Bioresource Technology 128 (2013) 235–240

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

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

Separation efficiency of a vacuum gas lift for microalgae harvesting

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HIGHLIGHTS

- Determination of microalgae harvesting efficiency and concentration factor.
- Demonstration of positive effect of airflow rate and bubble size reduction.
- Demonstration of positive effect of harvest volume reduction on concentration factor.
- Measurement of harvesting energy costs below 0.2 kWh kg^{-1} DW.

ARTICLE INFO

Article history:
Received 9 April 2012
Received in revised form 10 October 2012
Accepted 12 October 2012
Available online 26 October 2012

Keywords:
Microalgae
Foam
Flotation
Vacuum gas lift
Harvesting efficiency

ABSTRACT

Low-energy and low-cost separation of microalgae from water is important to the economics of microalgae harvesting and processing. Flotation under vacuum using a vacuum gas lift for microalgae harvesting was investigated for different airflow rates, bubble sizes, salinities and harvest volumes. Harvesting efficiency (*HE*) and concentration factor (*CF*) of the vacuum gas lift increased by around 50% when the airflow rate was reduced from 20 to 10 L min^{-1}. Reduced bubble size multiplied *HE* and *CF* 10 times when specific microbubble diffusers were used or when the salinity of the water was increased from 0‰ to 40‰. The reduction in harvest volume from 100 to 1 L increased the *CF* from 10 to 130. An optimized vacuum gas lift could allow partial microalgae harvesting using less than 0.2 kWh kg^{-1} DW, thus reducing energy costs 10–100 times compared to complete harvesting processes, albeit at the expense of a less concentrated biomass harvest.

1. Introduction

Microalgae may be used as an alternative to land crops for the production of oil with many advantages: (1) biomass productivity is significantly superior to that of land crops (Chisti, 2007; Borowitzka, 2008; Chen et al., 2011; Park et al., 2011) and fatty acid content is high, (2) microalgae production does not compete with food production for agricultural land because arid and saline land are suitable for the cultivation of microalgae (Amaro et al., 2011), (3) to the best of our knowledge, there is no need for pesticides or herbicides and (4), microalgae production could be a solution for industrial carbon dioxide bioremediation (Borowitzka, 2008). However, fuel produced from microalgae is not yet cost-competitive with fossil fuel (Park et al., 2011).

The choice of microalgae harvesting method is of great importance as it represents 20–30% of the total production cost (Molina Grima et al., 2003; Brennan and Owende, 2010). Lowering the energy costs of algae harvesting is thus considered a major challenge for full-scale production of algal biofuel (Sturm and Lamer, 2011; Christenson and Sims, 2011) and for other uses of microalgae biomass, such as animal feed or chemicals. The high cost is largely due to the small size of algal cells (<20 μm) which have a density similar to water and are thus very difficult to collect without energy intensive processes (Molina Grima et al., 2003; Park et al., 2011).

The selection of the most appropriate harvesting technique depends on microalgal density, size and hydrophobicity (Golueke and Oswald, 1965; Park et al., 2011). It also depends on culture conditions such as water composition and salinity (Demirbas, 2010), particularly when diffused air flotation (DAF) systems are employed since bubble size depends strictly on salinity (Ruen-ngam et al., 2008; Kawahara et al., 2009; Barrut et al., 2012).

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0960-8524/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2012.10.056

Continuous centrifugation is currently the preferred process for biomass separation is as it is rapid and efficient (Rawat et al., 2011). However, the method requires a high energy input and a primary concentration step for it to be viable for extensive biofuel production (Sun et al., 2011). Gravity sedimentation is also used as it is simple and highly energy-efficient (Rawat et al., 2011), but the process only works for microalgae of a relatively large size and that grow to high densities e.g. *Arthrospira* spp., or when the pH is increased and/or chemical flocculants are added to the water (Knuckey et al., 2006; Amaro et al., 2011; Chen et al., 2011), which is often expensive. A solution would be to induce auto-flocculation, which is the spontaneous aggregation of particles favoring their sedimentation. Auto-flocculation may be induced by interrupting or limiting carbon dioxide supply (Demirbas, 2010). Filtration by microstrainers is also commonly used for solid–liquid separation. Some problems encountered with this method include incomplete solids removal and membrane fouling by bacterial biofilms. Although the first problem may be solved by using flocculation, regular cleaning or membrane replacement, generating sizable costs, is required to solve the second problem (Amaro et al., 2011; Rawat et al., 2011).

Air flotation has also emerged as a means for harvesting of microalgae. DAF is often used for water treatment as an efficient clarification step, notably when treating water containing hydrophobic matter and algae (Demirbas, 2010; Sturm and Lamer, 2011). The method consists of injecting air at the bottom of a water column to form an upward stream of bubbles. Tiny air bubbles may attach to the surface of microalgae and carry them to the surface, forming a concentrated layer of foam which is separated from the water by skimming. The main cost of this method is related to the power required for the injection of air. Furthermore, chemical flocculation is often necessary prior to DAF, which increases total harvesting costs (Christenson and Sims, 2011).

