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SOLID WASTE MANAGEMENT BY ALGAE: CURRENT APPLICATIONS AND FUTURE PERSPECTIVES

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ABSTRACT

Solid waste management is a major social and environmental concern among the developed and developing countries. Solid wastes in the form of municipal, industrial, commercial and agricultural wastes create harmful effects for the terrestrial and aquatic ecosystem. Many physical, biological, chemical, physicochemical and biochemical processes have been employed for testing wastes before and after disposal. Dumping and incineration are the most common method in small and large towns or cities, which may create a major threat to living organisms. The landfill sites, over time, form toxic leachate when mixed with rainwater and directly pour into the water ecosystem to contaminate surface and ground water. With increasing demand for sustainable development, algae based green technology has been suggested for management of solid wastes in landfill sites. The monocultures of algae and algae-bacteria co-cultures may reduce the environmental footprints and enhance the production of biomass when cultivated in landfill leachate. The biomass obtained can be applied for the production of biofuel, biofertilizers, animal feed, nutraceuticals and pharmaceuticals in a sustainable way. Hence, algae-based bioremediation can be a potential alternative for solid waste management in landfill sites.

KEY WORDS : Algae, Cultivation, Environmental footprint, Landfill leachate, Solid waste, Sustainable development

INTRODUCTION

Solid wastes may be defined as any garbage or refuse including municipality waste, sludge from wastewater treatment plant, industrial plant, commercial, mining, agricultural operations and other discarded materials. Solid waste management (SWM) is the process of collecting, treating and disposing solid wastes by the methods of segregation, dumping, composting, drainage, using scrubbers or electrostatic precipitators and incineration. In developing countries, SWM is the major issue for the authorities especially in cities with high population density. The handling system and high cost are two important factors that affect the SWM system. Rapid industrialization, urbanization, increase in standards of living, increasing population and booming economy in developed and developing countries have significantly promoted the formation of solid wastes. Therefore, adoption of new technologies for SWM should be taken into consideration for the environmental, socio-cultural, political and economic benefits of the community (Abdel-Shafy and Mansour, 2018). Most common and easy way to dispose solid waste materials is landfilling but it causes several environmental health hazards. In rural and urban areas of most of the developing countries, solid waste products including organic and inorganic wastes are disposed in open drains and canals, which leads to blockage and non-functionality in the long run. Most of the dumped materials also contain hazardous toxic substances, which are released in the water body and subsequently increase the biological oxygen demand (BOD) and chemical oxygen demand (COD). However, the formation of landfill leachate (LL) becomes high due to continuous dumping and landfilling, which creates major environmental issues (Dogaris *et al.,* 2020). As a result, contaminations of surface and ground water have become major threats for human civilization and a major environmental concern for government sector. To overcome this problem, novel biological treatment method like algae technologies are introduced due to easy applicability, long term sustainability and high efficiency.

In this review, the overview of SWM system and treatment technologies using algae is highlighted. In addition, large-scale outdoor cultivation of algae related to LL and wastewaters are discussed to obtain biomass based value added products for sustainable economy. Broadly, the integrated phycoremediation technologies with other existing remediation technologies are mentioned to overcome the solid waste issue.

Solid Waste Disposal

Disposal of solid wastes mainly depends on the nature of wastes and collection practices in proper bins. Lack of proper management systems, poor planning, difficulty in collection schedule, vehicle issue, poor roads and insufficient infrastructure promotes dumping in open areas (Abdel-Shafy and Mansour, 2018). Pokhrel and Viraraghavan (2005) identified some limitations of solid waste disposal including engineered landfills, insufficient financial resources, well equipment and absence of legislation. Disposal of plastic wastes is another global environmental issue. Plastic waste disposal in landfill has become non-sustainable for the environment. Thus, they can be incinerated with municipal wastes to generate heat and power, which can replace fossil fuels (Abdel-Shafy and Mansour, 2018). The ash formed after burning or incineration may be used in blast furnaces and cement kilns. This process may cause emission of green house gases, which further increases global warming. Therefore, plastic wastes and other non-biodegradable wastes may be hazardous to the society and environment. Household hazardous wastes are another group of solid wastes, which gets disposed in the landfills with normal household wastes and causes harmful effect to the environment. These include batteries, electric wares, pharmaceuticals, sanitary pads, diapers and mercury containing wastes that need to be separated before disposal into the landfills (Slack, Gronow and Voulvoulis, 2004). The irresponsibility of the people for disposing solid garbage in nearby drains and open areas with untreated effluent may cause high risk for society and environment. Therefore, laws are ineffective to prevent exposure of hazardous substances to the environment until some green technologies could be achieved.

