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RESEARCH ARTICLE

INTEGRATED APPROACH OF PHYCOREMEDIATION IN WASTEWATER TREATMENT: AN INSIGHT

Nandini Moondra*, Namrata D Jariwala, Robin A Christian

Civil Engineering Department, S.V. National Institute of Technology (SVNIT), Surat, Gujarat, India-395007
**Corresponding Author E-mail: nandini7808@yahoo.in*

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ABSTRACT

Even after secondary treatment, wastewater has a high convergence of nutrients, which frequently causes eutrophication and different destructive impacts on biological systems. Wastewater treatment is a critical activity that must be considered necessary for the improvement of society. The secondary contamination of sludge formation and disposal also makes the treatment difficult. The vitality and financial amount required for tertiary treatment of wastewater remain an issue for local bodies, limiting its use for treatment. Hence, to address most of the challenges of sewage treatment, an algal-based system can be more affordable and biologically secure with the additional advantages of asset recuperation and reusing. Phycoremediation system even eliminates the need for tertiary treatment. The paper illustrates the benefits and challenges of phycoremediation, with some recent studies on microalgae as a wastewater treatment alternative along with the factors affecting the wastewater treatment through microalgae. The in-depth knowledge of the microalgal treatment in every aspect could result in an advancement to the conventional treatment process if applied in the field.

KEYWORDS

Water hyacinth, Greywater, Constructed wetland, Batch study.

1. Introduction

Wastewater is an unpredictable blend of natural and inorganic materials and also human-made mixes. Most wastewaters are usually unsafe to human populaces and the earth and should be treated as per the receiving bodies' disposal norms. Optional treatment of household and agro-industrial wastewater still discharges a lot of phosphorus and nitrogen, which regularly causes eutrophication and different destructive consequences for biological communities while varying the pH, diminishing dissolved oxygen hence causing the demise of aquatic life forms (Zhang et al., 2014). Wastewater treatment is a critical activity that must be considered necessary for the improvement of society. A notable prerequisite of wastewater treatment is the need to remove a high number of supplements, specifically N and P, that can result in eutrophication and generation of dead pockets in water bodies. However, finding remedial outcomes for the treatment and secure disposal of the wastewater is a troublesome task. It incorporates procedures in which specialized and money related thought comes into play. Thus, it is essential to ensure that proper treatment systems and innovative technologies are selected for treating wastewater.

Phycoremediation may be defined as algae for the removal or biotransformation of pollutants, including nutrients from wastewater. Microalgae are photosynthetic microorganisms that consume CO_2 and colonize in the presence of moisture and nutrients (Mata et al., 2010; Kesaano and Sims, 2014). Microalgae in wastewater treatment can ensure water treatment without poisonous mixes and lessen the eutrophication issue. Moreover, wastewater can be a supplement for microalgae to increment microalgae biomass with wastewater treatment. Therefore, research on wastewater treatment using microalgal can be the most suitable alternative for tertiary treatment.

Not at all, like the conventional wastewater treatment process, where the slime is utilized to debase natural carbonaceous issue to its more straightforward form, algae can absorb natural toxins into cell constituents, for example, lipid and starch, consequently accomplishing poison decrease in an environment-friendly way. Microalgae based treatment framework is additionally one of the suitable answers for taking care of the ecological issues, for example, global warming, the expansion of ozone gap and atmosphere changed because of its capacity to devour a high amount of carbon dioxide in photosynthesis procedure to deliver oxygen and glucose (Ahmad et al., 2020).

This paper reviews the benefits and limitations of microalgae in wastewater treatment with some recent literatures and factors affecting algal growth and nutrient removal.

2. Benefits and Challenges

Microalgae are favored for the bioremediation process because of their high photosynthetic proficiency, quick take-up of nutrients, short life expectancy combined with basic growth requirements. Algae consume nitrogen and phosphorus for building biomass, thus contributes to the self-purification of waters. Oxygen is produced in the photosynthesis process during treatment contributes to the waters' oxygen supply (Duk et al., 2006). These systems can tolerate extreme environmental

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conditions (Goncalves et al., 2017). The microalgal biofilm network can hold the biomass while working at a short detention time (Moondra et al., 2020a). It is expected that practically zero detachment of microalgae and water is required before releasing the effluent (Boelee et al., 2011). Purification capacity of microalgae, which incorporates: increment in pH of wastewater, making adverse conditions for pathogenic organisms, emission of antibacterial substances, generation of lethal extracellular mixes by specific algae, exhaustion of organic matter and nutrients (Mishra and Mishra, 2017) and also eliminates the need for tertiary treatment (Moondra et al., 2020b).

