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Bioremediation of textile wastewater and successive biodiesel production using microalgae

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ABSTRACT

Microalgal biodiesel has emerged as an environment friendly alternative to the existing fossil fuels. The commercial production of this biodiesel is still challenging due to several technical and economic issues, which span from mass cultivation of microalgae to the biodiesel production. Mass cultivation is the most critical step in terms of water and nutrient requirement. Industrial wastewater such as textile wastewater (TWW) is a cheap source for water, which additionally contains necessary nutrients (phosphate, nitrates, micronutrients etc.) and organic dyes (potential carbon source) for algae cultivation. The application of microalgae for biodiesel production employing single objective strategy is not sustainable. Microalgae can be effectively employed to bioremediate TWW (dyes and nutrients removal) and to produce biodiesel from grown microalgae. This process integration (bioremediation-biodiesel production) can potentially improve biodiesel production and wastewater treatment. However, this process coupling needs to be thoroughly investigated to identify and optimize critical process factors (algal species, cultivation and harvesting methods, bioremediation mechanism etc.). This study has reviewed the status of TWW as potential source of water and nutrients, role of different algal species in the bioremediation of TWW, different cultivation systems, harvesting and biodiesel production methods. This review also suggests future research and development challenges for coupled textile wastewater treatment and microalgal biodiesel production.

1. Introduction

The growing human population has posed several challenges to the global economy particularly in terms of environmental conservation and energy security. Global economy is mainly relying on non-renewable and finite fossil fuels [1–4]. This overuse of fossil fuels has resulted in two highly correlated challenges of environmental pollution and energy insecurity. These fossil fuels have considerably contributed to greenhouse gas (GHG) emissions where CO_2 level has approached up to 400 ppm [5–8]. Besides the use of fossil fuels in vehicular emissions, they are also use in diesel generators to produce electricity for small and medium enterprises (SMEs) in developing countries like Pakistan. This excessive use of fossil fuel (i.e. diesel) does not only cause financial liability to the local industry. Thus, local industry needs to look for alternative strategies to make their production cost competitive and environment friendly.

Textile industry is one of the most important industrial sectors of Pakistan that contributes a huge financial share. Recently, this industrial sector has confronted energy shortage that caused financial loss. This industry switched their energy sources from national grid to in-house diesel run generators to meet energy requirements. Although this strategy has partly worked and provided continuous energy to the industry but it also added financial liability. In order to save local textile industry, there is an immediate need to search for sustainable energy sources. Besides energy supply, textile industry is also facing the challenge of wastewater management. Textile industry consumes several hundred thousand gallons of water each day, and proportionally produces huge volume of wastewater [9]. Textile wastewater contains variety of dyes and auxiliary chemicals which may pose serious risks to the environmental recipients [10–14]. The global concerns of energy demand and non-tariff bindings regarding environmental conservation

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may risk the fate of textile exports of Pakistan. Local textile industry contributes 9% to the global textile needs [15] and more than 60% to the total exports of the country [16]. Textile sector earned $13.7 billion in 2013–2014 which dropped to $12.5 billion during 2015–2016 [17] mainly due to energy liabilities.

Textile wastewater treatment is a big challenge because it contains organic dyes, phosphates, nitrates etc. which cause multiple and multiscale damage to the receiving environment [18,19]. Pakistan require textile wastewater treatment and reclamation to meet its domestic and industrial water requirements [20]. Thus, sustainable energy supply and textile wastewater treatment appear the biggest challenges to Pakistan textile sectors [21,22]. In order to meet energy supply, textile industry has already installed diesel run electricity generators. These generators require financial liabilities in terms of both diesel consumption and CO2 emissions. However, textile wastewater treatment still remains unaddressed challenge. CO_2 emissions can be manage employing direct carbon capture, indirect carbon sequestration and biological carbon mitigation techniques. Textile wastewater effluents can be treated using several physico-chemical methods [23–29]. These physico-chemical processes inherit several drawbacks such as expensive, less efficient, limited application and sludge handling [8,30,31]. On the other hand, biological methods are cost effective and environmentally friendly [14]. Though biological processes are attractive, but microorganisms (bacteria and fungi) require additional carbon source for their growth to treat colored wastewater [32,33].

Recently, microalgae have received great attention due to their potential to fix CO_2 and bioremediation of textile wastewater [4]. Microalgae can simultaneously be used first for the remediation of textile wastewater and later can be used as a feedstock for the biodiesel production [34]. Thus, biodiesel can be used as an eco-friendly fuel in the generation of electricity and can fulfill the energy requirements of textile industry. Microalgae can use atmospheric CO_2 (from diesel generator) as carbon source along with organic dyes, and convert them into carbohydrates through photosynthesis [35]. These carbohydrates are converted chemically and biochemically into lipids which can be used to produce biodiesel [36]. Microalgae biomass can contain up to 85% of total lipid content in dry biomass [37]. Therefore, microalgae biofuels have potential to replace fossils fuels [4,38]. Microalgae are a potential feedstock for biofuel production due to the requirements of less amount of water for the growth as compared to terrestrial crops [39]. Microalgae have also been reported to remove CO_2, nitrogen, phosphorus, and toxic metals from a different type of wastewaters [40,41]. There are extensive studies available about the microalgae cultivation in industrial wastewaters [42,43]. These organisms are photosynthetic and categorized under third generation biofuels. Different species of microalgae: *Chlorella vulgaris, Chlorella pyrenoidosa, Spirogyra sp., Oscillatoria tenuisin* and *Scenedesmus sp*. have shown their capability to remove reactive dyes from textile wastewater [44,45]. Microalgae can be used to produce biodiesel [46–48], residual microalgae as fertilizer [49], and as cultivated biosorbent to treat wastewater [50,51]. Microalgae may simultaneously solve all of the problems of local textile industry as proposed in Fig. 1.

