WATER RESEARCH 53 (2014) 168–179

Available online at www.sciencedirect.com

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# The impacts of replacing air bubbles with microspheres for the clarification of algae from low cell-density culture

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ARTICLE INFO

*Article history:*
Received 9 October 2013
Received in revised form
7 January 2014
Accepted 8 January 2014
Available online 24 January 2014

*Keywords:*
Microalgae harvesting
Dissolved air flotation
Ballasted flotation
Floc structure
Carbon footprint

ABSTRACT

Dissolved Air Flotation (DAF) is a well-known coagulation–flotation system applied at large scale for microalgae harvesting. Compared to conventional harvesting technologies DAF allows high cell recovery at lower energy demand. By replacing microbubbles with microspheres, the innovative Ballasted Dissolved Air Flotation (BDAF) technique has been reported to achieve the same algae cell removal efficiency, while saving up to 80% of the energy required for the conventional DAF unit. Using three different algae cultures (*Scenedesmus obliquus*, *Chlorella vulgaris* and *Arthrospira maxima*), the present work investigated the practical, economic and environmental advantages of the BDAF system compared to the DAF system. 99% cells separation was achieved with both systems, nevertheless, the BDAF technology allowed up to 95% coagulant reduction depending on the algae species and the pH conditions adopted. In terms of floc structure and strength, the inclusion of microspheres in the algae floc generated a looser aggregate, showing a more compact structure within single cell alga, than large and filamentous cells. Overall, BDAF appeared to be a more reliable and sustainable harvesting system than DAF, as it allowed equal cells recovery reducing energy inputs, coagulant demand and carbon emissions.



## 1. Introduction

Algae harvesting optimisation is a fundamental need for the feasibility of third generation biofuels (biodiesel, bioethanol, biohydrogen and biogas from microalgae) (Lee, 2011). This is most apparent in the cases where algae are grown in wastewater to provide a dual benefit of nutrient removal and biofuel generation. A reduction of the energy and costs associated with this process has the potential to make algae-biofuels more economically competitive in the market (Molina Grima et al., 2003). Furthermore, as carbon emissions are becoming an important factor in decision making in the water/energy sector (OFWAT, 2010), more sustainable technologies are required to provide environmental benefits often measured in terms of reduced carbon footprint.

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0043-1354/$ – see front matter 
http://dx.doi.org/10.1016/j.watres.2014.01.012

Centrifuges, membrane filtration and flocculation–-flotation units are the common harvesting systems applied in large scale culture (Christenson and Sims, 2011). While the energy demand for centrifuges or pressure and vacuum filters ranges between 1 and 8 kWh $m^{-3}$ of treated water, flocculation–flotation configurations require lower energy inputs (0.1 and 0.5 kWh $m^{-3}$) which has seen progressing increase in research related to flocculation–flotation systems in recent years (Rawat et al., 2013; Molina Grima et al., 2003). In the Dissolved Air Flotation (DAF) system, micro-bubbles attached to the pre-flocculated algal biomass, float the algae floc to the surface allowing high cell recovery (Rawat et al., 2013; Edzwald, 1993) (Fig. 1A). The efficiency of this process, as in all flocculation-flotation treatments, relies on floc formation which is affected by particle morphology, suspension characteristics and coagulant properties (Pieterse and Cloot, 1997). In particular, the extracellular algogenic organic matter (AOM) of the suspension plays a key role in coagulant demand and floc structure and strength (Li et al., 2012; Henderson et al., 2010). AOM is composed predominantly of carbohydrates (hydrophilic) and proteins (hydrophobic) and has a negative charge ($\leq -15$ mV) depending on the algal strain and its growth phase (Henderson et al., 2008a). Optimal coagulant doses allow floc formation to be able to resist the shear rate generated during saturated flow injection (450–600 kPa) and have been observed to occur at zeta potential values close to $\pm 0$ mV where the coagulant is responsible for particle charge neutralisation (Henderson et al., 2008a).

