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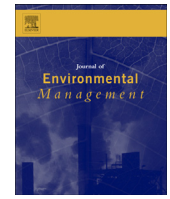

Review

Microalgae harvesting techniques: A review

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ABSTRACT

Microalgae with wide range of commercial applications have attracted a lot of attention of the researchers in the last few decades. However, microalgae utilization is not economically sustainable due to high cost of harvesting. A wide range of solid - liquid separation techniques are available for microalgae harvesting. The techniques include coagulation and flocculation, flotation, centrifugation and filtration or a combination of various techniques. Despite the importance of harvesting to the economics and energy balance, there is no universal harvesting technique for microalgae. Therefore, this review focuses on assessing technical, economical and application potential of various harvesting techniques so as to allow selection of an appropriate technology for cost effectively harvesting of microalgae from their culture medium. Various harvesting and concentrating techniques of microalgae were reviewed to suggest order of suitability of the techniques for four main microalgae applications i.e biofuel, human and animal food, high valued products, and water quality restoration. For deciding the order of suitability, a comparative analysis of various harvesting techniques based on the six common criterions (i.e biomass quality, cost, biomass quantity, processing time, species specific and toxicity) has been done. Based on the order of various techniques vis-a-vis various criteria and preferred order of criteria for various applications, order of suitability of harvesting techniques for various applications has been decided. Among various harvesting techniques, coagulation and flocculation, centrifugation and filtration were found to be most suitable for considered applications. These techniques may be used alone or in combination for increasing the harvesting efficiency.

Contents

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1. Introduction

Algae are eukaryotic photosynthetic microorganisms with variety of species living in an extensive variety of ecological circumstances such as freshwater, sea water, snow, soil, hot spring, etc. About 50,000 species of algae are present, but only around 30,000 of them have been analyzed (Richmond, 2004). These photosynthetic microorganisms can grow rapidly in large quantity requiring inorganic compounds such as CO_2, light energy source and nutrients like nitrogen and phosphorous for their growth (Grima et al., 2003). Algae are broadly divided into filamentous (frequently detach from the lake bottom to form raft-like masses over the water surface), macroalgae (algae that can be seen without the help of a microscope) and planktonic forms (free floating microscopic plants that are identified under microscope and usually measured in micrometers). The presence of these algae in water generally gives indication of higher concentration of nutrients in given water body. Depending upon the nutrient concentration lakes are classified as oligotrophic, mesotrophic, eutrophic and hypereutrophic. An overabundance of nutrient cause algal blooms which may cause clogging of screens, taste and odour problems in drinking water supply, poor aesthetic appearance of water body and loss in economy through decline in recreational uses the water bodies. Some of the harmful algal blooms produce toxins that can pose serious threats to animals and humans. However, when such conditions arises that hinders the use of the lake, control measures such as controlling agricultural, urban or storm water runoff, proper septic system management and controlled use of fertilizers should be taken to prevent human-induced fresh-water algal blooms. These measures are not too effective for immediate change so for many lakes limited algae control is opted in lake management programs.

The use of algae is very old and the phycologists are continuously working to get hold of their economic importance and many beneficial as well as harmful economic aspects of algae. Some of the beneficial roles exhibited by the algae are as primary producers, source of food for animals and humans, antibiotics and medicines, purifier of wastewater, biofuel, fertilizer and pollution controller by fixing CO_2. Microalgae biomass can be converted to biofuels such as biohydrogen, biodiesel, methane, etc (Demirbas, 2010). Nutraceuticals, fatty acids, stable isotopic biochemical, phycobiliproteins, carotenoids were also reviewed as commercial application of microalgae (Milledge, 2011). Beside extensive research on microalgae their commercial application is still uneconomical. Commercial development of microalgal biotechnology is well documented by Olaizola (2003). Cost for microalgae harvesting generally found to be 20–30% of the microalgal biomass cost (Mata et al., 2010; Grima et al., 2003; Verma et al., 2010). The most challenging task for algal biofuel production is harvesting with nearly half of the microalgal biomass cost (Greenwell et al., 2009). Their frequent harvesting from dilute suspension in comparison to conventional crops makes it more expensive. Also, harvesting of algae require high energy input. Amer et al. (2011) estimated that harvesting and dewatering equipment may cost 90% of total cost for producing algal biomass from open ponds.

In the present paper current techniques used for harvesting and concentrating microalgae are reviewed to assess their technical, economical and application potential and to suggest order of suitability of the techniques for four main microalgae applications i.e. biofuel, human and animal food, high valued products, and water quality restoration.

2. Algae harvesting techniques

Algae harvesting refers to the separation or detachment of algae from its growth medium. The harvesting method intensely depends on the physiognomies of the micro algae chosen, density and size of the microalgal cell, specifications of the final product and on allowability for reuse of the culture medium (Uduman et al., 2010; Amaro et al., 2011; Rawat et al., 2011). Regardless of the objective of harvesting process, growth in dilute suspension (0.02–0.05% dry solids), small cell size (<30 μm), negligible density difference of microalgal cells to their culture medium, negatively charged surface (zeta potential) and their high growth rates which needs frequent harvesting compared to land crops make harvesting process a challenging task (Edzwald, 1993; Amer et al., 2011; Zamalloa et al., 2011).

Currently algae harvesting involves mechanical, chemical, biological and electrical based methods. The macroalgae harvesting is simple and laborious work, whereas for microalgae harvesting relatively elaborated chemical or mechanical means are used. Grima et al. (2003) mentioned mechanical methods as the most reliable and commonly used methods for harvesting microalgal biomass. However, when mechanical methods are headed by coagulation and flocculation step, they improve harvesting efficiencies and reduce operation and maintenance costs. Several techniques such as flocculation, flotation, filtration and centrifugation, or a combination of any of these techniques are usually used to harvest and concentrate the algal biomass (Demirbas, 2010; Ho et al., 2011). The advantages and disadvantages of various harvesting techniques are presented in Table 1. A review on dewatering microalgae biomass concluded that "currently there is no superior method of harvesting and dewatering" (Uduman et al., 2010). So combination of several separation techniques has been proposed. Most of the times centrifugation and filtration are preceded by coagulation and flocculation to improve the harvesting efficiency and to reduce costs (Grima et al., 2003). Two methodologies that generally applied for microalgae harvesting are two step process and one step process (Uduman et al., 2010; Brennan and Owende, 2010). In two step process, the dilute algal suspension is concentrated to algal slurry of 2–7% TSS and then in second step the algal slurry is dewatered to 15–25% TSS, requiring more energy (Chen et al., 2011). The effectiveness of the harvesting process can be described in terms of recovery efficiency (RE) and the concentration factor (CF) (Pahl et al., 2013). The RE and CF together indicate separation efficiency of the process in terms of mass and volume of recovered microalgae biomass. The RE and CF are defined as following:

RE = *mass of the cell removed/mass of the cells in initial culture*
CF = *concentration of algae in final product/initial concentration of algae in culture*

The mass and concentration of microalgae cells can be estimated by measuring Chlorophyll-content, microalgae cell count, absorbance (optical density), dry weight and ashfree dry weight of the culture.