Algae absorb carbon dioxide and can be utilized to create sustainable power sources energizes and chemicals, in this manner diminishing petroleum product utilization and ozone-depleting substance emissions (Bhambri and Karn, 2020). Algal biomass can be utilized in bioenergy production, pharmaceuticals, natural manure and animal feed (Cai et al., 2013). Algae may likewise be nourished to an anaerobic digester for methane generation or used to create bioplastic materials (Christenson and Sims, 2011). Dried algal biomass might be utilized to produce vitality by direct burning. Also, hydrogen can be processed from algae by bio-photolysis (Pittman et al., 2011). Symbiotic relation between algae and bacteria in wastewater is shown in Figure 1.

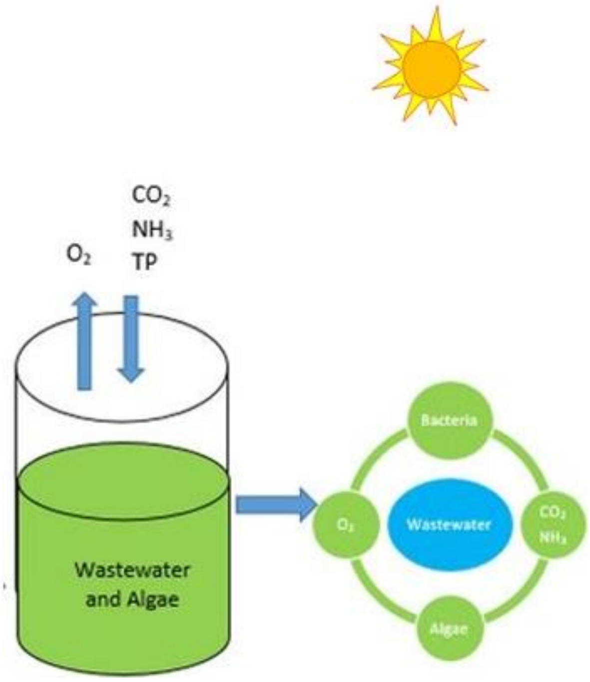

Figure 1: Symbiotic relation between algae and bacteria in wastewater.

High Rate Algal Ponds (HRAP) require a large amount of light, as the light entrance is restricted by an increment in cell thickness. Though increasing solids handling, the regularity of algal development, and a poor record for bio-flocculation/settling of algae, contagious parasitism and viral contamination can likewise radically decrease the algal populace inside a couple of days in HRAP and trigger changes in algal cell structure, a decrease of algal chlorophyll. 40% of the expense and vitality is used in miniaturized scale algal biofuel creation. The primary considerations that influence development are nutrient availability, land and water accessibility, gas exchange, photosynthetically active radiation (PAR) conveyance and culture uprightness. The harvesting alone takes 20-30% of the algal biofuel cost (Hoh et al., 2016). Advantages of phycoremediation treatment over conventional wastewater treatment is shown in Table 1.

