth rate and photosynthesis, for CO_2 absorption. Continuous cultivation of certain microalgae (e.g., *Chlorella* sp.) can produce value-adding products from their biomass (Yan et al., 2013a). Thus, using microalgal growth to remove CO_2 from crude biogas is an economical and efficient method for biogas upgrading.

Light intensity is a significant factor affecting microalgal cultures because light energy induces photosynthesis (Parmar et al., 2011; Yan et al., 2013). Light directly affects microalgal growth and photosynthesis (Travieso et al., 2001). In numerous laboratory cultures used for wastewater treatment research, low light

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Table 1
Characteristics of biogas slurry before and after pretreatment.

Item	COD(mgL^{-1})	TN(mgL^{-1})	TP(mgL^{-1})	pH	DIC(mgL^{-1})
Before pretreatment	1358.45 ± 51.19	457.31 ± 28.85	15.57 ± 2.31	6.97 ± 0.17	1301.42 ± 32.18
After pretreatment	1294.32 ± 41.88	419.49 ± 21.37	14.84 ± 1.95	7.14 ± 1.86	1275.28 ± 26.86

Fig. 1. Schematic of the photo-bioreactor bag.

intensity was maintained to allow logarithmic growth. In nature, light intensity is well above saturation and may be sufficiently high to inhibit microalgal growth during most of the day (Ugwu et al., 2007). The appropriate light intensity for the saturation and inhibition of certain microalgae depends on the suitability of other environmental factors, such as CO_2 level and nutrient supply (Maryam et al., 2012). Many researchers attempted to increase the efficiency of the production rate in indoor and outdoor cultivating systems by designing special photobioreactors (PBRs) that can increase the rate of photosynthesis (Maryam et al., 2012). However, studies on biogas slurry nutrient reduction and biogas upgrading using different microalgae, particularly those on the effects of different light intensities on microalgae, are incomplete.

For *Chlorella* sp., the optimal parameter for biogas upgrading and fluid removal is moderate light intensity (350 μmol m^{-2} s^{-1}) with cool white fluorescence (Yan et al., 2013). Ho et al. (2012) proposed engineering strategies to improve CO_2 fixation and bioethanol production by using the indigenous microalga *Scenedesmus obliquus* CNW–N. Their work validated that the CO_2 fixation ability and carbohydrate production of *S. obliquus* CNW–N are significantly enhanced under a light intensity of 220–240 μmol m^{-2} s^{-1}. In addition, *Selenastrum bibraianum* can utilize bicarbonate salt and CO_2 as carbon sources in the culture substrate. Moreover, *Selenastrum* sp. has a high extracellular carbonic anhydrase activity, which is responsible for the conversion of carbonate to free CO_2, thereby facilitating CO_2 assimilation under a light intensity of 100–125 μmol m^{-2} s^{-1} (Parmar et al., 2011). Thus, light intensity is the key factor affecting microalgal growth and treatment efficiency (Parmar et al., 2011).

In this study, we investigated the potential of using three microalgae (*S. obliquus*, *Chlorella* sp., and *S. bibraianum*) for biogas slurry treatment to reduce chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP), as well as enhance biogas upgrading effects. The primary purpose of this study was to evaluate statistically the effects of these green microalgae on the reduction efficiencies and CO_2 removal during 7 d of culture at 25 °C. Thus, we identified the optimal operating parameters for effectively upgrading biogas and reducing biogas slurry nutrients simultaneously.

2. Methods and materials

A PBR bag was filled with raw biogas (20 L) and biogas slurry (4 L). Culture media were cultivated at 25.0 ± 0.5 °C for 7 d under three light intensity levels of cool white light-emitting diode (LED). Then, the biogas component, microalgal cell dry weight (DW), and characteristics of biogas slurry were analyzed.

Table 2
Variations of physical and chemical parameters in biogas slurry culture.

