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A review on the use of microalgal consortia for wastewater treatment

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ABSTRACT

The development of anthropogenic activities has led to an excessive disposal of wastes into water bodies, thus reducing water quality and damaging aquatic ecosystems. To avoid the negative impacts associated to the discharge of wastes into water courses, effective remediation processes are required to reduce nitrogen and phosphorus concentrations in discharged effluents. Current methodologies applied for nutrients removal tend to be complex, expensive and energy demanding. Therefore, cultivation of microalgae has appeared as an emerging alternative for nutrients removal from wastewaters. These photosynthetic microorganisms require large amounts of nitrogen and phosphorus for their growth. However, since it is very difficult to maintain pure cultures of these microorganisms in wastewater treatment processes, several studies have reported the use of natural and artificial microalgal consortia composed exclusively by microalgae or by microalgae and bacteria. The use of these consortia in the remediation of wastewaters can be very advantageous because: (i) cooperative interactions between the co-cultivated microorganisms can occur, enhancing the overall uptake of nutrients; and (ii) these systems tend to be more resistant to environmental conditions oscillations. This study provides an updated review of the literature regarding the application of microalgal consortia in the remediation of wastewaters from different sources, focusing on the mechanisms involved in nutrients removal by microalgae and the main interactions established between the microorganisms integrating the consortia and how they can influence nutrients removal efficiencies.

1. Introduction

In the last decades, large amounts of wastewaters have been produced, mainly due to anthropogenic activities, such as agricultural practices, urbanization and industrialization [1–4]. The continuous disposal of wastewaters without adequate treatment can pose serious pollution problems. One of the major problems associated to the continuous discharge of effluents into water bodies is the so called eutrophication phenomenon – the enrichment of water resources in nutrients, mainly nitrogen and phosphorus. This phenomenon is responsible for the development of algal blooms, spread of aquatic plants, oxygen depletion and loss of key species, resulting in the complete degradation of freshwater ecosystems [3,5]. Besides the degradation of freshwater ecosystems, development of these blooms can be considered a public health risk for the surrounding populations [6]. This clearly evidences the need for effective treatment methods, able to reduce nitrogen and phosphorus concentrations in wastewaters before discharging into natural bodies.

Nitrogen and phosphorus removal in wastewaters are mainly removed in the tertiary treatment phase (Fig. 1). The most commonly used methods include biological processes, such as anaerobic digestion followed by nitrification and denitrification [3,7]. However, several anaerobic and nitrification and denitrification cycles are required to achieve the nutrient levels accepted by EU legislation. Additionally, these methods require several tanks and internal recycles of activated sludge, resulting in an overall increase of process costs, complexity and energy input [8–11]. Alternatively, nitrogen and phosphorus removal may be achieved by chemical methods, such as precipitation using aluminium and iron salts. However, these methods are costly and produce large amounts of sludge contaminated with chemical compounds [12–14], requiring further treatment.

To overcome the drawbacks associated to the commonly used tertiary treatment methods, biological treatment using microalgae (a general term commonly applied to refer to photosynthetic microorganisms, such as eukaryotic microalgae and prokaryotic cyanobacteria) has been extensively studied in the last decades. Microalgae require large amounts of nitrogen and phosphorus for their growth [3,15], meaning that these microorganisms can effectively uptake nitrogen and phosphorus from wastewaters. In fact, high nitrogen and phosphorus removal efficiencies (80–100%) from wastewaters of different sources (e.g. agricultural, industrial and municipal) have already been reported for microalgae [16–20]. Additionally, the use of microalgae for nutrients removal presents several advantages [1–3]: (i) nitrogen and phosphorus assimilated by microalgae can be recycled by the production of fertilizers from microalgal biomass; (ii) the resulting biomass can be used