3. Microalgae and Wastewater Treatment

Various literature has stated the importance of phycoremediation in domestic wastewater treatment. When microalgae were used to treat domestic wastewater, 68.4% and 67.2% removal efficiency was found for BOD and COD, respectively, with 97.8% removal of phosphorus (Biris-Dorhoi et al., 2016). Microalgal bacterial consortia (*Chlorella vulgaris* and activated sludge) had a promising reduction in BOD (89.02%), COD (88.96%), ammonia (94.85%) and phosphorus (99.79%) from raw sewage collected from a sewage pumping station at 8 hours HRT without any pre-treatment (Moondra et al., 2020a). Algal strain *Chlamydomonas polypyrenoideum* was capable of reducing COD by 60%, along with a 90% reduction in nitrate and ammonia levels and 70% reduction in phosphorous levels from dairy wastewater (Panda et al., 2020). Microalgal bacterial consortia led to nearly 86% and 97% removal of COD and TKN from pre-settled municipal wastewater in 48 hours duration (Foladori et al., 2018). A lab-scale study of consortia (*Chlorella vulgaris* and activated sludge) showed 90 % removal in COD when operated in SBR mode at an HRT of 2 days (Gutzeit et al., 2018). Monocultures of *Oedogonium sp.* effectively treat domestic wastewater and led to the reduction in COD, nitrogen, phosphorus, metals and microbes by 57%, 62%,75%, 99% and 99%, respectively (Neveux et al., 2016). A comparative study of wastewater treatment and nutrient recycle assessment with activated sludge, microalgae (*C. vulgaris*) and their combinations led to the results that proved microalgae alone and in combination are very effective in removing ammonia (99.2%), TP (83.2 %) and organic matter (87.3%) in 24 hours (Wang et al., 2016). *S. obliquus* and *C. vulgaris* can effectively remediate nutrients (>99%) from secondary treated wastewater at N:P>18 (Whitton et al., 2016). *C. vulgaris,* when used for tertiary treatment of sewage, led to 72% and 99% of reduction in nitrate and orthophosphate, respectively in 10 days HRT (Shaker et al., 2015).
Literature states that microalgal treatment effectively treats domestic wastewater (raw, primary treated and secondary treated). Studies by various researchers revealed that algae are quite efficient in treating wastewater and the removal efficiency of the system depends on different biotic and abiotic factors.

Table 1: Phycoremediation treatment v/s conventional treatment

Algal-Based Wastewater Treatment System	**Conventional Wastewater Treatment System**
A cost-effective and practical approach.	An Uneconomical and outdated approach.
Highly efficient in nutrient, organic load and heavy metals removal from wastewater.	Nutrient organic load and heavy metals removal from wastewater is low.
A non-skilled operator can take care of the treatment unit.	A skilled operator is required to handle the system.
Industrial, municipal, or agricultural waste can be treated with the same method.	Different effluents have to be treated differently.
Less energy-intensive system.	More energy-intensive system.
Photosynthesis-aeration leads to the removal of pollutants.	Mechanical aeration: artificial method of aeration is required for pollutant removal.
The system does not require any kind of chemical for treatment.	Chemicals are added for treatment.
Less operational and maintenance cost.	High operational and maintenance cost.
CO_2 sequestration through photosynthesis, environmentally friendly.	The treatment process increases greenhouse gases emission.
Compatible with the traditional method of treatment.	The system is process specific.
Nutrient removal, pigment removal, reduction in BOD and COD can be achieved in one step only once algae grown in wastewater.	Multistep processes are involved, removal of each parameter obtained through step by step.
Sludge generation is less.	The amount of sludge generated is high.
The system is associated with a low F/M ratio.	A High F/M ratio is found in the conventional system.
Algal biomass, a by-product of the treatment, can be used as a bio-based chemical and fuel.	Mostly generated sludge can become an additional source of pollution if proper care is not taken.
The system doesn't lead to secondary pollution.	The conventional system is associated with secondary pollution.

4.Factors Influencing Algal Growth and Nutrient Removal

Algal lifespan and reduction in nutrients depend on various biotic and abiotic factors that directly or indirectly affect the system's efficiency. Algal growth and nutrient uptake are influenced by the accessibility of nutrients, abiotic and biotic factors. The principal biotic factor affecting algal development is thickness. Nutrient removal efficiency directly depends on algal concentration. However, higher algal thickness results in self-concealing and a decrease in photosynthetic effectiveness. A few abiotic factors are impacting algal growth, for example, light (quality, amount), temperature, nutrient fixation, O_2, CO_2, pH, salinity, and toxic chemical; biotic factors, for example, pathogens (microscopic organisms, parasites, infections) and other operational factors (Wu et al.,2012; Wang et al., 2014).

Salinity influences the development and cell synthesis of microalgae because of dissipation. Salinity changes osmotic pressure, particle (salt) stress and the ionic cell proportions (Mata et al., 2010), which affects the efficiency of the microalgae system.

Mixing helps in the algal dispersion, warmth, encourages gaseous transport, leads to dispersion of light and prevents settling (Goncalves et al., 2017), thus empowering nutrients disintegration (Khan et al., 2018). However, high fluid velocity and disturbance can harm microalgae because of shear stress (Mata et al., 2010). Nonetheless, even though the light is frequently restricting microalgae development, an excess of light may likewise cause brought down photosynthetic effectivity, which is known as photoinhibition. Hence it is necessary to keep algae in suspension. Mixing also favors algal bacterial cell aggregation.

