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Review Article

Phycoremediation: An Eco-Solution to Environmental Protection and Sustainable Remediation

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Abstract: Phycoremediation involves the remediation of contaminants in a water body using algae (micro and macro). Algae fix carbon-dioxide by photosynthesis and remove excess nutrients effectively at minimal cost. It removes pathogens and toxic materials from waste water. Xenobiotics, chemicals and heavy metals are known to be detoxified, transform, accumulated or volatilized by algal metabolism. It offers advantage over conventional methods of remediation by its effectiveness, efficiency and eco-friendly nature. Commercially, it involves design and construction of Waste Stabilization Pond System (WSPs) and High Rate Algal Ponds (HRAP) with difference in that WSPs are unmixed or involves a little mixing, so can experience stratification, but the HRAPs involves process of mixing using paddle wheel. There are industries that are commercially involved in phycoremediation and they experience cost reduction and maximization of profit compared to the convectional system of remediation.

Keywords: Phycoremediation, Wastewater, Algal Pond, Pathogens, Oxygen

1. Introduction

Algae are plant-like, unicellular or multicellular aquatic organisms [22]. Bioremediation performed by algae is termed phycoremediation [9]. The use of algae to treat wastewater has been in vogue for more than 50 years with one of the first descriptions of this application being reported by Oswald in 1957 [19]. Phycoremediation is used to describe remediation of contaminants in a water body using algae (micro and macro algae). It is a branch of bioremediation that makes use of algae. It is a bio-restoration technology involving the use of algae and it is relatively new in Africa [7]. Algae can fix carbon dioxide by photosynthesis and remove excess nutrients effectively at minimal cost. Phycoremediation is employed for improving water quality. In addition, photosynthetically produced oxygen can relieve biological oxygen demand (BOD) in the waste water. Microalgae are superior in remediation processes as a wide range of toxic, and other wastes can be treated with algae and they are non-pathogenic. The risk of accidental release of pollutants into the atmosphere can cause health, safety and environmental problems, but are avoided when algae are employed for remediation. Algae use the wastes as nutrient and enzymatically degrade the pollutants. The xenobiotics and heavy metals are known to be detoxified, transformed or volatilized by algal metabolism [21]. They have the ability to take up various kinds of nutrients like nitrogen and phosphorus [16]. They can utilize various organic compounds containing nitrogen and phosphorus from their carbon sources. Many researchers have studied microalgae as pos-Department of Botany, Centre for PG studies and Research, Sacred Heart College etc. Some other researchers such as [22], [6], [15], [12] etc have also documented some studies on phycoremediation. The choice of microalgae to be used in wastewater treatment is determined by their robustness against wastewater and by their efficiency to grow in it and take up nutrients from wastewater [16]. Some algae which are generally used for the waste water treatment are *Chlorella, Scenedesmus, Synechoccystis, Gloeocapsa, Chroococcus, Anabaena, Lyngbya, Oscillatoria, Spirulina* etc. Pollution has been a common feature in almost all rivers and lakes because of organic and industrial wastes. The use of microalgae to treat wastewater is an environmental friendly method with no secondary pollution as long as the biomass produced is reused and efficient nutrient recycling is allowed. The microalgae consume the minerals in the waste to optimize of their growth process. In addition to treating the water, the created biomass has a variety of applications including production of bio-diesel, animal feed, products for pharmaceutical and cosmetic purposes [4], or it can even be used as a source of heating or electricity [24]. Algal biomass forms an important food source for shellfish or other aquatic species [25]. This wide variety application of microalgae explains the interest in controlling their growth.

Microalgal biomass generated from remediation process offers more advantages compared to conventional biomass production because do not require arable land for cultivation. Innovations to microalgae production allow it to become more productive while consuming resources that would otherwise be considered as waste [1]. In this circumstance, wastewater can be considered as resources. Microalgae biomass can be produced at extremely high volumes and this biomass can yield a much higher percentage of oil than other sources [1].

In recent years, many researchers have studied the potential of dual application of microalgae for wastewater treatment and biomass production [19], [10], [8]. The high nitrogen level in wastewater had become a growing concern which has increased the necessity to develop simple, efficient, and cost effective nitrogen removal techniques. High nitrate wastes (>1000 ppm) are usually generated by fertilizer, metal finishing, cooking and organic chemical industry, nuclear industry [14] and nitrified landfill leachate [26]. Species of chlorophyta, Rhodophyta, Cyanophyta, Diatoms, Pheophyta, Charophyta e.t.c. can be utilized in this technology. Phycoremediation can be incorporated into secondary effluent treatment stage. Several industries in the world are utilizing this technology and examples of such companies include; Algae tech International (Malaysia,) Sunrise Ridge Algae, Inc. (USA), Snap Natural &Alginate Products LTD (India), Nutraville International (Chennai).

