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Review article

Harvesting microalgal biomass and lipid extraction for potential biofuel production: A review

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ABSTRACT

Renewable feedstock for biofuel production is a worldwide concern. Microalgae as the third-generation feedstock puts the problem to rest as many researchers have been proving that biofuel; especially biodiesel, can be produced by various microalgae species. The crucial challenges are microalgal biomass harvesting and lipid extraction methods This paper reviews various microalgal biomass harvesting methods, such as centrifugation, sedimentation, flocculation, flotation, and filtration. Other than that, the development of harvesting technology is also discussed, namely, flocculation using magnetic microparticles and biopolymer as well as electrical approach. Overall, this review offers general ideas to improve these harvesting methods and the production of renewable energy for future development.

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1. Introduction

The increasing demand for alternative energy, such as biofuel, the exhaustion of oil reserves, the rising fossil fuel prices, and

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global awareness of the negative impact of greenhouse gases to the environment have led to the development of sustainable energy from renewable feedstock sources [1,2]. Microalgae are globally known as the third-generation feedstock and are excellent candidates for renewable energy source due to their ability to produce various bio-products, such as biofuel and bio-hydrogen, have higher biomass production compared to other plants, and only require small carbon footprints [3,4].

Prior to commercializing microalgae based biofuel, and to make the economy feasible, crucial challenges that need to be considered are microalgae harvesting and lipid extraction. In microalgae harvesting, the most eminent obstacles are the expensive harvesting technology and the absence of an economical, scalable, and environmental-friendly method. The cost of the harvesting process can be up to 20–30% of the microalgal biomass cost [5,6,7] or 50% of the total biofuel production cost [8].

2. Microalgae harvesting method

According to Show and Lee [9], two significant matters must be considered when choosing suitable harvesting methods, namely, the characteristics of the microalgae involved and their growth condition. The most common harvesting methods are centrifugation, sedimentation, flocculation, flotation, and filtration. The efficiency of these methods depends on the species of microalgae including size, morphology, and the composition of the medium used [10].

2.1. Common harvesting technology

2.1.1. Centrifugation

Centrifugation involves applying a centrifugal force that is higher than the gravitational force to escalate the separation of the suspension. Hydro-cyclone, solid-bowl decanter, nozzle-type centrifuge, and solid-ejecting disc are conventional centrifugation methods [11,12]. Despite their capability to harvest most microalgal cell types efficiently, these processes require high energy consumption as well as high capital and operational costs [13,6,14,12]. On average, centrifugation can harvest approximately 12–25% of microalgal biomass [11] with energy requirements of 50–75 kW [12]. More than 90% of microalgal biomass must be harvested to produce sufficient biofuel in a large scale. Harvesting large amount of microalgal biomass require high energy consumption, hence increase the operational cost.

2.1.2. Sedimentation

Sedimentation is the most conventional process commonly used at wastewater treatment plants for sludge treatment. This process facilitates liquid or solid particles to separate from suspensions with different densities, which produce effluents of mainly clear liquid [11,12]. It is also the simplest way to harvest microalgal biomass, particularly heavy microalgae suspension, which requires low capital and operating costs. However, if the density difference is small, it can become a sluggish process. Other than that, the average dry solids concentration of microalgal biomass that can be achieved is around 0.5–3% [13,6,14,12]. Golueke and Oswald [15] reported that they managed to harvest 85% of microalgal biomass using alum as coagulant in a flocculation-sedimentation process.

2.1.3. Flocculation

Flocculation is commonly used in unison with other harvesting methods [16], such as coagulation-flocculation, and flotation-flocculation. This process can enhance the particle sizes of the microalgal suspension via aggregation, and increases the settling rate altogether [5,12]. There are four types of flocculation that are widely used, which are auto-flocculation, bio-flocculation, physical flocculation, and physico-chemical flocculation.

Auto-flocculation will usually disrupt the carbon dioxide (CO_2) supply to the microalgal system when the pH in the culture increases to higher than 9, and causes the microalgae to flocculate on its own [17,9]. Several researchers have reported achieving 90% of maximum microalgae recovery via auto-flocculation despite its disadvantages whereby the process is slow, unreliable, and requires the presence of calcium and magnesium ions [18,19,12,20,21].

Table 1
Comparison of performance by flotation systems.

Flotation method	Microalgae species	Surfactant	Max. biomass concentration, DCW (g/L)	Harvesting efficiency (%)	Reference
Dispersed air	*Spirulina platensis*	None	n.d.	80	Kim et al. [28]
	Mixed culture	C-floc 60		77	Wiley et al. [30]
Dissolved air	Mixed culture	CTAB	n.d.	90	Pochinda et al. [27]
		SDS[a]		16	
	Chlorella sp.	CTAB		86	Liu et al. [42]
		SDS[a]		20	
	C. zofingiensis	Chitosan		81	Zhang et al. [37]
		$Al_2(SO4)_3$		86	
		$Fe_2(SO4)_3$		91	
		CTAB		87	
Foam flotation	*Chlorella* sp.	CTAB	39.0	n.d.	Coward et al. [35]
	Tetraselmis sp.	DAH[b]	5.5	85–93	Garg et al. [36]
		CTAB	2.0	71–82	
Flocculation-flotation	*C. vulgaris*	Bio-flocculant by *C. marina* L03	n.d.	92.7	Lei et al. [43]
Micro-flotation	*Dunaliella salina*	$Al_2(SO4)_3$ $Fe_2(SO4)_3$ $FeCl_3$	n.d.	95–99	Hanotu et al. [32]
Electro-flotation	Mixed culture	None	5.0	n.d.	Sandbank [44]
Ozone flotation	*Microcystis*	None	n.d.	<90	Benoufella et al. [45]
Vacuum gas	Mixed culture	None	61.2	3–23	Barrut et al. [33]

n.d. = not determine; [a]SDS = sodium dodecyl sulfate; [b]DAH = dodecylamine hydrochloride.