Microalgae for bioremediation of textile wastewater: An overview

Abstract

In early 1960’s, the Japanese company Nihon Chlorella was the first one to make microalgae commercially available. Since then, the microalgae cultivation at industrial scale has grown and diversified significantly. Among the microalgae applications, bioremediation of textile wastewater is one the most promising technologies due to the simultaneous benefits: microalgae cultivation using textile wastewater as culture medium (bioremediation and CO₂ mitigation) followed by microalgae lipid application (biodiesel production). Therefore, the aim of this work was to put a light on the main keys in bioremediation of textile wastewater using microalgae.

Keywords: microalgae, bioremediation, textile wastewater

Introduction

The textile industry generates large volumes of wastewater, as an example, ≈7×10⁵ tons of organic dyes/year. Textile wastewater is a complex solution composed by organic dyes, phosphates, nitrates and heavy metals. Thus, textile wastewater has a potential environmental hazard and should be properly treated. When compared to physico-chemical methods that can be applied for textile wastewater treatment (photochemical, activated carbon), biological systems have advantages mainly in terms of cost effectiveness, eco-friendly approach, easy and safe operation–green chemistry concept. Biological methods include the application of bacteria, yeasts, fungi and microalgae (or their metabolites) in situ or ex situ. In this sense, microalgae have risen prominence, mostly due to their potential to simultaneously bioremediation, CO₂ mitigation and also high added-value molecules production.²,³ In addition, there are approximately 50,000 species of microalgae present on earth, which represents countless strategies of microalgae study and application.¹

Microalgae cultivation systems

There are many microalgae cultivation systems, in which it can be classified into 3 groups (I) suspended culture systems, (II) microalgae immobilization and (III) innovative submersible aquatic microalgae cultivation technology.⁴,⁵

Suspended culture systems (open, close and hybrid systems)

Open: The raceway pond—an open system for microalgae cultivation— is the most used cultivation system at industrial scale, due to easy scale up and low cost (facilities). On the other hand, as an open system, water loss by evaporation should ne take into account. Contamination is other significant issue.

Close: Compared with open ponds, closed bioreactors significantly reduce water loss and contamination. Closed bioreactors include flat plate bioreactors, tubular photobioreactors and bag systems. However, the high cost restricts the use of closed bioreactor at large-scales.

Hybrid: It is a two-stage cultivation system, in which in the first stage closed photobioreactors are used to microalgae cultivation (inoculum for the second stage). Then, microalgae are cultivated in open ponds (volume first stage volume second stage). The hybrid cultivation system minimizes the contamination in the second stage and also favors a specific dominance of the chosen microalgae. However, the first stage (high cost) limits the hybrid applications at large-scales.

Microalgae immobilization

One of the major bottlenecks for microalgae suspended culture systems is the clarification (biomass separation from culture medium), that includes chemical, mechanical, electrical and biological approaches. Thus, microalgae immobilization is an interesting strategy. When compared to microalgae suspended culture system, microalgae immobilization shows higher productivity in bioremediation applications, no or lower washout phenomenon and mainly easier downstream processing (harvesting and water recycling). However, the high cost is the limiting factor for microalgae immobilization.

Innovative submersible aquatic microalgae cultivation technology

As mentioned both suspended microalgae culture system and microalgae immobilization have drawbacks. Thus, alternative systems have been drawn attention, for instance Bussel⁶ that describes a patented floating pond system in which microalgae are grown in a controlled space separated from surrounding water.