A modified DAF system, Ballasted Dissolved Air Flotation (BDAF), has been reported to achieve the same removal efficiency while saving from 60 to 80% of the energy demand, and related $CO_2$ emissions, compared to conventional flotation units (Jarvis et al., 2009). Unlike traditional ballasting techniques where high density granular additives (e.g. microsand) are used to improve sedimentation efficiency (Desjardins et al., 2002), BDAF uses low-density microspheres to support flotation (Fig. 1B). Microspheres are added into the system during the rapid mix stage in the same way as conventional ballasting agents, and then incorporated into the floc matrix to drive the flotation process, replacing the use of micro-bubbles (WO/2006/008474 and US Patent 6890431). Once the algae-bead floc has been harvested, the microspheres can be separated from the algal biomass and recycled into the system. The effect of low density glass microsphere addition on the pre-flocculation process was first investigated by Jarvis et al. (2009), who identified an optimal glass beads concentration close to 300 mg $l^{-1}$ for harvesting an algae cells suspension of $10^6$ cells $ml^{-1}$. Although the author reported a floc size reduction due to the beads addition, the effect of the physical (cells size and shape) and chemical (soluble content) algae characteristics on the strength and structure of the ballasted algae floc was not investigated. In addition, as the

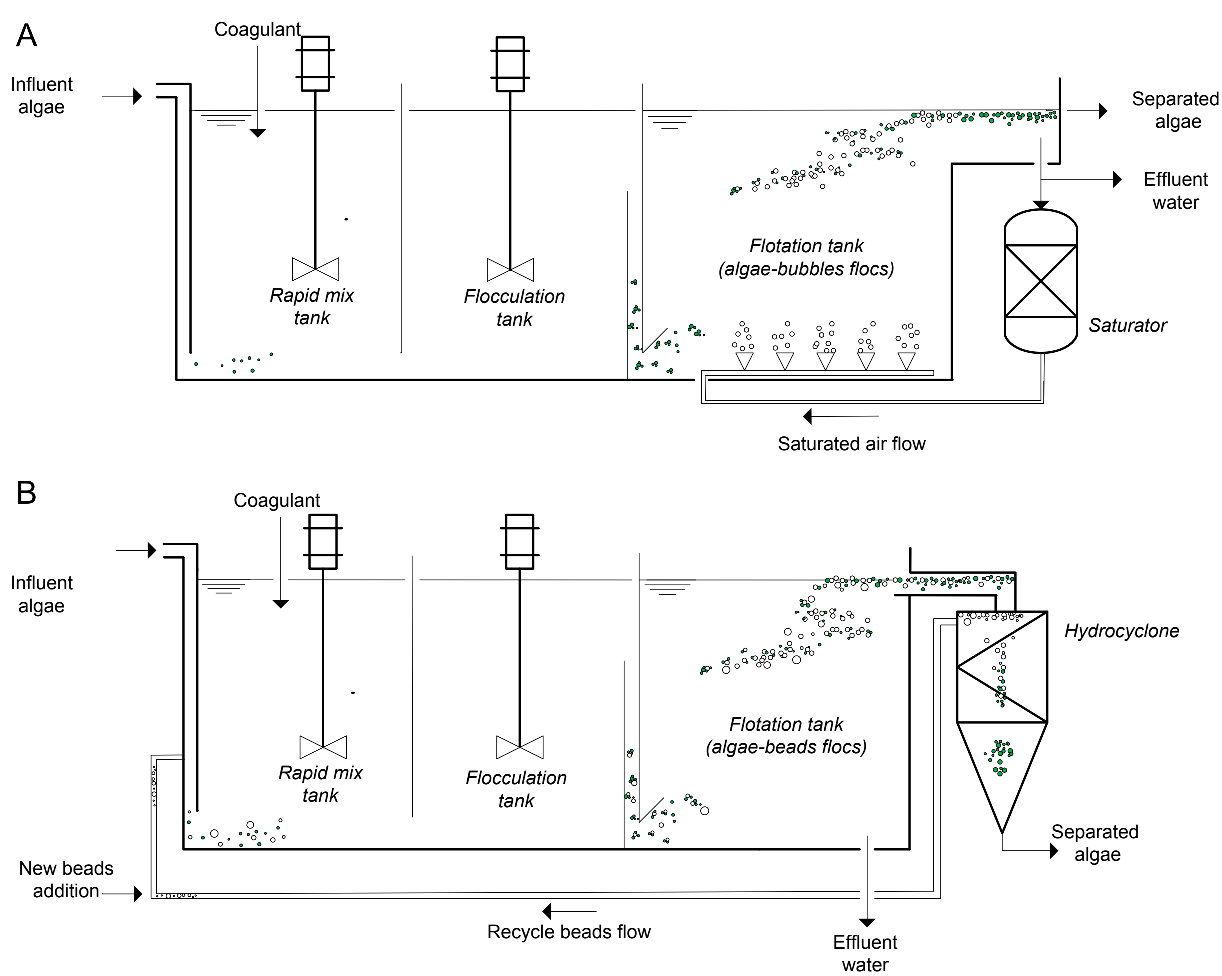


**Fig. 1 – Schematic representation of Dissolved Air Flotation (A) and Ballasted Dissolved Air Flotation (B) systems.**