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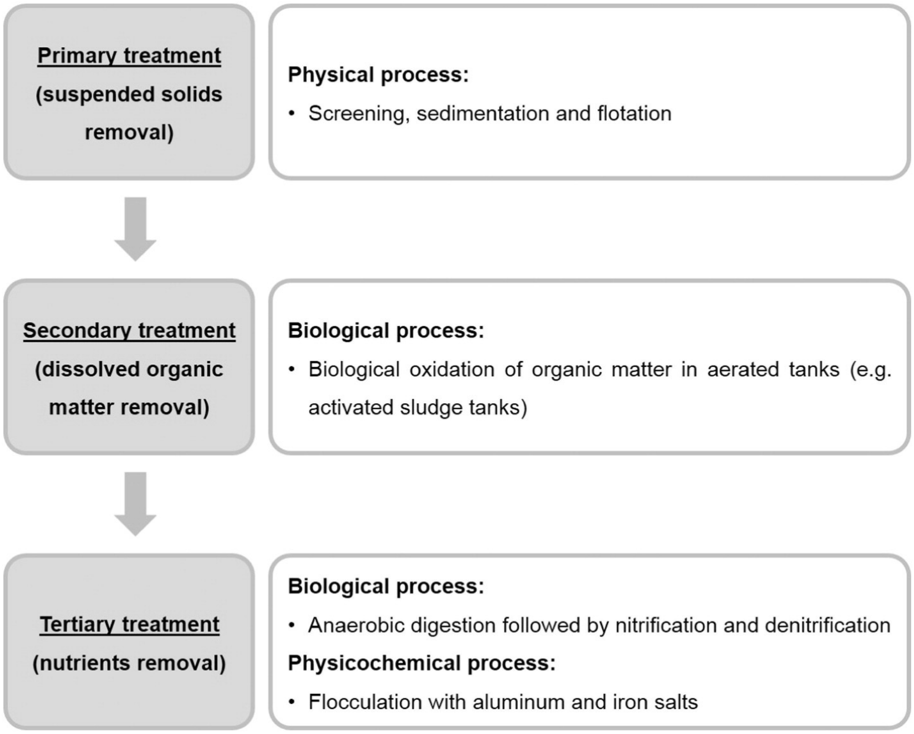

Fig. 1. Main steps involved in wastewater treatment processes and currently applied methods [2,4].

for the production of bioenergy, food, animal feed and pharmaceuticals; and (iii) an oxygenated effluent is discharged into the water bodies.

More recently, several studies have reported the potential of microalgal consortia (microalgal and microalgal-bacterial) in different applications, including biomass production and nutrients removal [2,15,21–24]. The use of polycultures for nutrients removal purposes can be very advantageous since combining microorganisms with different metabolic activities and adapted to different environmental conditions was found to allow the development of a robust biological system that can operate under different environmental conditions and nutrient loads [25–27]. Additionally, cooperative interactions can be established between the microorganisms integrating the consortia, which can result in higher nutrient uptake rates [3]. Accordingly, this manuscript highlights the advantages of using microalgal consortia in the bioremediation of wastewaters, providing an updated overview of successful consortia already applied in this field.

2. Microalgal culturing

Microalgal cultivation for wastewater treatment purposes can be performed in suspended- or immobilized-cell systems [20,28–30]. Table 1 presents the main advantages and limitations of these systems in wastewater treatment. For an effective cultivation and remediation process, some parameters, such as light, temperature, pH, nutrients supply and mixing should be carefully controlled [31–34].

2.1. Suspended-cells cultivation systems

Cultivation in suspension is the most commonly used form for microalgal growth [35]. Systems typically used for microalgal growth in suspension include closed or open bioreactors. Closed photobioreactors (PBRs) for microalgal growth can be more advantageous because (i) culture conditions and growth parameters, such as pH, temperature, mixing, carbon dioxide (CO_2) and oxygen (O_2) concentrations, can be strictly controlled; (ii) evaporation and contaminations can be easily avoided; and (iii) higher cell concentrations can be achieved [36–38]. Despite these advantages, PBRs have some limitations in terms of overheating, difficulties in scale-up and higher construction costs [37]. The most commonly used PBRs include flat plate reactors, bubble-column reactors and tubular reactors [36,38,39]. Microalgal production in open systems is less expensive in terms of construction and operation and has a larger production capacity [37,40,41]. However, due to insufficient mixing, oscillations in the culture conditions and higher susceptibility to contaminations, biomass productivities and nutrients removal efficiencies are lower than those achieved in closed PBRs. Additionally, these systems are more prone to CO_2 diffusion to the atmosphere, evaporative losses of water and poor light utilization by cells [37,38,41,42]. Open systems can be divided into two categories: natural ponds, which include lakes, lagoons and ponds, and artificial ponds or containers [36,38,42]. The most commonly used systems include shallow big ponds, tanks, circular ponds and raceway ponds [38,42,43]. The growth of microalgal consortia in suspended cultivation systems has already been reported in the literature. Cultivation

Table 1
Advantages and limitations of suspended- and immobilized-cells cultivation systems in wastewater treatment processes.

Cultivation systems	Advantages	Limitations
Suspended-cells cultivation systems	• Widely studied and optimized • Larger amounts of wastewater can be processed • Applicable in large scale operations	• Microalgal harvesting prior to the disposal of the treated wastewater is required
Immobilized-cells cultivation systems	• Microalgal harvesting prior to the disposal of the treated wastewater is simpler • Aging cultures are more protected against photoinhibition • Immobilization matrix confers cells higher resistance to harsh environments, such as salinity, metal toxicity and pH	• High costs associated to the polymeric matrix (in the case of cell entrapment) • High surface area required (in the case of microalgal adhesion and biofilm formation) • Light limitation may occur • Applicable only for small and pilot scale operations