2. Algae-Based Waste Water Treatment Systems

To construct algae based wastewater treatment system, it is essential to consider both wastewater treatment as well as algal cultivation. Cell retention time, nutrient addition rate, water depth, and degree of mixing are parameters to be considered for growth of algae. In addition to these parameters, BOD reduction, TDS reduction, pH, nitrogen removal rate and phosphorus removal rate should be considered for wastewater treatment. Therefore, the system should be designed accordingly to allow both growth of algae and wastewater treatment. Main reasons for failure are;

1. Failure to consider all relevant local factors at the pre-design stage
2. A lack of technical knowledge
3. Inappropriate discharge standards

Two types of wastewater treatment systems are available for algae based treatment.

1. Waste Stabilization Pond Systems
2. High Rate Algal Ponds

2.1. Waste Stabilization Pond Systems (WSPs)

They are large, shallow basins. Wastewater is treated entirely by natural processes involving both algae and bacteria. They are used in temperate and tropical climates and is one of the most cost-effective, reliable and easily-operated methods for treating wastewater. They are very effective in pathogen removal, e.g faecal coliform bacteria. Sunlight energy is solely required for its operation. Furthermore, it requires regular cleaning of the outlets and inlet. The temperature and sunlight in tropical countries offer a high efficiency and satisfactory performance for this water-cleaning system. The advantage of these systems in terms of removal of pathogens is one of the most important reasons for its use.

Wastewater treatment in Waste Stabilization Ponds (WSPs) is "green treatment" which is achieved by mutualistic growth of microalgae and heterotrophic bacteria. The algae produce oxygen from water as a by-product of photosynthesis. This oxygen is used by the bacteria as they aerobically bio-oxidize the organic compounds in the wastewater. Carbon dioxide is the end-product of this bio-oxidation which is converted into cell carbon by the algae during photosynthesis.

2.2. Varieties of Waste Stabilization Ponds

WSP system consists of anaerobic and aerobic ponds for BOD removal and maturation pond for pathogen removal.

Anaerobic ponds: These don't contain dissolved oxygen or algae. In these ponds, BOD removal is achieved by sedimentation of solids and anaerobic digestion of the resulting sludge. The anaerobic bacteria is sensitive to pH <6.2. Thus, acidic wastewater should be neutralized before its treatment in anaerobic ponds [13]. A well-designed anaerobic pond can achieve about a 40% removal of BOD at 100°C, and more than 60% at 200°C. A shorter retention time of 1.0 - 1.5 days is usually used.

Aerobic ponds

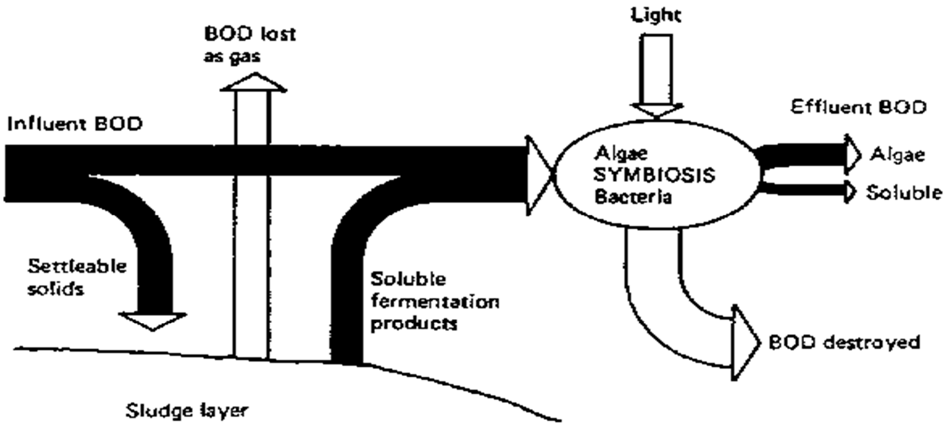
This includes;

Primary facultative ponds: It receives raw wastewater. The BOD is majorly removed by the oxidation of organic matter. It involves use of aerobic bacteria.

Secondary facultative ponds: These ponds will receive the wastewater from the primary facultative ponds or an earlier treatment process such as anaerobic digestion. The remaining BOD is oxidized by heterotrophic bacteria. The oxygen needed for oxidation of BOD is usually obtained from photosynthetic activity of the microalgae.

Maturation ponds: These ponds receive the effluent from the facultative ponds. Their primary function is to remove pathogens.

