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Review article

Polyelectrolyte flocculants in harvesting microalgal biomass for food and feed applications

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ABSTRACT

Harvesting microalgal biomass at industrial scale is a techno-economic bottleneck for the algal biomass industry, compounded by the small cell size of microalgae and dilute biomass concentrations in culture. As a result, large volumes of water need to be removed during harvesting, making the process energy and cost intensive, accounting for up to 30% of the total cost of biomass production. Among the various harvesting techniques adopted commercially, flocculation is convenient and cost effective. The choice of a flocculant depends on its effectiveness on multiple microalgal strains, efficiencies at low biomass concentrations, its environmental footprint, being inexpensive and non-toxic for end application of the recovered biomass. Of the various flocculants, polyelectrolyte flocculants are widely utilised for various industrial applications such as wastewater treatment and mining, but also for effective harvesting of mass cultures of microalgae. Polyelectrolyte flocculants are polymers that are either branched or linear, but carrying ionic charge along their chain. They are accordingly classified as cationic, anionic or non-ionic polymers. These flocculants neutralise surface charges on cells and bind particles together by physical or chemical forces. The efficiency of polyelectrolyte flocculants depend on the type of polymer used, its molecular weight and charge density, dosage concentrations, cell concentration in the medium, type of strain, ionic strength and pH of the medium, and other parameters. Bulk harvesting of toxicant free microalgal biomass by polyelectrolyte flocculants is regarded to be one of the most economically viable techniques, with the cost of flocculants ranging between US$1.50 and 7.50 kg^{-1}, and requiring very low dosage for effective harvesting. This review focusses on polyelectrolyte flocculants to harvest cultivated microalgae for non-toxic residue free applications of the harvested biomass in the food and the feed industry and evaluates various commercial polyelectrolyte flocculants, their properties and application in harvesting microalgal biomass from high density cultures.

Contents

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1. Introduction

With an ever increasing population we face numerous challenges, in particular a significantly higher demand for feed, food and energy to meet the ever increasing global demand, predicted to increase in excess of 50% in the next decade [1]. Microalgae is touted to be a promising feedstock for the production of bioenergy [2], but hold much greater promise for food and feed applications as they are a rich source of proteins and lipids [3]. As microalgae belong to different evolutionary lineages than terrestrial plants, they are capable of producing unique metabolites such as polyunsaturated fatty acids (e.g., eicosapentaenoic acid or docosahexaenoic acid), natural photosynthetic and non-photosynthetic pigments (e.g., phycocyanin, different carotenoid pigments, etc.), antioxidants, anti-inflammatory and anti-tumour compounds [4]. A large number of polysaccharides and other metabolites that cannot be sourced from terrestrial plants [5] are known to be present in algae. Considering their rapid growth rate, ease of culture and the fact that they do not compete with traditional agriculture for arable land for cultivation [1], microalgae hold significant promise as a feedstock for new biotechnological products.

As part of the production process, harvesting microalgal biomass at an industrial scale continues to be a techno-economic bottleneck for the algal biomass industry. This is largely attributed to the small cell size of microalgae (1–30 μm) and dilute biomass concentrations in the culture media (~1 g L^{-1}). As a result, the harvesting process requires large volumes of water to be removed, making it energy and cost intensive. Increasing the efficiency of the process by adopting low-energy, cost effective and environmentally friendly harvesting techniques is a major challenge in microalgal biotechnology, especially when the cost of harvesting can account for >30% of the total cost of the biomass production [6]. Harvesting techniques such as centrifugation can be used efficiently to obtain a clean solid-liquid separation for high value applications, but is too energy-intensive and costly for large scale applications [7].