Treatments			Experimental time (d)						
Light intensity (umol $m^{-2}s^{-1}$)	Available microalgae	Parameter	1	2	3	4	5	6	7
80–100	*Scenedesmus obliquus*	pH	7.21 ± 0.34	7.29 ± 0.37	7.27 ± 0.25	7.32 ± 0.41	7.18 ± 0.54	7.22 ± 0.59	7.34 ± 0.45
		DIC mgL^{-1})	1284.13 ± 35.19	1280.44 ± 29.33	1295.17 ± 34.58	1288.37 ± 41.07	1298.11 ± 39.57	1291.39 ± 28.44	1289.95 ± 30.98
	Chlorella sp.	pH	7.17 ± 0.29	7.37 ± 0.51	7.25 ± 0.43	7.29 ± 0.32	7.24 ± 0.41	7.28 ± 0.57	7.45 ± 0.19
		DIC mgL^{-1})	1287.47 ± 52.18	1291.87 ± 49.03	1289.55 ± 39.31	1294.38 ± 45.88	1299.27 ± 59.19	1286.75 ± 51.09	1308.51 ± 45.32
	Selenastrum bibraianum	pH	7.25 ± 0.45	7.28 ± 0.48	7.19 ± 0.31	7.16 ± 0.25	7.39 ± 0.38	7.23 ± 0.27	7.28 ± 0.34
		DIC mgL^{-1})	1291.27 ± 52.71	1288.09 ± 62.14	1294.85 ± 49.25	1281.36 ± 40.38	1294.57 ± 48.51	1287.35 ± 36.87	1305.49 ± 39.85
150–170	*Scenedesmus obliquus*	pH	7.18 ± 0.21	7.22 ± 0.31	7.29 ± 0.24	7.24 ± 0.18	7.31 ± 0.37	7.20 ± 0.24	7.25 ± 0.43
		DIC mgL^{-1})	1287.45 ± 60.22	1291.87 ± 49.33	1298.59 ± 39.08	1304.55 ± 42.11	1296.08 ± 39.74	1288.49 ± 47.18	1281.49 ± 30.19
	Chlorella sp.	pH	7.25 ± 0.43	7.28 ± 0.36	7.20 ± 0.22	7.19 ± 0.32	7.28 ± 0.39	7.18 ± 0.21	7.29 ± 0.34
		DIC mgL^{-1})	1280.38 ± 51.81	1289.49 ± 62.18	1293.08 ± 35.77	1288.97 ± 42.38	1289.65 ± 31.25	1271.08 ± 41.87	1263.54 ± 59.72
	Selenastrum bibraianum	pH	7.19 ± 0.37	7.25 ± 0.41	7.15 ± 0.31	7.27 ± 0.39	7.26 ± 0.42	7.19 ± 0.27	7.32 ± 0.45
		DIC mgL^{-1})	1269.44 ± 49.15	1285.08 ± 53.27	1288.77 ± 59.87	1291.08 ± 54.38	1296.77 ± 62.45	1299.84 ± 51.31	1301.19 ± 48.75
200–240	*Scenedesmus obliquus*	pH	7.21 ± 0.35	7.19 ± 0.21	7.15 ± 0.31	7.24 ± 0.34	7.35 ± 0.43	7.19 ± 0.57	7.29 ± 0.28
		DIC mgL^{-1})	1278.59 ± 39.87	1293.47 ± 47.85	1298.07 ± 59.32	1305.07 ± 62.36	1279.44 ± 58.48	1299.30 ± 62.18	1307.45 ± 43.09
	Chlorella sp.	pH	7.24 ± 0.43	7.27 ± 0.35	7.22 ± 0.28	7.18 ± 0.32	7.29 ± 0.38	7.35 ± 0.21	7.37 ± 0.36
		DIC mgL^{-1})	1307.54 ± 58.11	1289.08 ± 59.48	1292.33 ± 49.51	1295.38 ± 50.83	1298.42 ± 48.09	1309.77 ± 48.57	1279.08 ± 69.95
	Selenastrum bibraianum	pH	7.25 ± 0.37	7.28 ± 0.44	7.18 ± 0.33	7.15 ± 0.38	7.26 ± 0.25	7.33 ± 0.38	7.35 ± 0.57
		DIC mgL^{-1})	1280.47 ± 59.18	1286.37 ± 51.08	1294.85 ± 61.74	1299.71 ± 68.49	1281.09 ± 48.15	1219.88 ± 51.05	1271.35 ± 39.57