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An experimental investigation of microalgal dewatering efficiency of belt filter system

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ABSTRACT

The objective of this study was to investigate the microalgal dewatering efficiency of a belt filter system for feed concentrations below 10 g dry wt./L. A prototype belt filtration system designed for 50 g dry wt./L microalgal feed concentration was used for this investigation. The highest concentration of microalgal suspension available for testing on the prototype belt filtration system was 6 g dry wt./L obtained from biomass settling tanks at the Lawrence, Kansas domestic wastewater treatment plant. For preparation of feed suspension with concentrations below 10 g dry wt./L, microalgal cultivation was followed by flocculation. A mixed laboratory culture of freshwater species dominated by three eukaryotic green microalgae (Chlorella vulgaris, Scenedesmus sp., and Kirchneriella sp.) was cultivated in wastewater effluent. This was followed by flocculation which resulted in a microalgal feed suspension concentration of 4 g dry wt./L. Belt dewatering tests were conducted on microalgal suspensions with feed concentrations of 4 g dry wt./L and 6 g dry wt./L. The maximum microalgal recovery with the belt dewatering system was 46% from the 4 g dry wt./L, and 84% from the 6 g dry wt./L suspensions respectively. The results of this study indicate that microalgal suspension concentrations as low as 6 g dry wt./L can be recovered with a belt filter system improving the overall dewatering efficiency of the system.

1. Introduction

Climate change policy and concerns regarding future energy security have stimulated an unprecedented increase in the production of bioenergy sources that have the potential to reduce future greenhouse gas emissions (Smith et al., 2012). Microalgae are of particular interest because many of the resources required for their mass cultivation can be provided by waste streams (e.g., municipal wastewater: Sturm and Lamer, 2011; carbon dioxide from industrial flue gas: Brentner et al., 2011), and because microalgal cells synthesize many different harvestable bioproducts having a wide variety of compositions and uses (Menetrez, 2012). In particular, microalgae possess many favorable characteristics as a biofuel feedstock, including rapid growth rates and high lipid contents (Chen et al., 2011), high areal energy (Chisti, 2007; Hu et al., 2008), and the ability to avoid undesirable 'food versus fuel' conflicts via the cultivation of microalgal biomass on marginal lands (Singh and Gu, 2010). Production to processing of microalgae is shown in Fig. 1. Nonetheless, profitable large-scale production has not yet been demonstrated (NRC, 2012).

The high operational costs associated with microalgal harvesting are a major challenge (Uduman et al., 2010) due to the very dilute nature of the microalgal suspension and their small cell size (Grima et al., 2003). An optimal harvesting method for microalgae should be independent of the microalgal species being cultivated, and also should have a low chemical and energy demand (Amaro et al., 2011). Centrifuge and belt filter are commonly used microalgal dewatering systems (Spellman, 1997). The primary difference between a centrifuge and the belt filter system is the principle of separation. A centrifuge applies centrifugal forces to the solution to aid the separation of solid and liquid. For a belt filter system, the principle of separation is gravity drainage followed by compression shear (Spellman, 1997). Centrifugation is a highly effective method for harvesting microalgae but it has a high energy demand and is expensive (Knuckey et al., 2006). Compared to a centrifuge, belt filter system has lower energy consumption (Grima et al., 2003) and operational costs (Spellman, 1997), has a continuous mode of operation and can be up-scaled. However, microalgal suspension with a concentration of 10–40 g dry wt./L is needed prior to dewatering on a belt filter (Grima et al., 2003; Sturm and Lamer, 2011).

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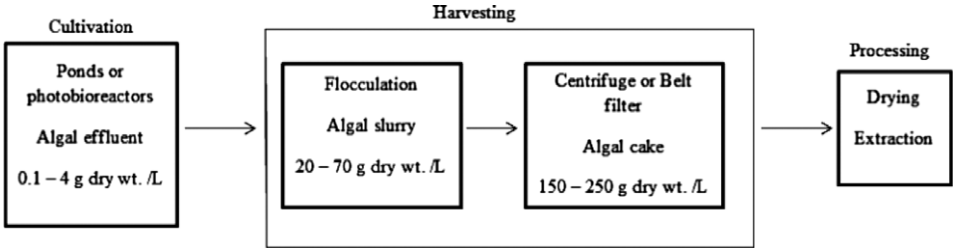

Fig. 1. Schematic of microalgal production and processing (Shelef et al., 1984).

The objective of this study was to further investigate the microalgal dewatering efficiency of a belt filter system for feed concentrations below 10 g dry wt./L.