WSP systems consist of a single string of anaerobic, aerobic and maturation ponds in series or several such series in parallel. In essence, anaerobic and aerobic ponds are designed for the removal of Biochemical Oxygen Demand (BOD), and maturation ponds for pathogen removal, although some BOD removal also occurs in maturation ponds and some pathogen removal in anaerobic and facultative ponds [27]. In most cases where the effluent is to be used for restricted crop irrigation and fish pond fertilization as well as when weak wastewater is to be treated prior to its discharge to surface waters, only anaerobic and aerobic ponds will be needed for BOD removal. Maturation ponds are only required when the effluent is to be used for purposes that demands WHO guideline of ≤ 1000 faecal coliform bacteria/100 ml. The WSP does not require mechanical mixing. Sunlight supplies most of its oxygenation. Its performance can be measured in terms of its removal of BOD and faecal coliform bacteria.

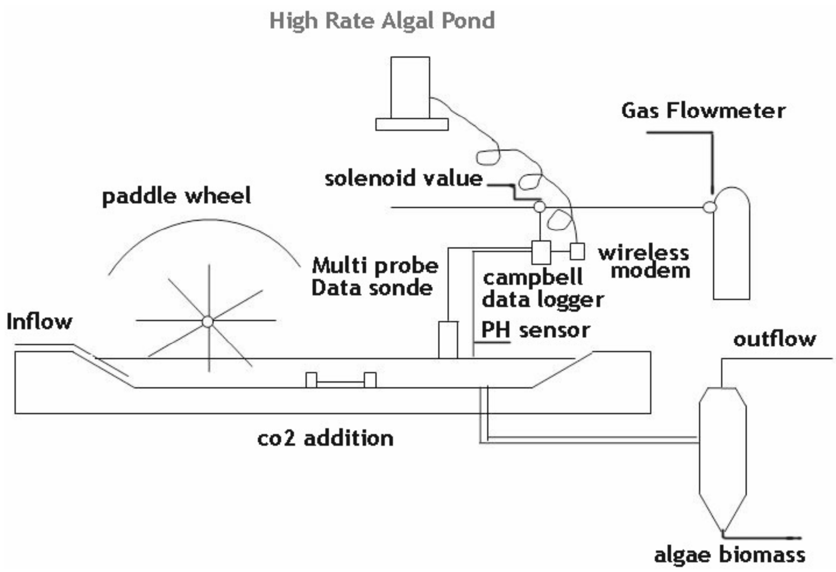


Source: (Oilgae Guide, 2013)

Figure 1. *A waste Stabilization Pond Systems.*

2.3. High Rate Algal Pond Systems

This design achieves two purposes: secondary wastewater treatment and algal biomass production. It is a combination of intensified oxidation ponds and an algal reactor. Algae supplies oxygen for bacterial degradation of organic matter and bacteria excrete mineral compounds that provide the algae with nutrition. HRAPs are greatly effective in removing organic matter, reducing bacterial contamination and a number of nematode eggs [12]. They are shallow, paddlewheel-mixed open raceway ponds and provide much more efficient wastewater treatment than conventional oxidation ponds. This is as a result of algal photosynthesis providing saturated oxygen to run aerobic treatment and assimilation of wastewater nutrients into algal biomass. High-rate algal ponds have been studied for many years as a means of wastewater treatment and it enables resources recovery in the form of protein-rich microalgal biomass [17]. The High–Rate Algal Pond is an effective disinfection mechanism required for sustainability. In addition, HRAP is also active in nutrient removal mechanisms and especially in the removal of phosphate. HRAPs are much more cost-effective than energy intensive mechanical wastewater treatment systems providing similar wastewater treatment.



Source: (Oilgae Guide, 2013)

Figure 2. *A high Rate Algal Pond Systems.*

Table 1. *Major differences between conventional facultative ponds and high rate algal ponds.*

Parameter	Conventional Facultative Pond	High Rate Pond
Mixing	Little mechanical mixing	Paddle wheel mixing
Residence time	20-100 days	4-10days
Efficiency	Very good	More efficient
Cost	Costlier	Cheaper
Energy	More Input	Less Input

Source: (Adapted from Oilgae Guide, 2013)

HRAPs significantly more efficient wastewater treatment than conventional oxidation ponds primarily as a result of intense algal photosynthesis providing saturated oxygen to drive aerobic treatment and assimilation of wastewater nutrients into algal biomass [28]. Sunlight helps in wastewater disinfection as a result of the shallow pond depth and continuous mixing of HRAP. A 1000-m2 HRAP is capable of treating 50 m3 of wastewater daily [18]. Most ponds are operated at an average velocity from 10 - 30 cm/second to avoid deposition of algal cells [11].

2.4. High Rate Algal Pond and Waste Stabilization Pond System

In various parts of the world, WSPs and HRAPs are operated independently. However, the performance of these systems has rarely been compared in the same location.