Bioremediation of textile wastewater using microalgae

As already mentioned microalgae can be applied in different types of wastewater such as textile, metropolitan wastewater, swine manure, dairy, poultry, winery, tannery, paper mill and olive mill.⁴,⁷

Particularly regarding textile wastewater, it has been estimated that more than 100,000 different dyes has been globally used by industries. The dye industry generates 7×10⁴ tons of organic dyes/year, in which 40% (<2.8×10⁴ tons/year) are incorrectly disposal.¹,² Textile wastewater contains organic dyes, phosphates, nitrates, trace heavy metals (Ph, Cd, Zn, Mn, Cr, Ni, Cu, Fe, Ar), etc. (Table 1), that have
potential environmental hazard. In addition, textile wastewater has 
aesthetic pollution (color) even at low concentration. In this sense, the 
UNESCO’s World Water Development Report raised concern about the 
hazardous industrial wastes, in particular dye effluents. Several 
physic-chemical methods can be applied for textile wastewater 
treatment such as fenton’s reagent, ozonation, photochemical, NaOCl, 
cucurbituril, electrochemical destruction, activated carbon, peat, wood 
chips, silica gel, membrane filtration, ion exchange and irradiation, 
however these methods are not aligned to the green-chemistry concept 
and have many drawbacks (e.g. expensive, low efficiency). In this 
sense, biological approaches are the most prominent eco-friendly 
treatment, in which microalgae (Chlorella vulgaris, Chlorella 
pyrenoidosa, Spirogyra sp., Oscillatoria tenuis and Scenedesmus sp.) have risen prominence due to their potential to simultaneously 
textile wastewater bioremediation, CO₂ mitigation and produce high 
added-value molecules as long-chain polyunsaturated fatty acids; 
phenolic compounds; volatile compounds; sterols; proteins, amino 
acids, peptides; vitamins; polysaccharides and pigments.\(^1,^2,^3,^4\)

Even with a great potential for bioremediation of textile 
wastewater, the microalgae cultivation still faces many obstacles, for 
instance the complex chemical composition of textile wastewater 
affects the microalgae growing (reproducibility), contamination 
(bacteria) and design of the microalgae cultivation system. Therefore, 
further research is needed.

**Table 1 Textile wastewater: chemical properties**\(^1\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.6-9.0</td>
<td>Pb</td>
<td>0.5 mg/L</td>
</tr>
<tr>
<td>Temperature</td>
<td>35-45°C</td>
<td>Cd</td>
<td>0.3 mg/L</td>
</tr>
<tr>
<td>Conductance</td>
<td>6.89 mS</td>
<td>Zn</td>
<td>1 mg/L</td>
</tr>
<tr>
<td>COD</td>
<td>250-8,000 mg O₂/L</td>
<td>Mn</td>
<td>2 mg/L</td>
</tr>
<tr>
<td>BOD</td>
<td>50-550 mg O₂/L</td>
<td>Cr</td>
<td>1.5 mg/L</td>
</tr>
<tr>
<td>TSS</td>
<td>100-700 mg/L</td>
<td>Ni</td>
<td>1 mg/L</td>
</tr>
<tr>
<td>TDS</td>
<td>5,000-10,000 mg/L</td>
<td>Cu</td>
<td>0.2 mg/L</td>
</tr>
<tr>
<td>NH₄⁺(^+)</td>
<td>50 mg/L</td>
<td>Fe</td>
<td>0.2 mg/L</td>
</tr>
<tr>
<td>NO₃⁻(^-)</td>
<td>350 mg/L</td>
<td>Ar</td>
<td>0.01 mg/L</td>
</tr>
<tr>
<td>Total PO₄(^-)</td>
<td>4.0-12 mg/L</td>
<td>Total CN</td>
<td>1 mg/L</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>50-900 mg/L</td>
<td>Free residual Cl</td>
<td>100-500 mg/L</td>
</tr>
</tbody>
</table>

**Conclusion**

The textile industry generates large volumes of wastewater \(\approx7\times10^4\) 
tons of organic dyes/year. Textile wastewater is composed by organic 
dyes, phosphates, nitrates, heavy metals, among others that represent 
environmental hazard. When compared to physic-chemical methods 
(ozonation, electrochemical destruction, activated carbon), biological 
methods (bioremediation using microalgae) show advantages in 
terms of cost effectiveness, easy scale up and mainly the potential to 
simultaneously carried out the bioremediation, CO₂ mitigation and 
biosynthesize high-added value molecules. In addition, there is no 
consensus on the best microalgae cultivation system.

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**Conflict of interest**

The authors declare no conflict of interest.

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