4.1 Light

Without nutrient confinement, photosynthesis increments with expanding light power until the most extreme algal development rate is achieved at the light saturation point (Park et al., 2011; Hoh et al., 2016). Light intensity, temperature, shear rates and nutrient concentration influence the succession of photosynthetic biofilms. Seasonal temperature, light and fluctuation influence the proportions of algal groups/species in biofilm (Schnurr and Allen, 2015). The ideal light intensity relies upon temperature and accessible CO_2, impacting photosynthetic action and decreasing energy costs (Kube et al., 2018).

Photosynthesis is a function of light, which affects the composition and biomass yield of microalgae. Light is also essential for NADPH and ATP synthesis that generates carbon skeletons (Sousa et al., 2013). When exposed to high illumination, microalgae secure their photosynthetic limit by diminishing chlorophyll content and expanding carotenoid content in their pigmentation. Uniform dissipation of light and proper penetration helps maintain a strategic distance from photoinhibition, also known as the self-shading effect. Abundance light intensity imposes confinement on photosynthetic efficiency, especially when combined with a high oxygen level or temperature.

The light energy is changed over to chemical energy during photosynthesis, yet large parts are lost as warmth. Only 10% of solar energy is changed over to chemical energy. Lee et al. (2015) studied the biomass formation and nutrient removal via microalgae-bacterial consortia under three specific photoperiod conditions such as 12h:12h, 36h:12h and 60h:12h dark-light cycles for 12 days. The outcomes demonstrated that carbon removal was dependent on the duration of dark cycles. Simultaneously, the nitrogen and phosphorus showed a contrary trend, showing that the dark-light cycle is crucial for microalgae-based wastewater treatment. The biomass generation would diminish when there are increments in N/P proportion.

The light/dark phase is a significant factor influencing the photosynthetic productivity in culture. Light intensity impacts biomass composition; it decreases with light intensity (Markou and Georgakakis, 2011). Light intensity and wavelength also affect the performance of nitrifiers. Both ammonium and nitrite-oxidizing activities can be hindered by intense light in the aquatic ecosystem. Dark periods between short flashes of light can enhance photosynthesis efficiency, especially under high light intensity. However, continuous illumination inhibits the denitrification process (Jia and Yuan, 2016).

4.2 Turbidity

An increment in turbidity because of the solid concentration of the wastewater affects light availability. Concentration over 3,000 NTU, identical to 1,000 mg/L, to a great extent, diminish the efficiency of microalgae. To tackle this issue, a pre-treatment of the wastewater is vital. It is essential to note that the suspended solids are at last hydrolyzed in the microalgae reactor. However, this is a time-consuming procedure, and these solids stay quite a while. Thus, the lesser amount of the suspended solid higher will be the system's efficiency (Acien-Fernandez et al., 2018).

4.3 Depth

Depth affects light intervention in the reactor (Grima et al., 2003). The general understanding that exists about the fixation of nutrients by microalgae is dependent on irradiance. The lesser the culture depth, the larger is the average irradiance and, thus, the higher the nutrient fixation rate (Posadas et al., 2015; Acien et al., 2016). Reduction in depth reduces the waste quantity to be treated. Hence, it is difficult to optimize the liquid depth. However, shorter depth (<0.2m) leads to maximum microalgae biomass production and nutrients recovery (Acien-Fernandez et al., 2018).

4.4 pH

In algal cultures, photosynthetic CO_2 assimilation leads to an increment in pH. In the case of high temperature and pH, ammonia acts as a toxin on algal growth. Optimum pH for maximum biomass productivity and growth rate for *C. vulgaris* is reported as pH 9–10 (Daliry et al., 2017). An increase in the pH beyond optimum value will lead to an increase of salinity in media, which acts as a toxin for algae cells (Khan et al., 2018), leading to the death of culture by disrupting various cellular processes. Greater pH and high temperature might restrict photosynthetic activity and lead to phosphorus precipitation as calcium phosphate (Cai et al., 2013). In a co-culture system of *Bacillus licheniformis* and *C. Vulgaris*, it was found that the maximum N-NH_3 removal was at pH 7. However, pH did not have a remarkable impact in the case of phosphate removal (Liang et al., 2013). pH variation impacts algal cell physiology and affects the form of nutrients by increasing alkalinity, affecting the algal intake capacity of nutrients (Kube et al., 2018). Photosynthesis is the reason for the rise in pH during algal treatment because of the release of H^+ ions by nitrification and ammonium as a nitrogen source for the photosynthesis process itself (Schumacher and Sekoulov, 2003). High pH also helps in the cyanobacterium's optimal productivity and pathogen disinfection (Goncalves et al., 2017). At high pH, auto -flocculation is observed, contributing to removing the suspended algae from the effluent and lessening the phosphorus concentration via interaction between cations and phosphates to precipitate as an algal–mineral complex (Hoffmann, 1998). pH also has a significant role in various cellular processes such as energy metabolism, the functioning of organelles, enzymes, and proteins, nutrient uptake. Whereas CO2 consumption and N-NH_4^+ uptakes also lead to variation in pH (Goncalves et al., 2017).