Table 2. *High Rate Algal Pond and Waste Stabilization Pond System.*

Parameter	High Rate Algal Pond	Waste Stabilization Pond
Depth	Shallow	Relatively Shallow
Mixing	Gently mixing	Unmixed
Stratification	Avoids Stratification	Can Stratify
Temperature Variation	Avoids Variation	12°C between the lagoon surface and bottom
Oxygen Variation	Homogenous	Little variation

3. Pathogen Removal by Algae

Certain mechanisms are involved in disinfection in High Rate Algal Ponds. These include;

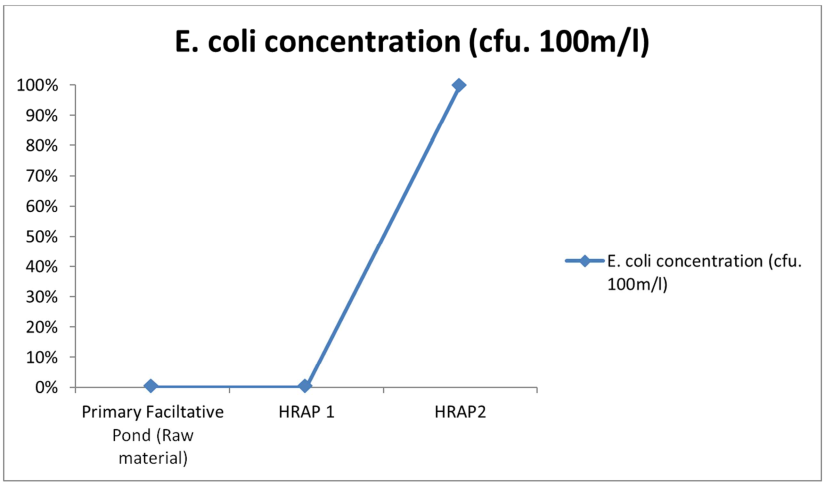
1. Predation
2. Sunlight
3. Temperature
4. Dissolved oxygen
5. pH
6. Sedimentation
7. Starvation.

Algal photosynthesis increases the pH due to the simultaneous removal of CO_2 and H^+ ions and bicarbonate uptake when the algae are carbon limited [3]. According to [29], pH of 9.2 for 24 hours will provide a 100% kill of *E. coli*, most pathogenic bacteria and viruses. [30] found that *E. coli* could not grow in wastewater with a pH higher than 9.2.

Table 3. *Pathogen Removal Performance of the High Rate Algal Pond Unit Operation, Configured In Series.*

Treatment units	E. coli concentration (cfu. 100m/l)
Primary facultative pond (raw effluent)	5.8×10^5
HRAP 1	6.7×10^3
HRAP2	4.8

Source: (Charles, 2005).



Sources: (Adapted from Charles, 2005)

Figure 3. *Percentage removal of E. coli concentration in HRAP.*

4. Significance of Phycoremediation in Environmental Sustainability

Phycoremediaton is of great significance and offers several benefits in comparism with other bioremediation processes. These include;

1. No yielding of toxic products.
2. Pathogen removal
3. Reduction in carbon-effect and concentration
4. It is an eco-safe process
5. Detoxification and removal toxic wastes.
6. Green House Gas emission reduction

4.1. Advantages of Algae Wastewater Treatment

Using algae for wastewater treatment offers some interesting advantages over conventional wastewater treatment such as in;

1. Cost effectiveness and safety
2. Green House Gas emission reduction
3. Reductions in sludge formation and low energy requirement
4. Production of algal biomass
5. Oxygenation of the systems through photosynthesis thereby enabling effective decomposition.
6. Effective reduction of nutrient load and consequent total dissolved solids as these are used up as nutrient sources
7. Production of high algal biomass which can be used as feed in aquaculture and as bio-fertilizer
8. Simple operation and maintenance
9. Potential for energy and nutrient recovery

4.2. Major Setbacks in Conventional Methods of Waste Water Treatment

1. Sludge formation is more often unavoidable which is difficult to dewater and dispose.
2. Physical methods such as reverse osmosis and other chemical methods are costly.
3. Addition of chemicals may increase the salinity and conductivity of water.
4. Ecological implications due to altered and increased water variables.
5. Problematic in the treatment of some effluents such as metal-bearing streams.

5. Conclusion

It is necessary to often invest in low cost and high effective phycoremediation method in treating wastewater from industries and agricultural lands before disposing. It offers eco-friendly method of waste water treatment before disposal or reuse. Government through her Environmental Protection Agency should ensure appropriate investment in this area of phyco-waste treatment. Research institutes, academic institutes, companies and industries should continue to conduct researches on the appropriateness of different algal species that can be used for efficiency in phyco-remediation.

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