To further investigate this, microalgal suspensions with feed concentrations of 4 g dry wt./L and 6 g dry wt./L were produced. A prototype belt filter dewatering system consisting of a filter section followed by two drying sections was designed and developed by the authors (Fig. 2(a) and (b)). A doctor blade was installed at the end of the drying section to scrape off the dried algal cake. Air drying was the chosen drying method, due to its low energy and cost requirements. The design was based on filtration tests conducted on 50 g dry wt./L microalgal suspension. The prototype is a 1% scale of a system proposed to process 60,000 gallons (or 227 124.71 L) of 50 g dry wt./L microalgal solution per day. The difference between a standard belt filter system and the prototype belt filter dewatering system developed is the dewatering mechanism. For a standard belt filter press, the principle dewatering mechanism is gravity drainage followed by compression shear. The principle dewatering mechanism of the prototype belt filter dewatering system is gravity drainage (Fig. 2(c)). Another system developed based on belt filter gravity drainage dewatering mechanism is Salsnes Water to Algae Treatment (SWAT) technology (Sahu et al., 2013). However, there are several differences between SWAT technology and the prototype belt filter dewatering system developed by the authors. Firstly, the filter section of the SWAT technology is enclosed in a chamber. Secondly, the belt movement in the filter sections of the prototype belt filter dewatering system and the SWAT technology are in opposite directions. Lastly, there is no drying unit in the SWAT technology.

To determine the filtration belt mesh needed for the prototype belt filter dewatering system developed, gravity filtration tests were conducted on microalgal samples at their stationary growth phase. These tests used a range of polyester mesh sizes from 10 to 200 μm. Based on the test results a 70 μm mesh size resulted in the highest microalgal recovery rate (Fig. 3). Using 70 μm polyester filter mesh, belt dewatering tests were conducted on microalgal suspensions with feed concentrations of 4 g dry wt./L and 6 g dry wt./L.

2. Materials and methods

2.1. Microalgal feed suspension preparation

2.1.1. Microalgal suspension with feed concentration of 4 g dry wt./L

A mixed culture of microalgal species dominated by three eukaryotic green algae (*Chlorella vulgaris, Scenedesmus sp.*, and *Kirchneriella sp.*) was cultivated in domestic wastewater effluent from the Lawrence, Kansas wastewater treatment plant. Flocculant type, dosage and pH that were the most efficient and cost-effective for the cultivated microalgal suspension were determined using jar tests. The results of the jar tests were then used to prepare sufficient volume of concentrated microalgal suspension for belt dewatering tests. A total of 54 l of 4 g dry wt./L microalgal suspension were produced.

Table 1
Optical density and biomass concentration measurements of microalgal culture over a cultivation period of 8 days.

Culture time (days)	$OD_{600\ nm}$	Biomass concentration (g dry wt./L)
2	5.4 ± 0.45	0.7 ± 0.09
4	8.2 ± 1.6	1.1 ± 0.3
6	11.3 ± 0.5	1.45 ± 0.1
8	12.5 ± 1.5	1.5 ± 0.3

2.1.1.1. Microalgae cultivation. Mixed-species microalgae were cultured in a 272 L glass photobioreactor with an operating volume of 208 L. This photobioreactor was initially filled with prechlorination wastewater effluent collected from the secondary treatment stage of the Lawrence, KS, wastewater treatment plant. Then an inoculum was added that was comprised of a natural mixed species assemblage of three eukaryotic green algae (*Chlorella vulgaris, Scenedesmus sp.*, and *Kirchneriella sp.*). 650 g of inorganic nitrogen (supplied as KNO3) and 160 g of inorganic phosphorus (supplied as KH2PO4) were added to the photobioreactor and replenished on a weekly basis to provide nutrients for the growing microalgal community. Light was provided by LED light panels (∼265 μmol/[m^2 s]) with a 12 h on, 12 h off light: dark cycle.

Because wastewater effluent typically contains insufficient inorganic carbon for optimal microalgal growth (Benemann et al., 2003), commercial-grade CO_2 was bubbled into the photobioreactor. The water column pH in the photobioreactor was controlled using a pH controller (Milwaukee Instruments, MC122) to regulate the flow of CO_2. For this experiment the pH of the photobioreactor was set at 6.5 and the room temperature was maintained at 23 ± 1 °C. To provide turbulent mixing, room air was bubbled into the tank at a rate of 4.6 L/min using four aerators placed at each of the four corners of the tank. This turbulent mixing helped to maintain the microalgal cells in suspension during cultivation. Microalgal biomass measurements were made at different stages of post-inoculation growth using a calibrated UV/Vis Spectrophotometer (Thermo Fisher Scientific Model G10S) followed by a standard total suspended solids test (Becker, 1994). Microalgal culture in the 272 L glass photobioreactor achieved a concentration of 1.5 ± 0.3 g dry wt./L at the stationary growth phase in 8 days (Table 1). Bench scale flocculation was conducted on the biomass samples taken from the photobioreactor.

2.1.1.2. Bench scale flocculation. Jar tests were conducted to determine the flocculation conditions (flocculant type, dosage and pH) that were the most efficient and cost-effective (Appendix). 52 L of microalgal culture harvested at their stationary growth phase concentration (1.5 ± 0.2 g dry wt./L) were pumped into a 56 L graduated cylinder equipped with a spigot to allow decantation of the flocculation product. Pre-test pH value of the microalgal suspension was adjusted to 6.5 using 0.1 M NaOH or 0.1 M HCl. Alum at a dosage of 200 mg/L was added to the microalgae suspension and mixed rapidly at 700 rpm for 60 s, followed by slow mixing at 60 rpm for 15 min using a 1.2 HP (895 W) variable speed mixer