LL Treatment by Algae

Landfilling is the most easy and most applied methodology for disposing solid waste materials. Over time, landfilling causes formation of leachate after mixing with rainwater, which becomes a major threat to the environment including contamination of ground and surface water resources. Leachate contains various harmful and potential organic pollutants, heavy metals, ammonia nitrogen compounds with high BOD and COD. Thus leachate poses a threat to aquatic organisms and human health, which ultimately affects the environment. Therefore, leachate treatment is required before it is discharged in the environment. Several existing conventional methods are discussed including leachate transfer with domestic sewage and leachate recycling (Reinhart and Basel Al-Yousfi, 1996; Renou *et al*., 2008), biological treatments with aerobic and anaerobic microorganisms (Renou *et al*., 2008), and many physical or chemical processes including coagulation, flocculation, chemical precipitation, chemical oxidation, adsorption, ion-exchange systems, flotation, membrane processes, air stripping and electrochemical processes (Kurniawan *et al.,* 2006; Nawaz *et al*., 2020). All the treatment technologies are mainly based on reduction or removal of nutrients and COD. The requirement is of a sustainable treatment technology, which is cost-effective and helps in long-term treatment of contaminants. Algae-based green technologies are economically and ecologically sustainable than other conventional methods. Algae grow naturally on the contaminated sites and wastewaters and remove toxic metals and nutrients by phycoremediation including biosorption and bioaccumulation. Moreover, the high biomass obtained from contaminated sites can be utilized for the biorefinery approach including biofuels, value-added products, bioactive compounds and nutrient supplements (Nawaz *et al*., 2020). Most of the studies have been focused on algae-based wastewater treatment and algae cultivation using wastewater. However few studies have demonstrated algae-based lab-scale and pilot-scale technologies.

Algae-Based Laboratory Treatment

The laboratory-based treatment of LL using algae started from 2007. At that time *Chlorella pyrenoidosa* and *Chlamydomonas snowiae* isolated from high ammonia leachate pond were treated with diluted and concentrated LL like 10%, 30%, 50%, 80% and 100% (Lin *et al.*, 2007). The maximum growth and remediation efficiency for *Chlorella pyrenoidosa* was shown at 50% LL, while, for *C. snowiae* it was 30%. Richards and Mullins (2013) have demonstrated a simple microalgae-detritus model using leachate-hypersaline water to estimate growth pattern, lipid content and heavy metal removal. The study showed 95% removal of heavy metals by *Nannochloropsis gaditana* and *Chaetoceros muelleri* with highest growth rate and lipid content. The culturing of *Chlorella vulgaris* in 150 mL flask showed better growth in less polluted LL compared to high-polluted LL obtained from garbage pit and showed removal of 65% of phosphorus, 65% ammoniacal nitrogen and 40% of nitrate nitrogen (Thongpinyochai and Ritchie, 2014). The 90% removal of total ammonia nitrogen in 10% permeate leachate was studied using *Chlamydomonas* sp. SW15aRL strain (Paskuliakova, Tonry and Touzet, 2016). An investigation done by Desai (2016) showed removal of nitrogenous compound when cultured *Chlorella* in 1 L flask at varied concentrations of diluted LL. In another study, *C. vulgaris* showed significant biomass productivity of 0.11 g/L/d and 77% removal of ammoniacal nitrogen when cultivated in pre-treated LL in addition to phosphorus (Pereira *et al.*, 2016). The study demonstrated by El Ouaer *et al.* (2017) showed 90% removal of ammoniacal nitrogen and 60% removal of COD when cultivated *Chlorella* sp. in 10% Tunisian LL. In addition, high biomass content of 1.2 g/L and lipid productivity of 4.74 g/L/d was obtained in 10% leachate in 13 days. In 100% raw leachate, *Chlorella* sp. was able to remove 90% ammoniacal nitrogen and 50.7% COD in 24 days. The application of microalgae in microbial fuel cell (MFC) showed evolution of higher dissolved oxygen (DO) and removal of 96.8% COD in anode chamber and 52.9% in cathode chamber respectively (Nguyen *et al.*, 2017). Further, 300 mg/L ammoniacal nitrogen removal in 4 days and 61.46% phosphorus reduction in 5 days were observed in 5-10% leachate medium by microalgae. In another study, *Chlorella*, *Scenedesmus* and *Oscillatoria* showed nitrate removal of 77.4%, 66.34% and 84% when cultivated in 20% nitrified LL (Nordin, Yusof and Samsudin, 2017). However, the maximum biomass production in *Oscillatoria*, *Chlorella* and *Scenedesmus* were observed in the order: 805.96 mg/L> 428.66 mg/L> 237.04 mg/L in 20-30% nitrified leachate. Biological denitrification treatment of LL using *C. vulgaris* showed 100% reduction of ammonia and nitrate but partial removal of nitrite when cultured in 1.5 L capacity vertical photobioreactor (PBR) (Casazza and Rovatti, 2018). A comparative study on cultivation of *C. vulgaris* FACHB-31 strain in membrane PBR versus traditional tubular PBR using LL showed membrane PBR functioned better than tubular PBR (Chang *et al.*, 2018). Moreover, the removal efficiency of nitrogen and phosphorus was close to 100% in association with better biomass production and lipid content for sustainable bioenergy.