This review targets to overview simultaneous bioremediation of TWW and the production of algal biomass, which can be useful in biofuels production. This review elaborates the role of microalgae in the bioremediation of TWW via biological and adsorption pathways, classification and short description of the cultivation methods, critical evaluation of microalgae cultivation, harvesting and oil extraction processes. It further discusses about future R&D perspectives about bioremediation-biodiesel process integration using microalgae and TWW.

2. Literature review

2.1. Textile wastewater characterization

Textile industries consume huge volume of water for their operations and thus, proportionally generate wastewater. Textile wastewater accounts for 30% (288,326 million gallons) of total wastewater (962,335 million gallons) in the Pakistan [20] according to literature, different sectors produce wastewater annually [52]. Unfortunately, only < 8% of this wastewater gets treated prior to its disposal [20,53]. Textile wastewater (TWW) mainly contains high concentration of different dyes [45]. Globally, more than 100,000 different dyes are used in different industrial sectors [54–57]. These dyes get discharged into wastewater to a variable extent (10–60%) [11,57–61] and cause wastage of 280,000 t dyes per annum [62–64]. The release of dye wastewater may pose several risks to the receiving ecosystem [18,65,66].

Textile wastewater is characterized in terms of strong color, salinity, temperature, pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total nitrogen (TN), total phosphorous (TP) and non-biodegradable organic compounds [18,19,60]. TWW also contains trace heavy metals like Chromium (Cr), Arsenic (Ar), Copper (Cu), and Zinc (Zn) as presented in Table 1 [67]. The concentrations of nutrients vary in textile wastewaters is source dependent [68]. For instance, TN ranges from 21 to 57 mg L^{-1} and TP varies from 1.0 to 9.7 mg L^{-1} in textile wastewater [41]. In addition, COD and BOD also vary due to the dyes used and their metabolites produced in wastewater because different dyes inherit different structure [69–73].

2.2. Bioremediation of textile wastewater

TWW has complex composition containing dyes, salts, heavy metals, reagents etc. [78–81]. Several processes have been investigated such as adsorption with activated carbon, flocculation, ion exchange, membrane filtration, electrochemical-destruction, ozonation and irradiation [11,25,36,82–87], however, there is no standalone process, which can treat TWW completely. Most of these processes are costly, energy intensive, low efficient and produce sludge etc. [31,45,88].

Bioremediation has emerged as a potential technology to treat textile effluents [33]. Different microorganisms (bacteria, fungi, yeast and algae) have been explored for the bioremediation of textile dyes [79,87,89]. However, microalgae is promising than other microbes because it cannot only treat textile wastewater by uptaking nutrients and dyes, but it can also accumulate lipids which can be trans-esterified into biodiesel [90–92]. Biodiesel is an environment friendly sustainable output of micrloalgal bioremediation process [93–96].

2.2.1. Micrloalgal bioremediation of TWW

Microalgae can be cultivated in textile wastewater, which use dyes and nutrients for its growth. Microalgal bioremediation of TWW may occur in two ways i.e. bioconversion or bioaccumulation process and biosorption process. During the bioconversion process, microalgae consume dyes as carbon source and convert them into metabolites. However, microalgae also work as biosorbent where dyes can adsorb to its surface. Both these phenomena can occur simultaneously for TWW bioremediation [59]. The mechanism of microalgae accumulation can involve enzyme degradation, adsorption or both [63] Additionally, dead and living microalgae also participate in these phenomena [91]. However, the dead microalgae can only participate in the adsorptive removal of dyes [77,97]. Microalgae result in high sorption capacity due to their high surface area and strong binding affinity towards azo dyes [98]. Microalgae species such as *Chlorella vulagris, Chlorella pyrenoidosa and Oscillatoria tenuisin* degrade azo dyes into simple aromatic amines and decolorize dye wastewater [44,99]. Cheriaa et al. [100] isolated new *Chlorella* alga and cultivated it in different textile dyes. This alga decolorized different dyes variably such as indigo (89.3%), direct blue (DB = 79%), remazol brilliant orange (RBO = 75.3%) and crystal violet (72.5%) [100]. El-Kassas and Mohammad [101] cultivated *Chlorella vulgaris* in textile wastewater, and observed that it could reduce COD up to 70% [101]. Another study found that *Chlorella vulgaris* could degrade 63–69% mono-azo dyes into simple aromatics