4.5 Temperature

Temperature fluctuation is observed during the day and seasons; therefore, it is almost impossible to control the temperature for large-scale outdoor ponds; thus, it is necessary to efficiently choose the algal strain, which can tolerate a broad range of temperature along with high productivity and nutrient removal. The biochemical processes are influenced by temperature variation in the algal cell. An increment in the temperature to the optimum range leads to exponential increases in the growth of microalgae. Still, any variation in the temperature beyond the optimal point decreases algae growth and activity, which leads to a more significant loss in biomass. The optimum temperature range is 20–30°C for most algal species (Singh and Singh, 2015; Goncalves et al., 2017). Low temperatures affect photosynthesis by a reduction in carbon assimilation activity. In contrast, the high temperature reduces the size of algal cells and respiration by inactivating the photosynthetic proteins and disturbing the energy balance in the cell hence leads to a decrement in growth rate (Goncalves et al., 2017; Khan et al., 2018), also affects the water ionic equilibrium, gas solubility and pH (Markou and Georgakakis, 2011; Park et al., 2011).

4.6 Mixotrophic Cultivation

Mixotrophic conditions are both autotrophic and heterotrophic mode, contributing to both inorganic and organic carbons (Christenson and Sims, 2011). The growth rate is faster in these cultures, and both autotrophic and heterotrophic pathways are used to synthesize compounds. Moreover, the cost of light energy is relatively less (Khan et al., 2018). Thus, mixotrophic be more beneficial as they are insensitive to light over saturation.

4.7 Dissolved Oxygen

In algal treatment, DO concentration increases > 200% saturation during the light phase because of photosynthesis. DO concentration beyond air saturation at standard temperature and pressure is assumed to affect algal productivity (Park et al., 2011). Ammonia–nitrogen is efficiently removed when DO concentration is adequate.

4.8 HRT

HRT is the most influential factor which directly affects the nutrient removal rate, growth rate, biomass concentration and solid-liquid separation efficiency (Xu et al., 2015). It influences energy consumption, cost and footprint of the installation. Process modification using a combination of co-cultures of microalgae/ bacteria can help decrease the HRT. SRT regulates biomass to be wasted and growth rate. High SRTs operated systems help form a diverse microbial community compared to bioreactors working at low SRTs. The larger the SRT lesser is biomass wastage leading to lesser nitrogen and phosphorus removal. Regulation of SRT, HRT and SRT/HRT ratio are vital to maximizing algal system efficiency. The lesser the SRT and HRT, the higher is the removal and biomass production (Xu et al., 2015). The influence of HRT in nutrient removal via microalgae bacteria system in algal ponds was studied at different HRT, and the highest COD removal (>92%) and ammonia (>85%) removal was obtained at 10 days HRT (Quijano et al., 2017).

5. CONCLUSIONS

Algal treatment of wastewater intervenes through a mix of nutrient take-up, high pH, and dissolved oxygen concentration results in an environment-friendly, more affordable, and increasingly productive way to evacuate supplements and metals than conventional tertiary treatment. Mass culture of algae in wastewater can permanently add benefit to freshwater biological systems by giving the more ecologically stable way to decrease point sources' eutrophication capability. Compared with conventional methods, the algal-based treatment system is beneficial because, along with nutrients, it can also remove heavy metals, sludge produced is significantly less in quantity and leads to no secondary pollution. The present study would help the researchers and academicians to have a deep understanding of this advanced, effective and environment-friendly system before dealing with it on a lab-scale or in larger-scale implementation.

CONFLICT OF INTEREST

There is no conflict of interest in this manuscript.

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