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Microalgae as Potential for Wastewater Treatment: Removal Mechanisms of Nitrogen (N) and Phosphorus (P)

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Abstract

The present study is a brief review approaching the potential of microalgae cultivation, its applications as a bioremediation solution for the treatment of wastewater and the current state of the art. The research reveals the main problems that make traditional techniques expensive and inefficient as the use of three stages of treatment and several repetitions of biological stages involving the nitrification and denitrification processes. As an alternative to mitigate the adverse effects of wastewater discard, microalgae present efficient mechanisms for the removal of N and P, such as phosphorylation and photodiode, based on mechanisms of active membrane transport, besides the mechanisms of precipitation and formation of phosphate for the removal of P. In this way, the cultivation of microalgae in wastewater enables biomass production with low costs and with differentiated biotechnological characteristics to support the exploration of several industrial sectors.

Keywords: Cultivation; Microalgae; Biomass production; Biotechnological; Nitrogen; Air pollution; Several anaerobic; European union; Bioremediation; Adenosine triphosphates; Carbon dioxide; Renewable energy; Toxicity; biomass; Phycocyanin; Aquaculture; pigments

Mini Review

Most wastewater treatment technologies cover chemical, physical and biological processes, consisting essentially of three stages: primary (clarification and removal of stabilized and floating materials), secondary (degradation of organic matter and removal of nutrients) and advanced or tertiary (use of chemical agents to eliminate viruses and bacteria) [1]. Mainly because the Nitrogen (N) is in the form of ammonia (NH3) being transferred from the solution to the air through the use of aerators. Meanwhile, this process has high operation and maintenance costs and can cause air pollution [2]. Most of the wastewater sources contain N and P and the mean permissible concentrations in indoor water bodies are Total Nitrogen (TN) <10 ppm and Total Phosphorus (TP) <0.5 ppm. These low concentrations represent an obstacle and disadvantage of conventional processes, because the lower the concentration of nutrients the more costly the separation of N and P from the effluent. In contrast, the concentrated form of nutrients prevents its reuse and causes the potential formation of harmful by-products, creating the need for the safe disposal of any waste generated [3].

The removal of N and P in wastewater is mainly removed in the tertiary treatment stage. The most commonly used methods include biological processes such as anaerobic digestion followed by nitrification and denitrification. Meanwhile, several anaerobic and nitrification and denitrification cycles are required to achieve the levels of nutrients accepted by European Union (EU). In addition, these methods require multiple tanks and internal recycling of activated sludge, resulting in an overall increase in process costs, complexity, and energy input [4].

As an alternative, the use of microalgae enables a significant reduction of the nutrient load in effluents, mainly the removal of N and P. The use of a biological agent in this process is named bioremediation, its efficiency depends on the selection of appropriate species and the metabolic processes performed in the removal (Figure 1). For this reason, microalgae cells are able to absorb these chemical species as relevant nutrients to metabolic activities and biomass synthesis, through the organization and storage of N and P for the synthesis of proteins, lipids, Adenosine Triphosphates (ATP), enzymes, nucleic acids, chlorophyll and other biomolecular forms, besides to consuming carbon dioxide (CO_2), renewable energy, fuels and chemicals [5].

The mechanism and rate of N removal depends on the system and treatment conditions, the microalgae are adapted to assimilate N based on the form and concentration available. The preferred source of N are nitrogenous forms; ammonia (NH_{4+}) can be removed by volatilization, since the ammonia (NH_3), due to its stability, is removed through the mechanism of photophosphorylation or increase of the direct diode under basic conditions. The toxicity will depend on pH, since the nonionized form of ammonia can be transported faster through the cell membrane. In this way, there is a direct proportional relation: the higher the N available in the wastewater the higher N uptake and the greater N amount being transported and assimilated by the cells, producing more vital components for growth and cellular activity [3-10].