Large-Scale Treatment by Algae

For commercial implementation, pilot-scale technologies have been incorporated for waste management. Therefore, few reports are available on large-scale cultivation using 40 to 2000L capacity bioreactors in outdoor condition. Mustafa, Phang and Chu (2012) have used five-species consortium using *C. vulgaris*, *Scenedesmus quadricauda*, *Euglena gracilis*, *Ankistrodesmus convolutus* and *Chlorococcum oviforme* to remove 100% ammoniacal nitrogen and 86% ortho-phosphorus and achieved highest biomass yield of 5 g/L when cultivated in 40 L open raceway pond (ORP) using treated LL. The mixed cultures of *Chlamydomonas reinhardtii* and *C. vulgaris* showed better growth performance when cultivated in 200L ORP using ultra-filtered LL (Khanzada and Övez, 2018). A low-cost cultivation system using novel horizontal bioreactor of 150 to 2000L capacity was demonstrated to grow *Picochlorum oculatum* in treated LL (Dogaris *et al.*, 2019). This study showed high biomass productivity ranging from 37 to 256 mg/L/d in 19-73 days cultivation period. The choice of algae species and cultivation condition are the two important criteria for phycoremediation of LL and wastewater.

Algae-Bacteria Co-Cultivation for Treatment of LL

The synergistic effect of algae-bacteria consortium resulted significant removal of pollutants from wastewater and LL by recycling nitrogen, phosphorus and carbon as major nutrients. Eukaryotic algae perform photosynthesis and produces oxygen, which can be utilized by heterotrophic bacteria to breakdown the complex organic matter found in LL through oxidation. A pilot scale LL treatment system employed using wild algae-bacteria consortium showed significant removal of COD (35-82%), ammonia (75-99%) and nitrogen (64-79%) (Martins *et al.,* 2013). The algae-bacteria consortium system using *Chlamydomonas* and *Cryptomonas* resulted in removal of 82% ammonium and 56% total organic carbon (TOC) when experimented in stabilization pond filled with LL (Fernandes *et al*., 2013). Costa *et al*. (2014) performed similar study and indicated 75% BOD and ammonia removal in 43 weeks. It has been studied that ammonia removal in LL or wastewater is linearly correlated with the initial ammonia concentration, biomass concentration and daylight hours (Nawaz *et al*., 2020). Zhao *et al*. (2014) have studied *Chlorella pyrenoidosa*-bacteria co-cultures in 500 mL flask with mixture of LL and municipal wastewater to remove upto 90% of total nitrogen, 95% of phosphorus and accumulate upto 20.8% lipid. Synergistic effect of *Scenedesmus* sp. ISTGA1 and *Paenibacillus* ISTP10 revealed removal of toxic organic compounds and heavy metals from 20% LL (Kumari, Ghosh and Thakur, 2016). Sardi Saavedra *et al*. (2016) have reported 100% removal of ammonia and more than 90% reduction of COD, nitrate and phenol when cultivated 28 species of algae and bacteria in a 300L horizontal raceway pond filled with LL. The most dominant algal species recorded in this study was *Chilomonas insignis* and *Euglena* sp. The municipal sewage for the bacterial load and a unicellular green alga *C. pyrenoidosa* were used synergistically to treat LL and resulted removal of 89% phosphate and 70% nitrogen when cultivated in 3L tubular PBR (Nair and Nagendra, 2018). In addition, 2.8 g/L microbial biomass was generated which may be utilized for sustainable biofuel production. The microalgal species and cyanobacteria including *Chlorella*, *Scenedesmus*, *Stigeoclonium*, *Microcystis* and *Oscillatoria* collected from a wastewater treatment plant have been used to treat 10% LL (Tighiri and Erkurt, 2019). However, most of the work carried out was mainly for research purpose. For commercial applications, techno-economic analysis using large-scale data is needed for LL treatment by algae-bacteria consortia.