In view of the potential interest in flotation, the purpose of the present study was to assess the harvesting efficiency of a vacuum gas lift associated or not to complete separation systems currently used in microalgae production. The innovative technology combines flotation and foaming under negative relative pressure (lower than 1 barA) to develop a very large interface between the liquid and gas phases that favors the retention of hydrophobic compounds present in the water.

2. Methods

2.1. Experimental setup

The experimental equipment included a 2,000-L buffer tank (1) open to the air and connected to a vacuum gas lift, kindly provided by COLDEP® (2), composed of two concentric vertical transparent 6 m long PVC pipes. The outer diameter (OD) of the internal pipe was 160 mm. The diameter of the external pipe was 315 mm (OD) along the first meter and 250 mm (OD) after the first meter and up to the top (Fig. 1). The top of the vacuum gas lift was hermetically closed and connected to a vacuum pump (3) (BUSCH–Mink MM.1100.BV) providing a maximal airflow of 60 $m^3\ h^{-1}$. The vacuum raises the water in the pipes. A pressure gage (4) ranging from −1 bar to +1 bar, connected to the frequency converter of the pump's electric motor, was used to control pressure and regulate water height in the vacuum gas lift. The vacuum increases the stripping of dissolved gasses, especially dissolved oxygen which, when present in excess, has an inhibiting effect on photosynthesis (Park et al., 2011) and allows the gas removed from the fluid to be collected for storage and treatment if required. At the top of the vacuum gas lift, the water surface level was maintained above the internal tube (Fig. 1) to establish the circulation between the riser (internal tube) and the downcomer (space between internal and external tube) and to collect the foam by skimming. The separated foam was then stored under vacuum in a 100 L harvest tank (6), equipped with an outlet valve at the bottom to collect the harvest. In the downcomer, the water flowed back to the pumping tank with a velocity ranging between 0.15 and 0.25 m s^{-1}, which is the range generally used for algal ponds (Craggs, 2005). The vacuum gas lift

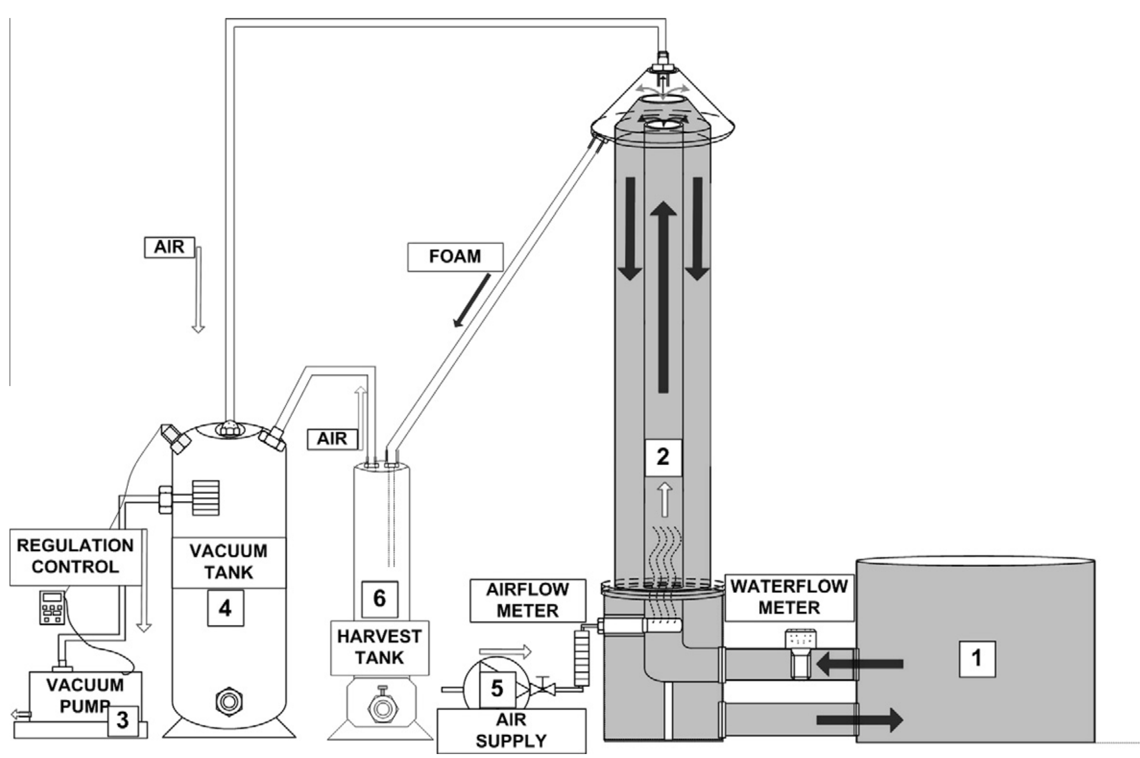

Fig. 1. Vacuum gas lift experimental set-up.