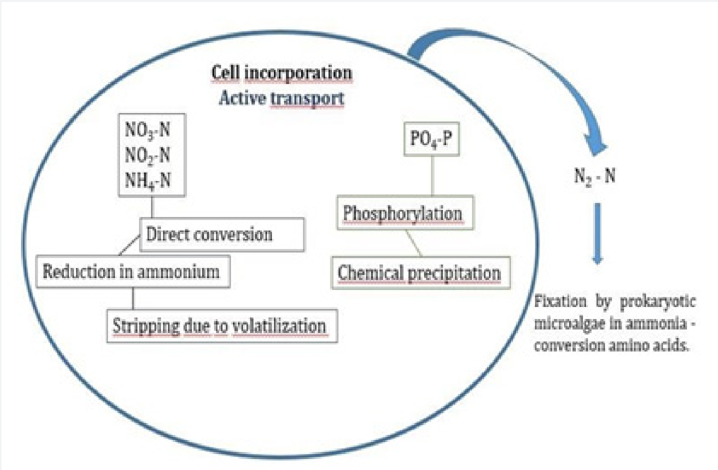

Figure 1: Mechanisms involved in the removal of nutrients (nitrogen and phosphorus).

Phosphorus is fundamental for the cellular energy cycle, meanwhile, the mechanism of removal of P may not depend on the system or treatment conditions [1]. The mechanisms can be classified in two: direct assimilation, where the additional absorption of P occurs besides the necessary for the cellular growth, stored in the form of polyphosphate; and PO_4^{3-} precipitation, which occurs when pH is basic due to cell growth [6]. Both cited mechanisms function through active transport on the cell membrane. Due to these mechanisms' microalgae have been the focus of several current research (Table 1), aiming at the application of new technologies for the biomass production, starting from the laboratory scale to the cultivation on an industrial scale, betting on simple and low-cost methods. Because microalgae can be exploited for a variety of applications, such as the generation of bioenergy, pigments, bioactive compounds, human nutrition, animal feed, aquaculture and the synthesis of various interest compounds to the pharmaceutical, nutraceutical and cosmetic industries, such as Phycocyanin, combining the obtaining of biomass of low cost and different properties to its cultivation in wastewater, bringing diverse economic and environmental benefits [11-13] (Table 1).

Table 1: Bibliographical survey of the most recent researches for the cultures of microalgae carried out in wastewaters.

Microalgae Used	Bioreactor	Results	Author
Dunaliellasp., Nannochloropsis, Tetraselmis sp	2LErlenmeyer photobioreactor	*Nannochloropsissp.* (1.81 g L^{-1}, day 15); *Dunaliella* sp. and *Tetraselmis* sp. (1.37 gL^{-1} day 14 and 1.33 gL^{-1} day 12)	Alva et al. [17]
Spirulina platensis	1.3 L Erlenmeyer	The specific growth rates (day-1) and biomass productivity (mg L^{-1} day-1): 0.11CE (0.4882 and 58.38); 0.30CE (0.5131 and 56.61) and Control (0.5172 and 41.35)	Lu et al. [8]
Spirulina (Arthrospira maxima)	50 mL photobioreactor	Exponential growth (0.85 g L^{-1}), with a maximum of 0.011 h^{-1}	Rodríguez et al. [9]
Chlorella sp	Stirrer (500 mL) operated at 120 rpm	Maximum biomass concentration of 1.197 g L^{-1}	Gao et al. [10]
Chlorella sp. Scenedesmus sp.	1L photobioreactors with magnetic stirring (150 rpm)	Microalgae biomass concentration was 211 ± 18 mg L^{-1} and a growth rate of 39.6 ± 1.4 mg L^{-1} d^{-1}	Iasimone et al. [11]
Chlorella vulgaris	1L Erlenmeyer photobioreactor	Growth of 50.0 mg L^{-1}	Nguyen et al. [12]
Chlorella vulgaris Tetradesmus obliquus	Aquaculture recirculation system (ARS) consisted of three circulars glass fiber fish tanks with a total volume of $5m^3$, with natural light	Biomass (dry weight) between 8.6 and 29.7 g L^{-1}	Egloff et al. [13]

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