Problems, Challenges and Solutions

Recent developments in the area of algal research in wastewater treatment have suggested its potential application towards SWM. But SWM is a complicated system because majority of Government and private sectors mainly follow the conventional dumping, composting and incineration processes, which has damaging effects on the environment. Though there are some difficulties of SWM by algae on commercial scale, some challenges are worth taking for a better future. Firstly, physico-chemical parameters involved in the algae-based treatment; secondly, availability of large-scale algae industries for biotechnological applications; thirdly, cost-benefit ratio; fourthly, high toxicity of leachate needs pre-treatment in terms of dilution; fifthly, balancing the nitrogen and phosphorus ratio for better algal growth; sixthly, improving the rate kinetics process; seventhly, species dependent remediation; lastly, sustainability and resource recovery (Nawaz *et al*., 2020). It has been found that algae-bacteria co-cultures have better tolerance to toxic elements compared to unialgal strains. Hence the synergistic effects and symbiosis of different algal species and bacteria can be applied to reduce the metal toxicity compared to monoculture system. Similarly, the problem related to nitrogen and phosphorus supplementation for better algal growth in LL can be overcome by using agricultural run-offs, which are rich in nitrogen and phosphorus. High turbidity and heavy metals lead to a barrier, which prevent light penetration and thus photosynthetic activity becomes hampered (Dogaris *et al.,* 2020). To overcome this problem, the LL may be diluted to 5-50% with municipal and industrial wastewaters or regular natural waters.To separate the e-waste and hospital waste, the conventional segregation method is followed, which cannot be replaced directly by algae-based treatment. These factors are beneficial to overcome the societal and environmental problems.

Future Suggestions

- In low and middle-income countries, household waste is still a major problem as no definite solution has yet been identified. In this regard algae based treatment in landfill site can be a good alternative to solve this problem in future.
- Proper bin collection practices, identification of biodegradable and non-biodegradable wastes and transfer of wastes are needed before dumping in open areas.
- Co-cultivation of algae and bacteria is the most effective green technology can be engineered with the landfill system to remove the toxic substances in LL.
- The large-scale cultivation of algae in open raceway ponds can generate high biomass,

which may be utilized for the production of biofuels, pharmaceuticals, nutraceuticals, biofertilizer and other valuable substances when co-cultivated with LL.

CONCLUSION

Algae can abundantly grow in natural environment and functions as natures' kidney for its capability in biosorption and bioremediation of heavy metals, nitrogen, phosphorus, ammonia and toxic chemicals from waste waters and LL. Away from the conventional technologies including landfilling, incineration, composting and valorization, algae-based treatment was found to be more sustainable to the environment. But still it is not adopted commercially yet at landfills because it is not economical compared to standing technologies. Moreover, algae has high demand for its biorefinery approach towards its '3F' application i.e., food, fodder and fuel. The integrated technologies of raceway ponds for large-scale algae cultivation with commercial LL treatment plants can be suggested to obtain high biomass for biofuel, biogas, biofertilizer and other bioproducts, which may be cost effective and beneficial to the environment.

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