This study aims to review various commercially adopted microalgal harvesting techniques, with a specific focus on the utilisation of various commercially available polyelectrolyte flocculants to harvest residue free microalgal biomass for food and feed applications. The review also encompasses general properties and efficiency of different commercial polyelectrolyte flocculants, together with their advantages and limitations. From a review of the published literature, this study evaluates various commercially available polyelectrolyte flocculants and their application in harvesting cultivated microalgal biomass. As far as we are aware, this comprehensive review is the first in the published literature that has undertaken an in-depth review of various commercially available polyelectrolyte flocculants for food and feed where the harvested biomass is expected to have no toxic chemical residues and is clean for human or animal consumption. From an environment and economic standpoint, it is also important that these flocculants are non-toxic to microalgae cultivation when the medium is recycled after the recovery of the flocculants for reuse.

2. Commercially adopted microalgal harvesting techniques

Out of the several harvesting techniques commonly used in commercial scale algal production systems, microfiltration is not only simple, but is also cost-effective. However, the technique is limited in its efficiency to separate cells from high density microalgal cultures [8], leading to clogging of the filters that require periodic cleaning. Microfiltration is efficient in harvesting biomass of chain forming or larger cell size microalgae such as *Arthospira*. Smaller cells are recovered using microstrainers [9] or diatomaceous earth [6].

Flocculation is one of the most convenient and cost effective method to harvest microalgal biomass [10,11]. The technique has undergone considerable technological advancements over the years with various novel spinoff technologies developed and optimised. As the technique is cost effective and has a low energy demand, flocculation is regarded to be a promising choice for environmentally sustainable applications. Various techniques to flocculate microalgae are well documented in the published literature, accomplished by physical, chemical and biological means. Physico-chemical flocculation techniques involve the use of magnetic nanoparticles, differential pH gradient, mineral salts and polymers. Flocculation by biological means include autoflocculation and bioflocculation.

The use of ultrasound in harvesting microalgae has been demonstrated to be satisfactory in the recovery of biomass [12]. The technique leaves no residue in the harvested biomass as the algal culture suspension does not come in contact with any chemical agents unlike other techniques. However, the cooling system required to control temperature gradient needed to homogenise the field, is energy intensive and therefore increased process costs especially at scale [12].

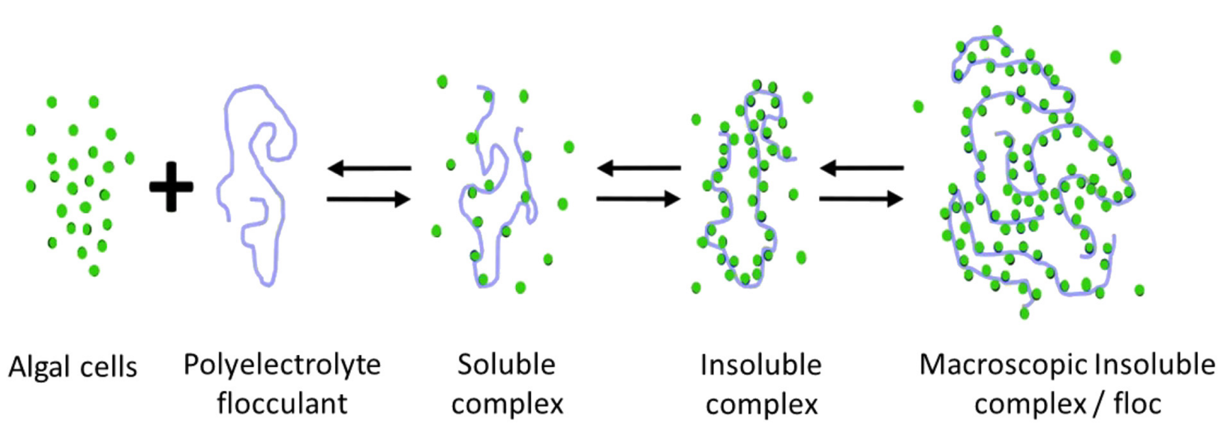

Fig. 1. A schematic illustrating the mechanism of action of polyelectrolyte flocculants in flocculating microalgal cells (modified from [115]).